Reimagining agriculture in the Midwest US:

Exploring environmental and social solutions

to better support farmers, communities, and the environment

By

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Abstract

Intensive annual row crop production dominates the Midwest US landscape, but this comes at the cost of environmental degradation and harm to human health and well-being. However, our agricultural system can be reimagined with more sustainable practices, such as well-managed rotational grazing of perennial grasslands. To support successful sustainability transformations where land management aligns with community-identified goals, it is important to better characterize environmental impacts of agricultural practices and understand barriers to and opportunities for sustainable agriculture from farmers' perspectives. In the first chapter, I explored my positionality in this work, why agricultural transformation is necessary, and the role of place-making theory in shaping and driving transformative change. Through the second chapter, I investigated limits to soil organic carbon (SOC) accumulation, an important metric for soil health and climate change mitigation and adaptation, across two agroecosystems: annual row crops and rotationally grazed perennial pastures. I considered how two characteristically different fractions of SOC, particulate organic carbon and mineral-associated organic carbon vary across these agroecosystems, which has implications for accurate SOC modeling and offsetting greenhouse gas emissions. In the third chapter, I used interviews with Midwest crop farmers to explore their conceptions of the "good farmer", which helps us better understand regional farming norms and how agriculture in the region is shaped. Through additional Midwest crop farmer interviews in the fourth chapter, I examined challenges to using SOC as a metric for assessing environmental impact in agriculture. These challenges included trust in researchers and different ways of knowing. In the fifth chapter, I reflected on my experience as an interdisciplinary researcher and literature characterizing challenges to interdisciplinary research

more broadly. Collectively, this work becomes not only a call to reimagine agriculture but a reimagining of how researchers and farmers can engage in this process together.

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Chapter 1. A new vision for agriculture

Place-making as a strategy to transform agriculture

Reflections from a farm kid

Growing up on our Iowa farm, I dreamt a world of my own in the line of evergreen trees bordering the lawn. I ran barefoot under the big maple that shaded the backyard and tossed rotten apples that littered the ground to the pigs for fun. I climbed around our cherry tree, awaiting the time when its tart berries ripened. But I also spent my childhood drinking jugs of water delivered to our farm because we could not drink our well water that was contaminated by nitrates leaching from crops. And each time farmers sprayed nearby crops with chemicals, my brothers and I were instructed to stay inside for our safety, but what about my dad who applied them or the land where he sprayed them? As a kid, I never questioned this; it was my reality. Yet our practices seemed misaligned with caring for the land, and frankly, caring for ourselves. With this questioning came the rupturing of my worldview. I struggled to fit those warm childhood memories playing in the trees between these practices that I hated—polluting drinking water and spraying chemicals. Environmentalism seemed contradictory to farming, so I ignored my identity as a farm kid and began to resent my farming background. This tension felt uncomfortable, sometimes painful, and left me with no interest in agriculture, that is until I took on a new identity: researcher.

As an Environment & Resources graduate student at UW-Madison, I attended a field trip to explore the Wisconsin landscape, from cranberry bogs to grazed pastures. At an initial stop, we were asked how many of us grew up on a farm. As I raised my hand, I was surprised to see that mine was the only one in the air. This moment stays with me because it prompted reflection on what it meant to me to be a farm kid, an identity I had long ago written off. My personal connection to agriculture made me unique, so perhaps I did not want to run from it. In fact, if it allowed me to connect with the agricultural community, here was an opportunity to make a big environmental impact given the dominance of agriculture on the Midwest landscape. And importantly, it also enabled me to begin reframing the agricultural narrative I struggled with. Farming *could* align with conservation. And so, for the first time, I wanted to explore reclaiming my identity as a farm kid.

As I reconsider what it means to be a farm kid doing agricultural research, I am grounded in the place of my family farm, where my dad, younger brother, grandpa, uncles, and cousin still work. As I imagine how agricultural change will affect them, this serves as an important reminder: I am a farm kid and an agricultural researcher, but I am *not* a farmer. This distinction matters because it reminds me of my responsibility as a researcher[1] to listen. I may have expertise in farming practices as defined by their impacts on soil health, yet I lack expertise in what it means to farm. If we aim to reshape our agricultural system to reflect the values of those working within it, farmers' voices are critical to capture.

In listening to farmers like my dad, I know reshaping our agricultural system requires more than asking farmers to make different choices. Like me, my dad frequently expresses his dislike for applying chemicals to our fields, yet he does it anyway. This cannot simply be explained as his aversion to change given the other ways our farm changed over time. We had both pigs and cattle when I was little, then just cattle, and now only row crops. So, what makes this change more difficult than the others? Clearly, change is possible, but the question that

[1] I recognize that farmers also act as researchers on their own farms, conducting experiments and making observations (Hansson, 2019). I do not want to minimize farmers' ways of knowing but rather distinguish between researchers and farmers to call out my specific positionality as a university researcher, which can apply to other university researchers as well.

remains is how we create the change we want to see. Farmers' expertise can help us interrogate the structures and stories that uphold the current agricultural paradigm and address barriers to realigning agriculture with our collective values. But first, we must characterize the problem.

Agricultural change is necessary

The problems I experienced growing up on our Iowa farm are not isolated, but rather a widespread outcome of an industrial agricultural system that supports high input (e.g., fertilizers, pesticides, fossil fuels), high yielding row crop monocultures and large-scale farms (Gordon et al., 2022). In the Midwest US, this primarily includes intensive corn and soybean production (USDA NASS, 2022). However, intensive agricultural production is not sustainable[2] across several metrics. Substantial losses of topsoil due to row crop production reduce productivity and contribute to financial losses (Thaler et al., 2021). The number of farms is decreasing (USDA NASS, 2022), with Wisconsin losing 64,000 dairy farms since 1968 despite increases in milk production (Oncken, 2023). Excess nutrients from fertilizer and livestock operations are harming water quality (Glibert, 2020) and industrial agriculture threatens human health, from farmers to consumers (Horrigan et al., 2002). Intensive management of monocultures fails to provide critical ecosystem services, such as nutrient retention and water infiltration (Wepking et al., 2022) as well as limits resiliency to stressors, such as drought (Sanford et al., 2021) and pest pressure (Liu et al., 2022). These issues leave no one unscathed, but alternatives do exist.

Well-managed rotational grazing of perennial grassland has the potential to remedy both the environmental and social problems perpetuated by industrial agriculture (Spratt et al., 2021),

[2] Definitions of "sustainable" agriculture vary within the literature (Velten et al., 2015). The same is true for synonyms, such as "regenerative" agriculture (Newton et al., 2020). Thus, no term is perfect. I use "sustainable" to mean preserving the environment and sustaining human well-being, at a minimum.

yet widespread adoption of rotational grazing in the Midwest US is lacking (USDA NASS, 2022). In Wisconsin, for example, just over 6,000 farms employed rotational grazing while approximately 44,000 farms harvested cropland per the 2022 Census of Agriculture (USDA NASS, 2022). While those totals may not be mutually exclusive and are likely overestimates given the continued decline of farms in Wisconsin, particularly dairy farms (Hadachek & Deller, 2024), they starkly illustrate which types of agriculture dominate the landscape. Thus, the critical question is how to shift our agricultural system towards practices that promote healthy soils, clean water, farm vitality, and vibrant communities, which are goals that benefit farmers and the public alike.

Agricultural change is possible

With a well-established need to transform our agricultural landscape, researchers have explored relationships between individual farmer attitudes and characteristics and their conservation behavior as a strategy to increase the adoption of pro-environmental agricultural practices. As one example, previous research explored relationships between land tenure and conservation adoption (Knowler & Bradshaw, 2007; Prokopy et al., 2008). One study of U.S. corn farmers found that those who owned the land were more likely to use conservation tillage and practices with long-term benefits, such as grassed waterways, than cash-renters (Soule et al., 2000), with this difference used to argue for long-term lease agreements and more owner-operated farmland to protect soil health (Stevens, 2022). However, limited evidence of a relationship between land tenure and conservation adoption exists (Prokopy et al., 2019). Instead, a recent review of the research cautions that relationships between land tenure and conservation remain uncertain (Ranjan et al., 2022) with those relationships varying by the specific conservation practice (Leonhardt et al., 2019; Varble et al., 2016). Some research has emphasized understanding farmer typologies as a strategy to better connect with farmers' attitudes and beliefs, such as conservationist and productivist (Upadhaya et al., 2021) or traditional and business-oriented (Daloğlu et al., 2014), though this still emphasizes individual characteristics. Overall, despite decades of research, few, consistent predictors for promoting conservation behavior among farmers have been uncovered (Doll & Jackson, 2009; Napier et al., 2000; Prokopy et al., 2019).

A limitation with exploring individual farmer attitudes as a strategy for behavior change is that the attitudes towards a conservation practice are simply one motivation of farmer behavior (Carlisle, 2016; Dentzman, 2022; Gosnell et al., 2019; Ranjan et al., 2019; Reimer et al., 2021). In a synthesis of farmer adoption literature, Ranjan et al. (2019) outline the complexity of farmer decision-making. In addition to the impact of the farmer's identity, goals, and experience with conservation practices on their likelihood of adopting a practice, Ranjan et al. (2019) note that economic factors and social norms serve as both barriers to and motivation for adopting practices. Gosnell et al. (2019) framed this complexity by describing factors impacting agricultural transformation at the personal, practical, and political spheres that likewise interact. As well, these interactions across scales were recognized by other researchers (Darnhofer, 2021; Seymour & Connelly, 2023). Farmer decision-making can be deeply personal (Kuehne, 2013), influenced by legacy and tradition as well as the desire to care for the land (Leitschuh et al., 2022; Strauser & Stewart, 2024). As such, farmer decision-making is not supported by a rational actor model (Carlisle, 2016). Instead, these interacting factors highlight that farmers, just as other people, operate *within* a larger context (Carlisle, 2016; Gosnell et al., 2019; Adam Reimer et al., 2014; Rose et al., 2018; Strauser et al., 2022). Changing the context, or rather changing the norms, policies, and economics of the *place*, can be an alternative approach to help shift the landscape. So, what is *place* and how do we reimagine it?

While "place" is a commonly used word in everyday language, it means more than just a location in space; it also encompasses the meanings we attach to a location and how we interact with that space (Relph, 1976; Tuan, 1974). In other words, the essential characteristics of a place are meanings attached to a physical environment (Agnew, 2011; Cresswell, 2015). These meanings, known as place meanings, can be both individual and shared (Cresswell, 2009), positive and negative (Manzo, 2003). Also, place meanings arise from and are impacted by how people communicate, perform, interact within, and intentionally shape the physical environment (Di Masso & Dixon, 2015). In addition, our positionalities, or personal perspectives of the world, shape the meanings we attribute to a place, such that different people can attach different meanings to the exact same environment (Greider & Garkovich, 1994). As a result, the construction of place is not pre-determined nor are places stagnant, even if they might feel permanent to the people experiencing them (Pierce et al., 2011). This process of changing and shaping places is known as place-making and is defined by Pierce et al. (2011) as, "the set of social, political and material processes by which people iteratively create and recreate the experienced geographies in which they live." Therefore, places are dynamic both in what they mean and how they look, but some meanings are more pervasive and institutionalized than others.

As outlined by Cresswell (1996), the construction of places informs the development of social norms around who and what is "in place" versus "out of place". These shared understandings of place dictate what behaviors are considered socially acceptable or not. Critically, "in place" behaviors are also propagated and enforced through laws, policies, economics, social hierarchies, etc., such that whole systems can reward “in place” behaviors and punish “out of place” behaviors (Cresswell, 1996; Rissman et al., 2023; Stuart & Houser, 2018). Thus, the establishment and reinforcement of what is considered “in place”, or *normative* place meanings, powerfully influence behavior. Place meanings create widespread adherence to the established norms at large spatial scales (Burton, 2004; Morse et al., 2014) as there is a cost to being deemed out of place (Burton, 2004; Cresswell, 1996; Di Masso & Dixon, 2015; Gosnell et al., 2019; Molho et al., 2020). For example, those behaving outside of social norms have been described and equated with language that reinforces this deviance from expectations, such as with words like “dirt” or “disease” (Cresswell, 1996). People practicing “out of place” behaviors can also face ridicule from their peers (Gosnell et al., 2019), feel a loss of their identity (Burton, 2004), lose out on financial supports (Rissman et al., 2023), and even get charged and arrested, with laws intentionally being passed to warrant those arrests (Cresswell, 1996). From severe consequences of acting “out of place” to reifying accepted behaviors, normative place meanings powerfully shape places.

While there can be such strong reactions to what is considered “out of place”, importantly, what is deemed “out of place” versus “in place” is not universal (Cresswell, 1996). Rather, it is context-dependent in space (Carolan, 2006) and in time (Burton et al., 2020). For example, in a study with Australian “regenerative farmers”, they believed in and practiced an anti-chemical approach that was normalized among other regenerative farmers, but contrasted with the dominant industrial agriculture practices (Gosnell, 2022). Similarly, during my master’s research, I interviewed graziers who believed rotationally grazing livestock was the best way to financially support their livelihoods and care for the land, which is contrary to dominant narratives of row crop farmers as stewards of the land that need to maximize crop production to "feed the world" (Hall, 2024). These examples illustrate how the farmers' identity, as regenerative farmers and graziers, shape what practices they consider to be "in place," i.e., chemical-free farming and livestock on the landscape, despite the dominance of chemical application and row crop production in their area. In particular, this contesting of the meanings of place by "in-groups" and "out-groups" is a key part of the place-making process (Cresswell, 1996), such that places are always being created, reinforced, and challenged (Cresswell, 2015; Di Masso & Dixon, 2015). More specifically, the establishment and reshaping of shared place meanings develops through the influence of other places, or *relational* place-making.

Relational place-making emphasizes that places are produced through their interconnections, across multiple spatial scales and among different entities (Pierce et al., 2011). Simply put, places are not isolated or bounded objects; they are fluid and shaped by other people and places (Agnew, 2011; Cresswell, 2015; Pierce et al., 2011). While previously establishing that places are constantly changing (Cresswell, 2015), the relational aspect adds to how places are produced and changed, recognizing the influence of these different people and places both concurrently as well as changes over time (Cresswell, 2013). Morse et al. (2014) detail how a pastoral New England landscape was constructed through "sentimentalization" of the characteristic open fields from tree removal during Vermont's colonization, followed by government promotion of that aesthetic to tourists and land managers, who then maintained and enacted that image. Specifically, farmers removed brush to prevent the encroachment of forest on open land, which was time-consuming and without financial incentive, and then those practices became reinforced through neighboring farmers engaging in the same behavior. Here, marketing elsewhere and the practices of other farmers shaped how the New England landscape looked and what that landscape communicated.

While recognizing the impact of other people and places on how agriculture is practiced is not new (Bell, 2004; Burton, 2004; Morse et al., 2014), current literature that advocates for the transformation of agricultural systems acknowledges the importance of a relational approach to landscape change (Darnhofer, 2021; Gosnell et al., 2019; Köhler et al., 2019; Seymour & Connelly, 2023; Thomas-Walters et al., 2024), regardless of explicit discussion of the concept of place or place-making. For example, Gosnell et al. (2019) recognize the key role of interactions between personal and systemic barriers, i.e., interactions across scales, as opportunities in transformational change. Darnhofer (2021) calls out the need for considering farms as relational, fluid entities themselves, rather than stable, concrete objects in order to shift our agricultural trajectory. Seymour and Connelly (2023) argue that applying a more-than-human ethics of care, which reframes our relationships to other beings, is key to agricultural transformation. Within sustainability transitions literature more broadly, relationality is called out as a key aspect of place-making, which must be incorporated into transitions research (Binz et al., 2020), and practically, intermediaries are being recognized as entities that can facilitate relational place-making (Loeber & Kok, 2024). Hence, each of these perspectives consider that people and places do not exist in a vacuum, and respect that relational influence is critical to transformational change because it can reshape normative place meanings, which reshapes place (Burton et al., 2020; Carolan, 2006; Cresswell, 1996). Moreover, such a transformation requires relationships and coordination across wide spatial scales, not just disparate individuals making change haphazardly (Strauser et al., 2022). Thus, we must consider how to scale place meanings that align with our agricultural values.

Because the attributes of a place, i.e., meaning and physicality, are not limited to a spatial size, a place and its place meanings can occur across spatial scales (Agnew, 2011; Cresswell, 2015; Tuan, 1974), from a farmhouse room to a field to a watershed to a *region*. Regions, in particular, are commonly conceptualized as objects defined by political or national boundaries, such as the state of Wisconsin or the Midwest region in the United States, but those designations are social constructions that materialized and gain further meaning through how they are written into law and enforced (Paasi, 2002). As such, Passi (2002) instead conceptualizes regions as socially-constructed, unbounded places, which are flexible and influential across spatial scales (Paasi, 2002). What we might consider a region, and its respective scale, is context-dependent (Cresswell, 2013), such that "regions" are fluid, and can change whether discussing a more local issue, like well water pollution, or a more national issue, like hypoxia in the Gulf of Mexico. Therefore, when it comes to addressing the problems perpetuated by industrial agriculture, this requires *regional* place-making (Strauser et al., 2022). We need to construct regions that align with our shared goals at a scale that matches the magnitude of the problems associated with industrial agriculture. Projects like Grassland 2.0, a USDA-funded project, aim to address systemic agricultural problems by facilitating collaboration among community members. This includes collectively defining what people want for agriculture in collectively-defined regions and supporting the discussion and actualization of how to get there (Grassland 2.0, n.d.). This collective, transformative effort strives to understand and reshape practices, markets, policies, and norms, i.e., normative place meanings, by working with the people in these places. While constructing regions to reflect shared values of caring for the land, farmers, and communities is no small task, my dissertation will help in laying the foundation for more widespread change.

My role in changing the agricultural landscape

Through my dissertation research, I explored underlying environmental and social phenomena that help shape agriculture in the Midwest US. Specifically, I 1) examined limits to soil organic carbon (SOC) accumulation under different agricultural practices in the Midwest to better inform expectations and management recommendations, 2) interrogated social norms around good farming and alignment with farmers' long-term goals in two Midwest towns with contrasting topography, and 3) explored farmers' conceptions of caring for the land, including discussions of SOC as a metric for environmental impact. Each of these examples contribute towards characterizing how these agricultural places are understood by farmers and researchers, which is critical groundwork to reshaping these places.

Importantly, it is not the intent of this work to criticize the perspectives of farmers, but rather to understand their viewpoints as well as to reflect on my own. I am grateful for the contribution of each farmer to this work, beginning with my own family, who have shaped and reshaped my personal understanding of farming in the Midwest. It is my hope that this research can support continued conversations with farmers and rural community members around what we hope for our agricultural systems and remind us that it is possible to create something better.

Chapter 2. The dirt on soil carbon: Aligning expectations for soil carbon sequestration

Introduction

Agricultural land use drives significant soil organic carbon (SOC) loss (Sanderman et al., 2017), which contributes to climate change that feeds back to agroecosystems (Poeplau & Dechow, 2023). These dynamics pose a major threat to critical soil functions including water infiltration, soil retention and nutrient provisioning, that underpin critical ecosystem services, such as food production, flood reduction, clean water, erosion control, and climate regulation (Cotrufo & Lavallee, 2022). The potential to regain these carbon losses under row crop agriculture is limited (DeLuca & Zabinski, 2011; Dietz et al., 2024), yet rebuilding SOC in agricultural systems has been proposed as a strategy for helping to mitigate climate change (Lal et al., 2018; Paustian et al., 2019; Rumpel et al., 2020; Sanderman et al., 2017), which must be coupled with reductions in fossil fuel emissions (Fawzy et al., 2020). Because SOC is a balance of carbon entering the soil, primarily from plant material, and carbon leaving the soil as microbes respire carbon during decomposition, agricultural practices that either a) increase carbon inputs or b) decrease carbon losses, may increase SOC storage. However, uncertainty remains about the degree to which agricultural practices affect this SOC balance (Chenu et al., 2019).

In particular, there is a need to differentiate between how much SOC accumulation is theoretically feasible and how much SOC accumulation actually occurs under current management (Amelung et al., 2020; Bai & Cotrufo, 2022; Georgiou et al., 2025; Schlesinger & Amundson, 2019). Improving our understanding of SOC accumulation and how land management practices mediate that accumulation enables more accurate carbon modeling and accounting (Georgiou et al., 2025), which is critical for informing climate change policy and adaptation responses as well as farmer expectations and management decisions. To develop a more nuanced understanding of SOC sequestration potential, it is important to maintain more nuanced discussions of SOC.

Not all soil carbon is the same

In recent history, the persistence of soil organic matter, which contains SOC, was attributed primarily to the molecular composition of the incoming plant material. Specifically, more complex molecules, such as lignin, were purported to persist more than simple compounds (Schmidt et al., 2011). However, the current view of SOC persistence recognizes the importance of interactions between environmental and microbial factors (Cotrufo & Lavallee, 2022; Schmidt et al., 2011). One framework that has received much attention for SOC persistence distinguishes between SOC that adsorbs to silt and clay particles making it less accessible to microbes, from SOC that does not adsorb to those soil minerals (Lavallee et al., 2020). This mineral-associated organic carbon (MAOC) fraction is characteristically different from non-mineral-associated forms of SOC (Lavallee et al., 2020). Thus, SOC should not be treated as a homogeneous pool (Angst et al., 2023).

As a result, current literature calls for considering particulate organic carbon (POC), which does not associate with soil minerals, and MAOC fractions separately given their differing characteristics, formation pathways, and environmental controls (Angst et al., 2023; Chenu et al., 2019; Derrien et al., 2023; King et al., 2023; Lavallee et al., 2020). One important difference is their mean residence time in the soil, with POC, on average, persisting much less than MAOC (Lavallee et al., 2020). POC has a mean residence time of years to decades compared to decades to centuries for MAOC (Lavallee et al., 2020). MAOC is also more persistent under warming temperatures compared to POC (Benbi et al., 2014; Cates et al., 2022; Lugato et al., 2021), indicating the importance of MAOC under a changing climate, though it is necessary to recognize that MAOC is not an untouchable pool of SOC. MAOC has a lower C:N ratio, which makes it of better quality to soil microbes when it becomes accessible (Lavallee et al., 2020), and current literature suggests that a portion of MAOC is fast-cycling (Jilling et al., 2025). Additionally, MAOC dominates in grassland soils used for agriculture (Cotrufo & Lavallee, 2022), and as a result, may be more vulnerable to losses (Lugato et al., 2021) as observed by Anuo et al. (2024). Given the potential for MAOC to be more persistent in the soil overall, it is valuable to explore its potential for accumulation as a strategy to support offsetting greenhouse gas emissions long-term. However, there may be limits to MAOC accumulation.

Saturation of MAOC is uncertain

The conceptual limit to the capacity for SOC storage is referred to as soil carbon saturation (Georgiou et al., 2025; Stewart et al., 2007). Evidence of saturation has come from both observed and modeled data (Cotrufo et al., 2019; Georgiou et al., 2022; Stewart et al., 2007; West & Six, 2007). While previous work has supported saturation across the entire pool of SOC (Stewart et al., 2007), current saturation debates have been applied to the MAOC fraction (Cotrufo et al., 2019; Georgiou et al., 2025). For MAOC, the potential for saturation is linked to the finite portion of silt and clay particles in the soil (Cotrufo et al., 2019; Hassink, 1997) and the distance from this saturation point could affect SOC accumulation efficiency (Georgiou et al., 2022). POC, alternatively, is not associated with minerals and can continue to accumulate indefinitely (Cotrufo et al., 2019). The saturation limit, as determined by mineral surface availability, has recently been distinguished from other measures of carbon saturation. As coined by Georgiou et al. (2025), the “theoretical mineral capacity” refers solely to the ability of the minerals to bind SOC without consideration of climate or management. In contrast, the "maximum observed capacity" and "effective capacity" refer to observed MAOC levels, which are less than the theoretical capacity because they consider other variables within the system.

Specifically, "maximum observed capacity" quantifies the highest MAOC accumulation achieved under global climate and management, while the "effective capacity" also refers to an observed maximum MAOC, despite increased inputs, but under a particular set of climate and management variables (Georgiou et al., 2025). This means that the maximum observed capacity is at a higher MAOC value than the effective capacity under a particular mineralogy and texture. Importantly, these concepts differ from a "steady state" where no increases in MAOC are similarly observed, *but* inputs have remained consistent (Georgiou et al., 2025). In other words, the effective capacity is only achieved when MAOC does not change despite increasing inputs, and the theoretical mineral capacity is a conceptual rather than practical metric. Of note, steady states, where the amount of carbon in the soil remains consistent under current carbon inputs, can likewise be observed with POC (Stewart et al., 2007; West & Six, 2007). Distinctions between saturation concepts are important to ensure what researchers compare is consistent, and saturation potentials under current land management practices warrant further research given current MAOC saturation debates (Begill et al., 2023; Cotrufo et al., 2019, 2023).

For example, saturation has been modeled to occur at ~5% SOC in European forest and grassland soils as indicated by no increases in the MAOC fraction even as overall SOC increases beyond 5% (Cotrufo et al., 2019). However, Begill et al. (2023) also examined the relationship between SOC and MAOC over a range of soil textures and carbon quantities in cropland and grassland soils, including those exceeding 5% SOC, and observed no evidence for saturation. Instead, their linear relationship between SOC and MAOC contradicted evidence of MAOC saturation illustrated by Cotrufo et al. (2019), which modeled the relationship using a subset of observed data. Interestingly, MAOC did not appear to be accumulating under Wisconsin pasture soils with nearly all SOC measurements well below 5% in Becker et al. (2022). While each of these three studies used the same method to determine saturation (i.e., exploring the relationship of MAOC to SOC concentrations), it is possible that these studies are not comparing the same measures of carbon saturation given the Georgiou et al. (2025) definitions.

For Becker et al. (2022) in particular, it seems likely that the estimated saturation reflects a steady state, rather than an effective capacity, given the lack of carbon input manipulations. Poeplau et al. (2024) argued that many carbon saturation values are underestimated because the observed equilibria likely stem from insufficient carbon inputs. Heinemann et al. (2024) did not find evidence of saturation in a case study of German soils while applying carbon inputs far exceeding what is common in agriculture, rather, carbon continued increasing linearly. Given that managing soils to maximize carbon accumulation, such as with the extremely high inputs in Heinemann et al. (2024), can come with tradeoffs (Moinet et al., 2023), it is important to understand how the management practices currently on the landscape affect MAOC accumulation.

MAOC accumulation is responsive to agricultural management

Building on the arguments of Poeplau et al. (2024) of insufficient inputs, the inability to accumulate MAOC may be more reflective of the agricultural systems dominating the landscape rather than the capacity of the silt and clay particles, especially given the ability of SOC to layer upon minerals (Kopittke et al., 2020). Annual row cropping systems do not match the belowground inputs of perennial prairies that most agricultural soils developed under (DeLuca & Zabinski, 2011), and belowground carbon inputs play a key role in efficient SOC formation (Moore et al., 2025; Sokol & Bradford, 2019; Sprunger et al., 2020). Specifically, perennial agricultural systems can increase belowground root biomass (Moore et al., 2025; Mosier, Apfelbaum, et al., 2021) and grazed perennial pastures can contribute to more consistent carbon inputs with a lower C:N ratio (Mosier, et al., 2021; Rui et al., 2022), which might then increase MAOC accumulation through improved carbon use efficiency (Rui et al., 2022). Notably, SOC storage has been strongly related to carbon use efficiency, or how efficiently microbes can turnover carbon inputs to build their biomass (Tao et al., 2023), especially for MAOC accumulation (Yang et al., 2025). At the same time, carbon use efficiency does not explain differences in MAOC in empirical research (King & Sokol, 2025; Ma et al., 2024). Regardless, the impact of perennial systems on SOC is reflected in studies showing greater amounts of persistent carbon under grazed perennial pastures relative to annual row cropping systems (Rui et al., 2022; Sanford et al., 2022) and under more sustainable practices generally (Prairie et al., 2023).

A study comparing the impact of 29 years of management on POC and MAOC found that MAOC was more prevalent under rotationally grazed pasture systems compared to cash grain and forage systems with organic and non-organic management (Rui et al., 2022). Greater MAOC measured in perennial systems relative to annual cropping systems was corroborated by Anuo et al. (2024) and Sanford et al. (2022). However, Sanford et al. (2022) also found that persistent carbon constituted a larger fraction of the SOC in highly disturbed agricultural systems relative to perennial systems, which was attributed to the inability of highly disturbed systems to maintain and accumulate less persistent carbon, like POC, not a greater ability to accumulate more persistent carbon, like MAOC. Within perennial systems, MAOC also varies, such that rotationally grazed pastures seem to better accumulate MAOC than continuously grazed systems (Mosier et al., 2021). Management strongly impacts MAOC accumulation contributing to different effective capacities and steady states, which adds further complexity to obtaining accurate carbon accumulation and saturation estimates. To address these knowledge gaps in the potential to accumulate different fractions of SOC with different management practices, I explored how 1) POC and MAOC concentrations covaried with SOC concentrations under rotationally grazed perennial pastures and annual row crop fields on Midwest farms to look for potential steady states by management type and 2) MAOC concentrations covaried with silt and clay quantities under those same management practices to understand how soil texture relates to MAOC accumulation and how that relationship is affected by management type. Finally, I examined how 3) MAOC and POC concentrations and stocks covaried with pasture age under Wisconsin cool-season pastures to infer how these SOC fractions changed over time following the addition of pastures sites to the prior analysis in Becker et al. (2022).

Methods

Sample collection

Soils were collected via three projects. The first subset of soil samples were collected from Wisconsin agricultural sites in 2020 as outlined in Becker et al. (2022). Paired annual row crop and rotationally grazed perennial pasture sites were identified throughout central and southern Wisconsin. From each field, 10 soil cores were collected with a hand probe to a depth of 30 cm. Each soil core was split in half to separate the 0 to 15-cm increment from the 15 to 30-cm increment. If I was unable to collect a sample to 30 cm, only the 0 to 15-cm depth increment was collected. Ten samples for each depth were combined so that each site had one composite sample per depth. After sieving samples to 2 mm and removing plant material >2 mm, all soils were air-dried. Some soil samples were removed in Becker et al. (2022) because the pairs were insufficient, but because data were not paired in this analysis, previously excluded samples could be incorporated back into the dataset.

The second subset of soils were collected from 6 “old” Wisconsin pastures. Old pasture sites were defined as those that had been established for at least 35 years according to the farmers currently managing them. Soil samples were collected at these sites in the fall of 2022 to a depth of 90 cm using a JMC probe, then separated into the following increments: 0 to 15, 15 to 30, 30 to 60, and 60 to 90 cm. These samples were processed in the same manner as above and the values were added to the Becker et al. (2022) dataset. Only data for the 0 to 15 cm depth appear in the results.

The third subset of soils were collected via the Soil Organic Carbon Network (SOCnet), a USDA North Central Region Sustainable Agriculture Research and Education (SARE) project (LNC22-475). These soils included samples collected from farms in Wisconsin, Iowa, and Minnesota, as well as soils from long-term cropping systems experiments in those states. Management practices included both grazed perennial pastures and annual row crops. These samples were collected to a depth of 90 cm using a Giddings probe, but for this work, only the 0 to 15- and 15 to 30-cm depths were analyzed. Similar to above, samples were sieved to 2 mm while removing plant material and then air-dried. Sample collection and subsequent carbon analysis at these sites predated this project, allowing for this work to specifically include soils from sites with SOC greater than 2.5%. Because sites with high SOC were limited in the dataset from Becker et al. (2022), SOCnet data enabled compilation of a more robust dataset.

Across the three datasets were 55 pasture samples and 45 row crop samples for analysis from the 0 to 15-cm depth. From the 15 to 30-cm depth, which did not include any old

Wisconsin pastures from 2022 data collection, were 47 pasture samples and 39 row crop samples.

Soil fractionation

All soils were fractionated into particulate organic matter (POM) plus sand and mineral-associated organic matter (MAOM) plus silt and clay following Cotrufo et al. (2019). Samples were dispersed with a 0.5% sodium hexametaphosphate solution and glass beads on a reciprocal shaker. Samples were then wet-sieved over a 53-µm sieve. The soil remaining on top of the sieve contained the POM fraction and the soil passing through the sieve contained the MAOM fraction. The soil fractions were washed into tins and dried at 55 °C. Dried samples were transferred to microcentrifuge tubes and prepped for carbon analysis.

Carbon analysis

Regardless of the soil fraction, all samples were prepped similarly for carbon analysis as follows. About 2 cm^3 of air-dried soil was transferred to microcentrifuge tubes and homogenized. To determine the appropriate mass needed from the homogenized soils, I estimated the lowest expected mass percent carbon present in the sample subset, then rolled all samples to the corresponding mass from the chart in *Appendix A*. This ensured carbon detection. Typically, 25 to 40 mg were added to tin capsules. Finally, most samples from Becker et al. (2022) were submitted for C analysis, while SOCnet POC and MAOC samples as well as any re-runs from Becker et al. (2022) and old pasture samples were analyzed in the Jackson/Sanford lab. All soil carbon quantities were determined via flash combustion. For total SOC as well as POC and MAOC from Becker et al. (2022), all soils were analyzed on a Flash EA 1112 elemental analyzer. All POC and MAOC SOCnet soil samples and old pasture samples were analyzed on a CE Flash Elemental analyzer, the same instrument used for the Becker et al.

(2022) samples but a newer version. Total soil carbon from SOCnet was previously determined prior to this project using the same methodology and was shared with the research team. Finally, while initial soil fractionation separates POM from MAOM, after carbon analysis these fractions are henceforth referred to as POC and MAOC.

Notably, the mass percent output from the elemental analyzers (EA) for POC and MAOC cannot be directly interpreted as the percent of POC and MAOC in the soil overall. Rather, the instrument output specifically indicates what percent of the mass of the soil fraction >53 μm (sand + POM) and <53 μm (silt + clay + MAOM) from the fractionation step above is carbon. However, this does not account for how much of the bulk soil is in either of those fractions. This is important because I am interested in how much of the soil overall (i.e., bulk soil) contains more stable carbon (i.e., MAOC) and less stable carbon (i.e., POC). Thus, I must account for how much of each fraction is carbon *and* how much each fraction contributes to the bulk soil to accurately determine how much of the bulk soil is POC and MAOC (Figure 1).

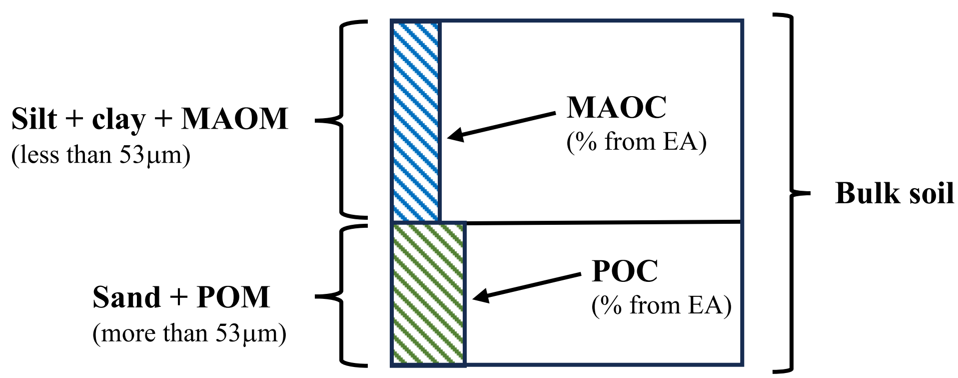

Figure 1. Bulk soil can be split into two fractions by size that have unique mineral and organic matter types: 1) sand and POM (>53 μm), and 2) silt, clay, and MAOM (<53 μm). I can use an elemental analyzer to calculate the carbon concentration within these two fractions, but to calculate the amount of MAOC and POC in the bulk soil, I must also know the amount of bulk soil that is >53 μm and <53 μm.

For example, the mass percent of carbon in the sand + POM fraction might be 8%, but the bulk soil might only be composed of 25% sand + POM. As a result, the amount of POC in the bulk soil would be less than 8%. I used the following calculations to determine the specific carbon value in the bulk soil:

$$Eq\ 1\text{:}\ \frac{g\ POC}{g\ sand + POM}\ x\ \frac{g\ sand + POM}{g\ bulk\ soil} = g\ POC\ in\ bulk\ soil$$

$$Eq\ 2\text{:}\ \frac{g\ MAOC}{g\ silt\ \&\ clay + MAOM}\ x\ \frac{g\ silt\ \&\ clay + MAOM}{g\ bulk\ soil} = g\ MAOC\ in\ bulk\ soil$$

Using the example above, I calculated 2% POC in the bulk soil. The same method is used for MAOC calculations and ensures the "right units" for testing for saturation were used (Six et al., 2024).

To check for inorganic carbon among Becker et al. (2022) samples, soils were tested using an adaptation from Sullivan et al. (2018). Homogenized soils were placed into well plates and ~0.4 mL of 5% acetic acid were applied. Positive controls were included, and effervescence was used to indicate the presence of inorganic carbon. Because effervescence was only observed in the positive controls, but not any of the pasture or row crop samples, total carbon was assumed to be equivalent to total organic carbon. As for the SOCnet samples, HCl effervescence was used to test for inorganic carbon. Inorganic carbon was found in two samples at the 15 to 30-cm depth, which were then removed from the data analysis. Thus, total soil carbon data from this research is henceforth referred to as soil *organic* carbon (SOC) in the results and discussion.

Statistical analyses

First, to build on the work of Begill et al. (2023) and Cotrufo et al. (2019), I determined best fit functions for POC and MAOC concentrations relative to SOC concentrations to explore evidence for saturation, or more accurately, a steady state. The subsequent analyses use the data from Becker et al. (2022) and the SOCnet project, but not the 6 old pasture sites as I did not have POC and MAOC concentrations beyond the surface 15 cm of soil. To begin, I plotted the relationship of POC and MAOC with SOC for annual row crops and perennial pastures. I first examined the combined data for both depths, then explored the 0 to 15-cm and 15 to 30-cm depths separately. Next, I fit linear and logarithmic functions to the data and calculated R^2 and AIC within *RStudio* to determine best fit for both POC and MAOC as well as crops and pastures. A linear fit would provide evidence *against* a steady state being reached, while a logarithmic fit would provide evidence *for* a steady state being reached within the respective agroecosystem. Of note, one iteration of the analyses involved log-transforming the data, then comparing the fit of a linear model to the transformed and non-transformed data. The linear model fit to the log-transformed data was comparable to the fit of the logarithmic function of the non-transformed data, so only the non-transformed data is included below.

Next, because MAOC adheres to silt and clay, I examined the relationship between silt and clay content with MAOC, again using R^2 and AIC to determine if a linear or logarithmic function provided the best fit for each agroecosystem. This relationship was only explored at the 0 to 15-cm depth as all samples have the percent sand, silt, and clay for this depth interval.

Finally, to build on the analyses of Becker et al. (2022) suggesting that MAOC was not accumulating in pastures over time, MAOC data from the six 2022 old pasture sites were added to the original dataset. These data were then reanalyzed with a linear regression to determine if there was a significant relationship between pasture age and MAOC. In particular, this relationship was examined using both MAOC concentrations (i.e., the C analyzer output), and MAOC stocks, which were calculated by applying the proportion of the soil that is in the MAOC fraction to the SOC stock. Notably, while SOC stocks are not used in any additional analyses, for this analysis, SOC stocks were calculated by using each field's SOC concentration and bulk density. SOC stocks are the best metric to use for determining SOC changes.

Results

Evidence of MAOC "saturation" in perennial pastures, not annual row crops

The relationships between POC and MAOC concentrations with SOC concentrations differed between perennial pasture and annual row crop systems regardless of the selected model, but only at the 0 to 15-cm depth (Figure 2). At the 15 to 30-cm depth, differences between the two agricultural systems were indistinguishable (Figure 3), and when looking at both depths collectively, differences observed in the surface depth prevailed (Figure S1). Specifically, pasture SOC was comprised of more POC relative to row crops at the same SOC concentration, and consequently, the opposite was true for MAOC. In row crops, MAOC comprised a larger fraction of SOC than pasture systems at similar SOC concentrations. However, this does not mean that pastures had more total POC and row crops had more total MAOC. These differences only indicate what percentage of SOC was in each fraction, but do not indicate differences in the quantities of POC and MAOC. In addition, from the range of pastures and row crops represented in this dataset, pastures had higher total SOC concentrations across these sites in the surface soils (Figure 2).

A linear model was the best fit for the relationship between POC and SOC for both pastures and row crops (Figure 4a). For pastures, the linear model had an AIC of 31.35 and R^2 = 0.81 ($p < 0.001$) while the logarithmic model had an AIC of 57.52 and R^2 = 0.68 ($p <0.001$). Across both metrics, the linear model was best given a lower AIC and higher adjusted R^2. The same was observed for row crops, as the linear model (AIC = 18.38; R^2 = 0.36, $p <0.001$) was a better fit than the logarithmic model (AIC = 25.63; R^2 = 0.25, $p < 0.001$). As for the relationship between MAOC and SOC (Figure 4b), for row crops, the linear model again was a better fit (AIC = 35.43; R^2 = 0.58, p < 0.001) than the logarithmic model (AIC = 39.76; R^2 = 0.54, p < 0.001). However, for pastures, the logarithmic model provided a better fit (AIC = 16.89; R^2 = 0.54, p <0.001) compared to the linear model (AIC = 19.41; R^2 = 0.51, p <0.001). These results indicated that while SOC increased across these pasture sites, MAOC appeared to contribute less and less to total SOC at higher SOC concentrations (Figure 4).

To further explore the potential of MAOC saturation, I examined how MAOC concentrations related to the percent of the soil in the silt and clay fractions. Again, pastures and row crops were considered separately. For both management types, a logarithmic model provided a slightly better fit than a linear model (Figure 5: pasture linear model: AIC = 106.74, R^2 = 0.27, p<0.001, pasture logarithmic model: AIC = 103.56, R^2 = 0.29, p<0.001; row crop linear model: AIC = 106.75, R^2 = 0.31, p < 0.001; row crop logarithmic model: AIC = 104.52, R^2 = 0.32, p< 0.001). This indicated that as the silt and clay fractions increased in the soil, MAOC concentrations also increased, but those increases were less at higher silt and clay percentages. Additionally, this modelled relationship is quite similar between perennial pastures and annual row crops such that their standard error shading is completely overlapping.

When examining the relationship between pasture age and MAOC accumulation, the results varied by MAOC concentrations and MAOC stocks (Figure 6a and 6b, respectively). No significant relationship was observed between pasture age and MAOC stocks (p = 0.35), but a significant positive, but weak, relationship was observed between pasture age and MAOC concentrations (R^2 = 0.18, p = 0.002). Importantly, soil bulk density significantly decreased with increasing pasture age (R^2 = 0.24, p < 0.001, Figure 6f), which helps us interpret why the relationship of pasture age and MAOC differs between MAOC concentrations and MAOC stocks. POC concentrations ($R^2 = 0.54$, $p < 0.001$, Figure 6c) and stocks ($R^2 = 0.41$, $p < 0.001$, Figure 6d), significantly increased with pasture age such that the ratio of POC to MAOC also significantly increased with increasing pasture age ($R^2 = 0.18$, $p = 0.002$, Figure 6e). As a result, the SOC in some pastures was dominated by POC rather than MAOC.

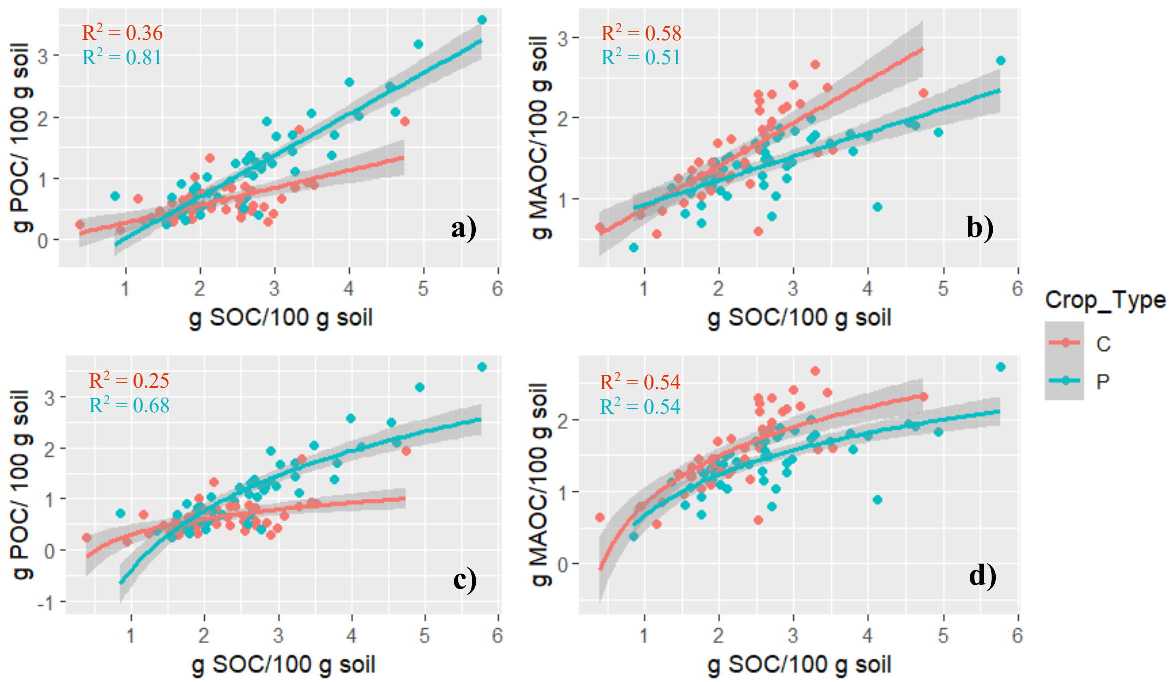

Figure 2. For the 0 to 15-cm soil depth, scatterplots of POC concentrations (a, c) and MAOC concentrations (b, d) by SOC concentrations under perennial pastures (P) and annual row crops (C). Linear models (a, b) and logarithmic models (c, d) are depicted.

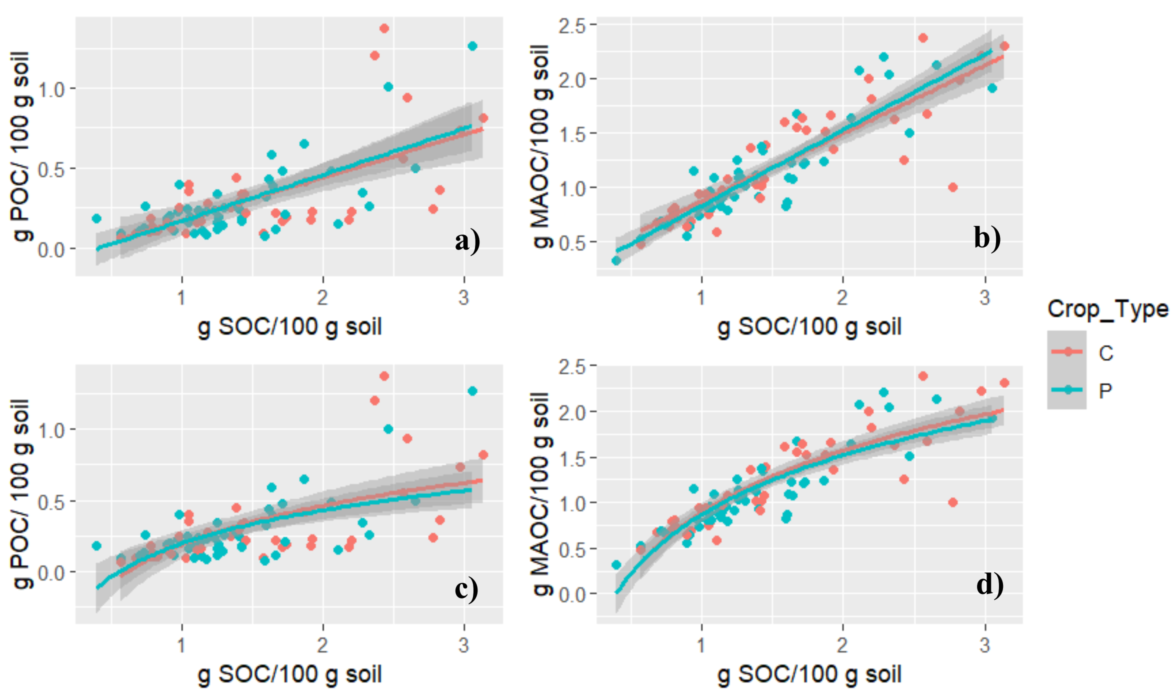

Figure 3. For the 15 to 30-cm soil depth, scatterplots of POC concentrations (a, c) and MAOC concentrations (b, d) by SOC concentrations under perennial pastures (P) and annual row crops (C). Linear models (a, b) and logarithmic models (c, d) are depicted.

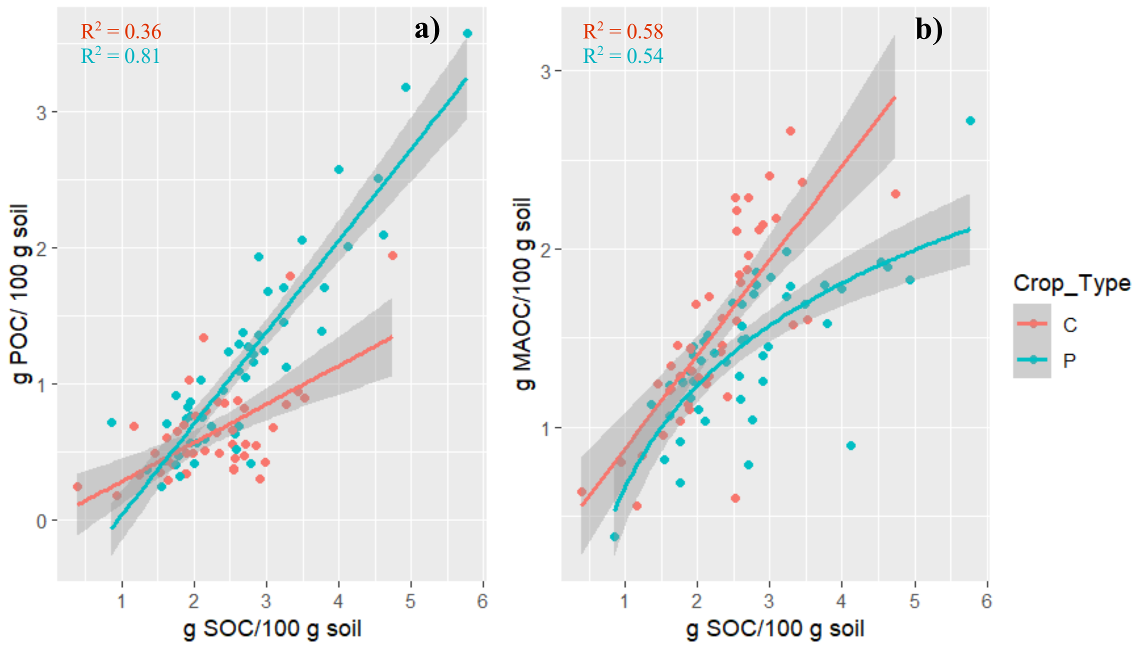

Figure 4. Scatterplots of a) POC concentrations and b) MAOC concentrations by SOC concentration in bulk soil (0 to 15-cm) for annual row crops (C) and perennial pastures (P) with model of best fit depicted.

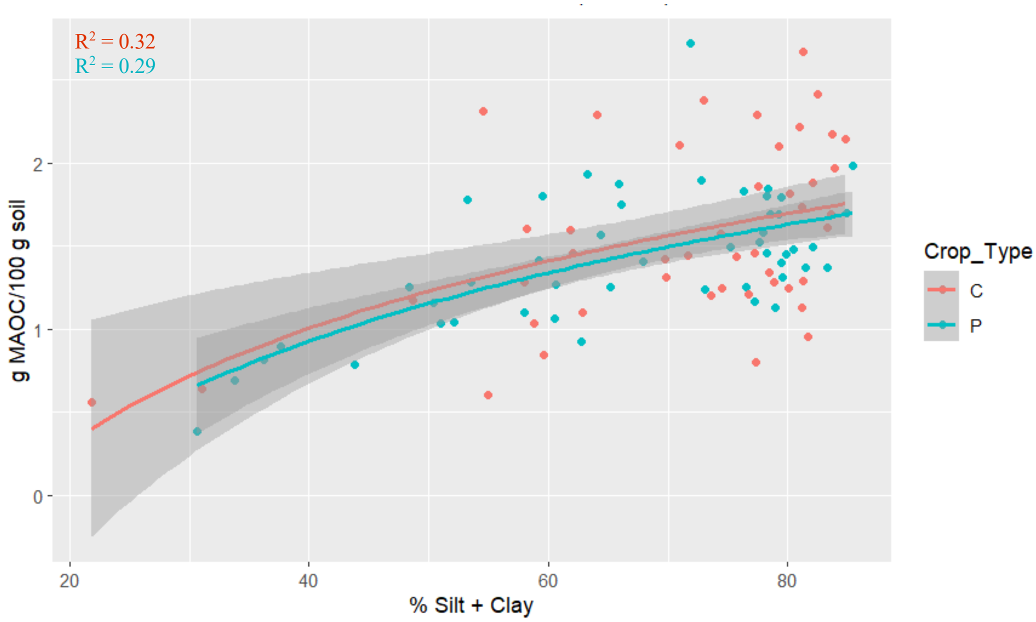

Figure 5. Scatterplot of soil fraction in silt and clay with MAOC concentration in bulk soil (0 to 15 cm) with best-fit logarithmic model for both perennial pastures (P) and annual row crops (C).

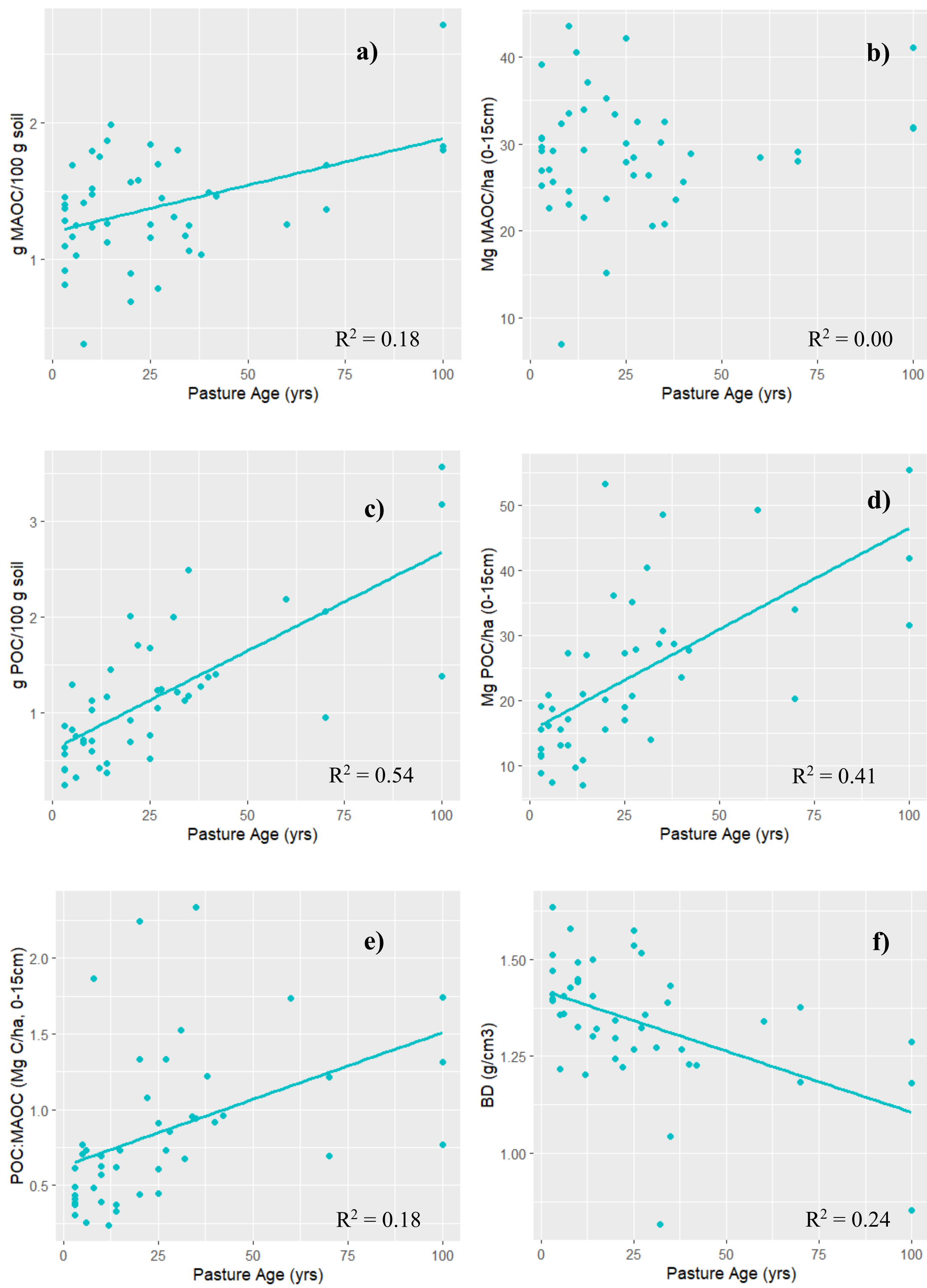

Figure 6. Scatterplots of a) MAOC concentrations, b) MAOC stocks, c) POC concentrations, d) POC stocks, e) the ratio of POC to MAOC, and f) bulk density by pasture age with linear fits depicted where significant.

Discussion

MAOC accumulation potential under rotationally grazed pastures is limited

MAOC may be saturating in rotationally grazed perennial pastures well below previous estimates of MAOC saturation. When examining the relationship between SOC concentrations and MAOC concentrations, the logarithmic relationship between MAOC and SOC indicated limits to MAOC accumulation under grazed pastures at higher SOC concentrations. Notably, more SOC came from POC than MAOC at the highest SOC concentrations in my dataset. While this relationship might not indicate true saturation given the absence of input manipulations in this study, MAOC may be approaching a steady state under current grazing management practices (Georgiou et al., 2025). Specifically, leveling off in pasture MAOC concentrations appeared at ~3.5% SOC, which seems to contrast with the saturation inflection point of ~5% in Cotrufo et al. (2019), but their inflection point communicates something different than my inflection point. In my data, MAOC appeared to be increasing with subsequent SOC increases even beyond 3.5% SOC, just in smaller increments. Cotrufo et al. (2019), instead, were identifying the point at which there were no increases in MAOC despite SOC increases. In addition, my data come from Midwest US pastures and croplands, while their data come from a database of European forest and grassland soils, with different soil forming factor influences and varied management. Even so, it is noteworthy that my data seemed to be approaching some equilibrium much sooner than suggested by the MAOC saturation curves of Cotrufo et al. (2019), and within agroecosystems generally thought to be well below their saturation capacity (Georgiou et al., 2022). This difference might also be explained by my methodology as the relationship observed by Cotrufo et al. (2019) was largely based on modeled data while I used empirical data. However, empirical data analyzed by Begill et al. (2023) supported yet another contrasting relationship between SOC and MAOC concentrations.

From soils with a range of SOC concentrations exceeding the range of these Wisconsin data, Begill et al. (2023) observed a continued linear increase in MAOC concentrations well beyond the ~3.5% SOC concentration inflection point in these data and the ~5% SOC inflection point of Cotrufo et al. (2019). While Begill et al. (2023) did not include rotationally grazed sites in their data, they did include both grasslands and croplands. Thus, their land management was comparable to these data generally, though livestock integration does affect SOC accumulation (Augarten et al., 2023; Stanley et al., 2024). Further, the data from Begill et al. (2023) came from archived soils with known, broad-ranging SOC concentrations used as the primary selection criterion. This may indicate those soils experienced different soil forming factors to reach higher SOC concentrations than the soils included in my dataset where management practices were the first selection criterion. While there are some notable differences between the land management, location, and data type employed by Cotrufo et al. (2019), Begill et al. (2023), and this research, each study illustrated a different relationship between SOC and MAOC concentrations. Because I used on-farm data from common Midwest agroecosystems, it suggests limits to MAOC accumulation in this region that might have been overlooked in previous MAOC saturation literature.

As further evidence of limits to MAOC accumulation in pastures, I found no evidence of accumulation in MAOC *stocks*, the best metric for assessing SOC changes, with increasing pasture age, even with six additional older pasture sites added to those reported in Becker et al. (2022). While MAOC *concentrations* increased with increasing pasture age, this could be an artifact of SOC analysis under a fixed-depth soil sampling approach of surface soils where bulk density changed, rather than reflecting an actual change in the MAOC quantity (Raffeld et al., 2024; von Haden et al., 2020). In particular, pasture bulk density decreased with increasing pasture age, which has been observed under perennial forage systems (Daly et al., 2023; McLenaghen et al., 2017) and is likely driven by increasing root biomass (Daly et al., 2023). This decreased bulk density could result in measuring increased SOC concentrations, even if SOC stocks remained the same (von Haden et al., 2020), though it could contribute to potentially underestimating SOC stocks as well (Raffeld et al., 2024). Making equivalent soil mass (ESM) corrections can account for the effect of bulk density differences on SOC stocks and concentrations to better estimate actual SOC change (Raffeld et al., 2024; von Haden et al., 2020), but using ESM corrections is not advised when comparing samples from various geographical areas (Rovira et al., 2022), such as in this work. Despite bulk density changes, POC stocks increased with increasing pasture age. While the space-for-time approach used here can limit conclusions about actual SOC change (Sanderman & Baldock, 2010), an increase in POC stocks suggests that pastures are accumulating SOC, just in the fraction not subject to mineral surface availability. Thus, based on the available SOC stock evidence, a lack of relationship between MAOC stocks and pasture age, coupled with continued increases in POC stocks, undermines the idea of continued MAOC accumulation under rotationally grazed pastures.

Further consideration of limits to, and drivers of, MAOC accumulation are needed as limits to MAOC accumulation within grazed pasture systems were surprising. Grasslands have some of the highest proportions of MAOC relative to other biomes (Sokol et al., 2022), indicating that grasslands have accumulated MAOC stocks over time. In addition, MAOC accumulation is expected under well-managed grazing because of its potential to increase inputs of high-quality plant material while distributing manure as a key nitrogen source (Stanley et al., 2024). However, increased MAOC stocks were not observed on the timescales these data encompassed, which might indicate that MAOC simply takes a long time to accumulate in these systems. That said, a recent meta-analysis concluded that SOC accumulation largely stems from POC accumulation on decadal timescales (Liu et al., 2025). In addition, perennial pasture systems today are dominated by cool-season grasses, which generally have much shallower rooting depths than the warm-season grasses (Mueller et al., 2013) that historically dominated much of the Midwest landscape where these farm sites were located (Curtis, 1987; Samson & Knopf, 1994; Wright & Wimberly, 2013). Root length is positively related to MAOC formation (Sokol et al., 2022), and pastures whose plants generally have short rooting depths might not lead to SOC accumulation as effectively (Spiesman et al., 2018). Consequently, different results may be observed by pasture systems dominated by warm season grasses (McSherry & Ritchie, 2013).

Also, these data add to the continued dialogue about the importance of SOC methodologies when claiming SOC change (Chaplot & Smith, 2023; Dietz et al., 2024; von Haden et al., 2020). In particular, if I had only examined pasture MAOC concentrations, I could have concluded that these pasture systems were increasing in SOC. Therefore, current expectations for MAOC accumulation might be reflective of common SOC methodologies, not actual MAOC stock changes (Dietz et al., 2024; Raffeld et al., 2024). Finally, there was a lot of variability in MAOC stocks and concentrations, with pasture age explaining only ~18% of the variability in the MAOC concentrations. Accordingly, there is still much we do not understand about drivers of MAOC, and examining different management systems strengthens our understanding.

Annual and perennial agroecosystems have different potential for MAOC accumulation

In contrast with grazed perennial pastures, MAOC continued to increase linearly with increases in SOC under annual cropping systems, albeit while reaching lower overall SOC concentrations than pasture systems. Annual row crop systems also appeared to have a higher percentage of MAOC than perennial pastures, though this does not mean that annual row crops were accumulating more MAOC. As outlined in Sanford et al. (2022), greater persistent carbon, like MAOC, under annual row crops was attributed to an inability to retain less persistent carbon with higher soil disturbance in annual cropping systems, rather than annual row crops accumulating persistent SOC. The highest SOC concentrations under annual row crops were lower than those of perennial pastures, as mentioned above, aligning with other studies showing that perennial pastures have a greater potential to accumulate SOC than annual row crop systems (Augarten et al., 2023; Becker et al., 2022; Dietz et al., 2024; Mehre et al., 2024; Shang et al., 2024). Also, the pastures, which experienced less soil disturbance, had a greater fraction of SOC in POC, the more accessible and less persistent fraction (Lavallee et al., 2020). This further lends credibility to the theory that soil disturbance drives differences in the fraction of SOC in POC and MAOC.

Next, differences across both annual row crops and rotationally grazed pastures seemed to be limited to the surface 15 cm of soil. This aligns with the analysis of the subset of these data explored in Becker et al. (2022), indicating that the addition of new study sites did not change this observation. Because plant roots are largely concentrated in the surface soil in these systems, SOC differences are similarly limited to the surface soil (Moore et al., 2025). As mentioned previously, my sampled pastures were dominated by cool-season grasses, which typically have a much shallower rooting depth than warm-season grasses (Mueller et al., 2013), though there is certainly variability among the different common cool-season grasses (Alber et al., 2014; Casler et al., 2020). However, relative to annual cropping systems, cool-season pastures have more belowground inputs than corn and soybean rotations (Moore et al., 2025; Sanford et al., 2012), contributing to the differences observed in the surface soils.

Finally, across both management systems, MAOC concentrations seemed to level off as silt and clay content of the soils increased, aligning with the conclusions of Poeplau et al. (2024) that MAOC loading is greater in soils with a smaller fraction of silt and clay. Given that this relationship was similar for both row crops and pastures, it suggests similar MAOC loading potentials across both management systems. Thus, the differences between systems in how POC and MAOC relate to SOC concentrations likely were not attributable to differences in soil texture. Overall, the percent of silt and clay at each site explained only ~30% of the variance in MAOC concentration, demonstrating that a large portion of MAOC concentration variability is due to more than basic soil texture classifications.

Getting SOC estimates "right" matters, and so does whole ecosystem functioning

Rather than manipulating management practices and carbon inputs to explore SOC change in Midwest agroecosystems, this research provided insight into achievable SOC concentrations, and particularly MAOC concentrations, under common management practices within the region. This approach is useful for establishing SOC expectations independent of ideal or merely proposed management changes. Importantly, these common practices represented a variety of annual row crop and rotational grazing systems. Therefore, differences observed in SOC accumulation between these two agroecosystems are likely robust, including that rotationally grazed perennial pastures had potential to reach higher SOC concentrations than annual row crop systems. However, my findings also suggested that MAOC accumulation may be limited, even under best agricultural management practices like rotationally grazed pastures. Evidence of a MAOC steady state under grazed pastures from these data contrasted with prior MAOC saturation research by Cotrufo et al. (2019) and Begill et al. (2023) that proposed a higher MAOC saturation limit than these data and no saturation evidence at all, respectively. These discrepancies matter as limits to MAOC accumulation can critically inform modelled responses of SOC change to different land uses. My data, and other regional data like this, can be useful in meeting calls for both model validation (Garsia et al., 2023) and model inclusion of saturation (Moinet et al., 2023). Because accounting for saturation drastically changes the promise of agriculture as a climate change mitigation solution (Moinet et al., 2023), getting regionally-specific SOC estimations right is key.

Beyond the importance of accurate SOC estimates, limits to MAOC accumulation and high fractions of POC indicate that practices such as rotational grazing, which at least seem to be retaining MAOC, and SOC generally, should be viewed as long-term practices. We cannot rely on the accumulation of persistent MAOC to justify disturbing the soils in these systems. Furthermore, rotational grazing can provide additional ecosystem services to benefit farmers and their communities (Spratt et al., 2021; Wepking et al., 2022). Bringing other ecosystem services into the conversation about sustainable agriculture enables farmers and consumers to move beyond SOC as a singular goal. When only SOC is prioritized, efforts to accumulate SOC can come with unnecessary tradeoffs, such as overloading soils with manure applications as a potential strategy for pushing continued SOC increases (Heinemann et al., 2024) at the detriment of water quality (O'Brien & Hatfield, 2019) or drawing attention away from necessary fossil fuel reductions (Fawzy et al., 2020). SOC change should inform agricultural practices and agricultural models because healthy soils underly sustainable, climate-smart agroecosystems, yet

SOC can also be part of a bigger picture. We can transform our agricultural system to support healthy soils and a healthy environment while supporting farmers and communities too.

Transforming agriculture to support people and the environment means that in addition to asking questions about SOC accumulation potential, researchers should think about our agroecosystems holistically (Iuliano, 2024; Moinet et al., 2023). This requires connecting with non-researchers and collaboratively imagining new systems, where practices like rotational grazing dominate the landscape to better meet our needs. SOC research can continue to be an important part of the strategy towards more sustainable agriculture, as long as we remember to critically ask “why?” and “for whom?” in the work we do.

Chapter 3. Reshaping agriculture: Farmer voices highlight opportunities for collective change

Introduction

Row crop agriculture, and corn production in particular, dominates the Midwest agricultural landscape in the United States (USDA NASS, 2022), so much so that it is reflected in the identity of the region, in its designation as the "Corn Belt"[3] (Green et al., 2018) and in sentiments among farmers that "corn is king" (Roesch-McNally et al., 2018). Intensive row crop production is further justified with narratives proclaiming farmers' responsibility to "feed the world" (Hall, 2024; Rissing, 2021), yet this type of production simultaneously contributes to major environmental and social consequences through its emphasis on high input, large scale monocultures. From declines in topsoil (Thaler et al., 2021) and soil health overall (Augarten et al., 2023; Dietz et al., 2024) to impaired water quality (Lark et al., 2022; Secchi et al., 2011) as well as declines in community socioeconomic status and social cohesion (Lobao & Stofferahn, 2008), industrial agriculture production jeopardizes human well-being and the landscape.

Despite these harms, intensive row crop production continues to dominate the landscape, with corn production even increasing in Midwest states (Rathore et al., 2024), reflecting a system that is structured to reinforce this intensive production (Roesch-McNally et al., 2018), through policies (Rissman et al., 2023), markets (Roesch-McNally et al., 2018), and social norms

[3] The boundaries of the US Corn Belt are contested and fluctuating (Green et al., 2018), and its meaning has changed over time (Warntz, 1957). For example, during its first uses in the early 1900s, a diversity of crops were grown in the Corn Belt states (Warntz, 1957). With this mind, I use the term "Corn Belt" here to illustrate how our language can normalize and perpetuate growing large amounts of corn and conversely, how growing large amounts of corn can lead to reinforcing language. Also, the boundaries of this region typically include southern Wisconsin and Iowa (Green et al., 2018; Thaler et al., 2021; Warntz, 1957), which are two areas of interest within my research.

(Rissing, 2021). However, this way of farming is not inevitable. Farms in the Midwest were more diverse historically (Roesch-McNally et al., 2018; Warntz, 1957), and farmers express many values separate from agricultural production, such as caring for the land (Leitschuh et al., 2022; Strauser & Stewart, 2024). Thus, farming in this Midwest region can change. To better align agricultural production with environmental and social values, we must restructure the system, or rather, the *place* that these practices occur within.

Place encompasses both the meanings and materiality of a space (Cresswell, 2015), such as how the region physically dominated by intensive corn production is deemed the "Corn Belt" and is aligned with a shared narrative of "feeding the world". The meaning and materiality likewise interact, such that they can and do reinforce each other (Cresswell, 1996). We might expect large amounts of corn to be grown in the place named the "Corn Belt", so by staking its name in corn production, corn production is reinforced as the regional norm and in the markets, economics, and policies too. In other words, the meanings associated with a place powerfully shape it (Cresswell, 2015), especially when those meanings are shared by many people in a region (Strauser et al., 2022). As a result, new shared meanings can lead to a new physical landscape (Burton et al., 2020; Di Masso & Dixon, 2015; Morse et al., 2014). Imagine how practices, purchasing patterns, and local policies might vary if what the region meant to farmers, consumers, and local government was staked first and foremost on feeding local communities and stewarding the land for future generations. Therefore, if we aim to reshape agricultural landscapes, it is pertinent to interrogate what shared meanings exist in agricultural communities, as those meanings shape the construction of those places just as the construction of those places shapes the shared meanings. Specifically, "good farmer" conceptions characterize shared understandings of acceptable farming behaviors in a place (Burton, 2004; Burton et al., 2020), and warrants further investigation in the pursuit of reshaping agriculture.

The "good farmer" reflects and shapes norms in the Midwest region

The norms for farming encompassed in conceptions of a "good farmer" powerfully shape places. These norms can create widespread coordination of farming behaviors that align with these "good farmer" norms (Strauser et al., 2022), despite the fact that cropland is almost entirely privately owned land in the US (Forster, 2006). Importantly, these social norms contribute to more than social pressure for land managers to farm a certain way (Cresswell, 1996); they shape the way our agricultural systems are structured. This includes shaping policy, marketing efforts, interactions with bankers, agribusiness priorities, and so on (Hall, 2024; Rissman et al., 2023; Rodriguez et al., 2009). While farming norms are context-dependent (Burton et al., 2020; Carolan, 2006), conceptions of the "good farmer" in the Midwest have included expectations on both what farmers should produce as well as how much.

First, the homogeneity of the Midwest agricultural landscape (USDA NASS, 2022) suggests some level of social agreement that a "good farmer" grows corn and soybeans (Strauser & Stewart, 2023). Corn production in the Midwest has continued to increase over time, reflecting increases in acreage, not just bushels produced (Rathore et al., 2024). Additionally, the narrative that farmers should maximize production to "feed the world" is pervasive (Comito et al., 2013; Hall, 2024; Rissing, 2021). Given the challenging economics of farming, farmers may also heavily focus on yields as a marker of "good farming" because they can control yields more easily than profits (Burton, 2004). Critically, "good farmer" conceptions extend beyond a sole focus on yields. Midwest farmers contest the idea that only productions matters (Strauser & Stewart, 2024), instead emphasizing other priorities like conserving the land (Leitschuh et al., 2022; Strauser & Stewart, 2024). Therefore, as farmers strive to align their practices with these different "good farming" norms, their practices are simultaneously influencing and being influenced by other people and places.

"Good farmer" conceptions influenced by other people and places

Notions of good farming, as part of the norms of the Midwest, are relational. As highlighted in Chapter 1, places, such as the Midwest region or even individual farms within it, are always interacting with and influencing other places (Agnew, 2011; Cresswell, 2015; Pierce et al., 2011). These interactions shape and change how the "good farmer" is conceptualized. Thus, one way the "good farmer" identity is shaped is from referencing others, particularly other farmers. This influence is evidenced by backlash, or even anger, experienced by farmers who adopted grazing practices contrary to the practices used by most farmers in their area (Gosnell et al., 2019) or respect for farmers who produce high yields from clean fields (Burton, 2004). Shared understandings of what should be on the landscape, such as a pastoral New England landscape (Morse et al., 2014) or dense, thriving corn fields along a busy Midwest highway (Strauser & Stewart, 2023), serve as a metric by which others judge one's own management, and similarly, a metric by which to judge others' management practices (Morse et al., 2014; Nassauer et al., 2009; Strauser & Stewart, 2023).

Influences also come from beyond the farm. Policies such as those emerging from Farm Bill legislation along with limited markets, can further promote corn and soybean production, while impeding viable options for diversification (Johnson, 2023; Traldi et al., 2024). These policies also support consolidation through subsidized crop insurance (Azzam et al., 2021), particularly promoting corn and soybeans over grazed perennial pastures (Rissman et al., 2023). Other entities working with farmers, such as universities, government agencies, and input dealers, also reinforce narratives that equate good farming with maximizing yields through touting narratives of "feeding the world" (Rissing, 2021) or uphold industrial agricultural management through limiting farmer independence (Stuart & Houser, 2018). Stuart and Houser (2018) demonstrate how a seed company's prevention of seed-saving, restriction of knowledge shared about new seed varieties, and reduction of seed lifecycles, all leave farmers dependent on the company's guidance for nutrient management. Consequently, farmers are pushed toward increased nitrogen application via seed company recommendations. Thus, these relational influences begin to constrain conceptions of good farming to industrial row crop monocultures, which can be shaped further by references to the past.

As outlined by Feola et al. (2023), our *group* identities inform what we remember from the past, which serves as a "reference point" for how we assess where we are at present and where we would like to go in the future. In other words, which past we choose to reflect on, such as how far back and which details we emphasize, can inform and justify how places are understood and shaped in the present. Similarly, Soga and Gaston (2018) described "shifting baseline syndrome" as a phenomenon of shifting reference points with each new generation that impacts assessments of environmental degradation, in particular. With each new baseline, or reference point, social norms for environmental goals can also shift (Soga & Gaston, 2018), shaping place construction. Thus, which "reference point" is selected greatly matters as the progress, or lack thereof, made by any present or future place is compared to that reference. While we can have reference points that are personal to us, the reference points articulated by Feola et al. (2023) are particularly impactful because they are shared among people, supporting collective visioning for places. As a more concrete example within an agricultural context, research by Strauser et al. (2019) captured how a focus group comprised of Iowa community leaders supported their desire to increase visibility of Iowa's agricultural production in the future by harkening back to the international importance of and interest in Iowa's agriculture in the past. Because Iowa agriculture was globally recognized historically, that was used to justify the aim of pursuing global recognition today. Similarly, Ingalls et al. (2019) described how a present-day conflict over land use between farmers and federal agents was reflective of conflicts in how each group understood historic land use changes. Hence, our relationships to the past, which are influenced by our relationships today, inform present-day beliefs and practices, including conceptions of the "good farmer".

"Good farmer" conceptions influenced by the physical landscape, yet shape the landscape too

Conceptions of the "good farmer" and how they inform what the landscape should look like are also influenced by the biophysical landscape itself. As synthesized by Prokopy et al. (2019), "land vulnerability", defined as highly erodible land, is positively related to the adoption of conservation practices. The biophysical landscape surrounding a field likewise determines how impactful a farmer's management decisions are on the broader landscape, which motivates targeted conservation adoption to respond to disproportionate effects (Kalcic et al., 2014). Farmers also can associate appropriate farming practices with a certain topography. Ranjan et al. (2019) identified a perception among some farmers that flat land does not require conservation practices. While biophysical elements certainly do not dictate which practices will dominate the landscape (Cresswell, 2013), those elements can influence the meanings we inscribe (Stedman, 2003). In the context of our agricultural landscape in the Midwest US, the corn and soybean fields that dominate the Midwest largely exist on the fertile soils of historic prairies (Popper, 2013). This demonstrates that while the current Midwest landscape has been reshaped around narratives of production and feeding the world, this same region also was suitable for growing corn and soybeans because of the rich grassland soils and climatic conditions (Green et al., 2018). As such, what it means to be a "good farmer" may differ based on the biophysical environments in which someone farms.

However, humans also manipulate the environment to materialize what we believe the landscape ought to be (Greider & Garkovich, 1994; Nassauer, 1995a). Social groups shape and give meaning to landscapes that reflect their values and beliefs, and changes to the landscape can confront those associated meanings. Different groups can attach different meanings to the same biophysical landscape as Greider and Garkovich (1994) highlighted by describing how a real estate developer, a farmer, and a hunter interpret an open field as a place for a new home, wheat fields, and deer habitat, respectively. Their values translate into different uses for the same piece of land. In agriculture, we expand the scope of arable acres with irrigation. Approximately 15% of farms use irrigation in the US (USDA NASS, 2022), and irrigation has been key component of expanding the "Corn Belt" region (Green et al., 2018). The landscape is made to fit corn production. Redefining "good farmer" beliefs and values will impact how the biophysical landscape is shaped.

"Good farmer" aesthetics communicate care and skill while associated practices cause harm

Given the highly visible nature of farming (Burton, 2004; Strauser & Stewart, 2023), management practices can visually signal what farmers value and demonstrate alignment with "good farmer" conceptions (Burton, 2004, 2012; Dentzman & Goldberger, 2020; Nassauer, 1988; Ryan et al., 2003). Straight rows and weed-free fields seem to be key to the desired aesthetic of many Midwest row crop fields (Carolan, 2006; Nassauer, 1988; Ofstehage, 2022). Similar expectations of neatness have been observed abroad, with homogenous fields, including straight crop rows, expected among farmers in Germany and Scotland (Burton, 2012). These aesthetic preferences can vary based on the farmer's identity, such as differences among organic and non-organic farmers (Sutherland, 2013) or "conventional" and "sustainable" farmers (Carolan, 2006). Farmer aesthetic preferences can also differ from public preferences for more natural landscapes (Brush et al., 2000; Burton, 2012). However, the dominance of neat row crop fields on much of the Midwest agricultural landscape may be explained through how the practices communicate care and skill to neighboring farmers and other observers.

Farmers may use the neatness of their fields to demonstrate and practice care for the land (Nassauer, 1988; Shipley et al., 2022), and caring for the land has been expressed as a component of good farming among Midwest row crop farmers (Leitschuh et al., 2022). Consequently, while clean fields can signal good farming, farmers with untidy fields can be perceived as bad farmers (Leitschuh et al., 2022). However, caring for the land remains in conflict with industrial corn production (Wepking et al., 2022), demonstrating that signaling care through aesthetics of tidy row crop fields might come at the cost of environmental and social harms (Nassauer, 1988, 1995b). The pervasiveness of well-manicured fields may also be explained, at least in part, because it serves as a reflection of farmers' knowledge and skill (Burton, 2004; Burton et al., 2020). Those with well-managed fields have been seen as efficient, skillful farmers, subsequently providing them with clout among other farmers (Burton, 2012). Interestingly, with technological advances in agriculture like GPS navigation, straight rows and weed-free fields may now be less of an indicator of farmers' skills than they were historically (Burton et al., 2020; Ofstehage, 2022). Overall, the practices farmers are employing convey meaning to all those who observe their fields, and so, aesthetic preferences within "good farming" conceptions are important to acknowledge. They can inform land management even more so than ecological functions (Gobster et al., 2007). Changing aesthetic preferences within "good farmer" conceptions can be key to supporting agricultural change, especially if the preferred aesthetics conflict with environmental and social goals.

Reshaping "good farmer" conceptions could disrupt industrial agriculture

As conceptions of the "good farmer" evolve, agricultural landscapes are consequently shaped and reshaped (Burton et al., 2020; Strauser & Stewart, 2024). Changing "good farmer" conceptions can result in farmers engaging in different practices that better align with those new meanings (McGuire et al., 2013). This interplay between land management and notions of what makes a good farmer, or more broadly, between social meaning and the construction of places, is happening constantly (Cresswell, 2015). Nassauer (1995a, p. 235) has captured this in different iterations of good farming in the US over time:

> "[I]n 1910 a farm that included varied enterprises of fruit, livestock, and grain crops would have looked progressive. In 1960 a farm that specialized in a single enterprise at a larger scale would have looked progressive. Two decades later a farmer would have been likely to be perceived as progressive if he skillfully used residue management."

This example illustrates the fluctuating meanings we have attached to progressive agriculture. As the expectations around which practices were employed by a "progressive farmer" changed, so too, did the agricultural landscape.

Changing "good farming" conceptions is not without challenges. Current literature has demonstrated that definitions of the "good farmer" in the Midwest are already multifaceted, including elements of cleanliness (Ofstehage, 2022), efficiency (Shipley et al., 2022), and conservation (Leitschuh et al., 2022). However, that does not mean that each aspect of good farming is given equal priority in our current system, especially given the structural factors (e.g., Azzam et al., 2021; Stuart & Houser, 2018) and social pressures (e.g., Gosnell et al., 2019) that constrain farmer behavior and perpetuate their role in the industrial agriculture system. While participating in industrial agriculture could create tension between farmers' identity as caretakers of the land and their practices, some Midwest crop farmers have been shown to adopt ideologies, like techno-optimism (Houser et al., 2020) or "feeding the world" (Comito et al., 2013), to justify their management practices within industrial agriculture. In other words, they have conceptualized the "good farmer" within the bounds of industrial agriculture, yet others may instead feel discontent with those conceptions.

As captured in interviews with row crop farmers by Houser et al. (2020), a small sample of farmers were disillusioned with the industrial agriculture system and acknowledged its inability to address current environmental concerns. Nonetheless, they could not articulate viable, alternatives. Similarly, other work has documented the misalignment of these industrial agriculture practices, which prioritize maximizing production, with farmer values and priorities (Leitschuh et al., 2022; Strauser & Stewart, 2024). These studies are noteworthy as they demonstrate both that the "good farmer", in theory, may already align well in some ways with more sustainable agricultural practices, yet farmers struggle to conceptualize viable alternatives within the current system constraints.

Fortunately, despite how norms, economic pressures, and policies limit identification of practices better aligned with farmers' values, more sustainable agricultural practices do exist. In particular, well-managed rotational grazing is an agricultural practice with the potential to support farmer livelihoods while preserving soil health and biodiversity (Spratt et al., 2021). Its environmental benefits are especially stark in contrast to annual row crops (Augarten et al., 2023; Becker et al., 2022; Dietz et al., 2024), and seems to be profitable for farmers (Winsten, 2024). That is, well-managed grazing is a sustainable practice for farmers and the environment. Yet despite potential alignment with farmers' environmental and economic values, this practice is vastly outnumbered by row crop fields on the landscape (USDA NASS, 2022). Thus, I aimed to capture farmer perspectives on barriers to and potential opportunities for a more sustainable agricultural system through exploring current "good farmer" conceptions and how those align with farmers' goals and sustainable agriculture practices. Specifically, I assessed "good farmer" meanings in two locations with contrasting topography in the Midwest US to understand its alignment with well-managed rotational grazing. In addition, I explored whether farmers were discontent with how the "good farmer" is conceived and their current practices as well as what changes to agriculture they might envision in their region. My research questions were:

1) How do row crop farmers conceptualize what makes a "good farmer" in their region?
2) How do row crop farmers experience, if at all, tensions between "good farmer" conceptions in their region and their current practices, long-term goals, and values?
3) How does well-managed rotational grazing align with "good farmer" conceptions?

Through this research process, farmers outlined how the "good farmer" is defined and discussed how the agriculture system could better support them and their communities. These conversations with farmers may support conversations within communities about shared visions for the future and provide an avenue for communities to engage in collective action to better meet their goals. My hope is that this research serves as an important step in the hard work of creating a new agricultural landscape, not the end.

Methods

Study sites

The Driftless Area encompasses a Midwest region that is both physically and socially constructed such that its boundaries are contested. By definition, the "Driftless Area" constitutes the unglaciated region in the upper Midwest, namely southwest Wisconsin and the northwestern tip of Illinois (Carson et al., 2023). However, a broader region surrounding this truly unglaciated area comprised of northwestern Illinois, northeastern Iowa, southeastern Minnesota, and southwestern Wisconsin, contains driftless-like topography, which constitutes steeper, more frequent and dissected hills relative to the surrounding areas (Cohee, 1934) and has also been deemed the Driftless Area historically (e.g., Cohee, 1934) and more recently (e.g., Mitchell, 2023). While this debate of boundaries offers an interesting example of the social construction of places, in this work, both the Driftless Area and surrounding driftless-like topography provide an opportunity to compare how the physical landscape impacts conceptions of the "good farmer" within and outside of this region.

One study location was centered within the Driftless Area in Dodgeville, Wisconsin, and the other on the southern edge the driftless-like topography in Maquoketa, Iowa. Despite only Dodgeville being located within the Driftless Area, both locations acknowledge their relationship to this unglaciated region on their city websites (*City of Maquoketa: One of a Kind*, n.d.; *Dodgeville: At the Heart of It All*, 2023). Importantly, their topography is such that Dodgeville constitutes a hillier landscape relative to Maquoketa, particularly compared to the southern side of Maquoketa (*United States Topographic Map*, n.d.). Since topography can impact perceptions of the need for and use of conservation practices (Prokopy et al., 2019; Ranjan et al., 2019), "good farmer" conceptions may vary with these biophysical differences between places. Beyond these topographical differences, Dodgeville and Maquoketa remain comparable across other demographic variables.

According to the 2022 US census data, Dodgeville and Maquoketa had populations of 5,088 and 6,054 residents, respectively (United States Census Bureau, n.d.). Both cities are the seat of their county, are predominantly white (>93%), and are composed of a similar proportion of individuals under 5 years and over 65 years of age. Dodgeville has a slightly higher median income (i.e., $64,844 versus $51,958) and lower poverty level (8.4% versus 18.9%). According to land use data from the USDA Ag Census at the county level (2017), Dodgeville, contained within Iowa County, and Maquoketa, contained within Jackson County, both have substantially more cropland than pastureland. Iowa County has 1,576 farms with an average area of 93 ha. Jackson County has 1,107 farms with an average area of 115 ha. It is important to note that Maquoketa is located near the Jackson and Clinton County border, so for some interviewees, Clinton County statistics would be applicable. However, these data provide a good general comparison of these study sites and highlight their similarities.

Participants

Using a purposive sampling approach, I invited farmers growing row crops to collaborate in this research. Additionally, I oversampled farmers younger than 40 years old, given the greater likelihood that they have more time to implement land use changes. Farmers were contacted via phone or email by first drawing on the networks of a local farmer contact in Iowa and Wisconsin and that of the research team. After these initial contacts, I used snowball sampling to connect with other farmers.

In total, I interviewed 34 farmers, with 22 farmers located near Maquoketa and 12 farmers located near Dodgeville, WI, which represented 29 different farms. While I did not ask participants to identify their gender, 30 participants presented as male with the remaining 4 presenting as female. Next, approximately one third of participants were in their 20s or 30s, and half were in their 40s or 50s. The remaining farmers were 60 years old or older. The average farmer age in Iowa or Wisconsin is approximately 57 years old, indicating that I successfully oversampled younger farmers. Finally, with my snowball sampling approach, though all farmers grew row crops in some capacity, over half of the farms also had livestock, including operations with hogs, dairy cows, and even beef cattle on pasture.

As a note, I did not confirm that all participants identified as farmers, an identity with which women and those engaging in production practices outside of the norms in the region might struggle, for example (Bell, 2024). However, each participant was considered a farmer in this work given their participation in farm activities or decision-making.

Data collection

After receiving Institutional Review Board approval, I conducted semi-structured, in-person interviews with each farmer to explore current regional conceptions of the “good farmer” as well as tension between that identity and farmer goals and values. The first 6 interviews served as preliminary interviews and were conducted between February and August of 2023 to inform any changes to the interview guide. While some questions then were tweaked or added, the overall goals of the interview guide remained the same (*Appendix A*). Subsequent interviews were conducted between December 2023 and January 2025. All interviews were audio-recorded. Recordings were transcribed using Otter.ai software or the Microsoft Word transcribe feature, then edited by the research team. Given similar questions and conversation trajectories across the preliminary and main interviews, both sets of semi-structured interview data were analyzed as one dataset.

In addition to the interviews, two workshops were held with participating farmers, one in each interview location. The purpose of these workshops was to share back my initial interpretations of the data and get farmers’ feedback. The feedback served as an opportunity to check how my interpretations resonated with farmers, have them participate in making sense of the data, and ask follow-up questions. I also invited the interviewed farmers to bring a partner or family member to engage in the discussion to broaden the perspectives I heard from. As a result, three additional farmers joined the workshop who did not participate in the interviews.

Data coding and analysis

The interview transcriptions were analyzed using a thematic analysis, employing both deductive and inductive coding. First, because prior research has provided strong evidence that farmers hold multiple priorities (Comito et al., 2013; Cusworth, 2020; Leitschuh et al., 2022; McGuire et al., 2015; Shipley et al., 2022; Strauser & Stewart, 2024), I similarly explored this phenomenon in my interviews. One framework for determining these different priorities included identifying four farmer identities put forward by McGuire et al. (2015): productivist, conservationist, civic-minded, and naturalist. When analyzing my interview data, I assessed whether these different identities were present, which would further add to the literature purporting that farmers are multidimensional and not solely profit-driven.

Next, in a more thorough analysis of the interview data, I began identifying the reference points farmers were using and the interpretations from those references as informed by Feola et al. (2023). After generating a list of codes and their descriptors, I used two coders, myself and one other member of the research team, to determine intercoder reliability (ICR). Then, we independently coded the same 10 pages from a single interview and checked for initial discrepancies in applying the codes.

After our first comparison, we achieved a total agreement level of 69% by calculating our proportion of agreements relative to total agreements and disagreements (Miles & Huberman, 1984) across 5 codes: ag system determinism, ag system disruption, conservation, reference point in time, and reference point in space (for definitions, see *Appendix A*). While a clear, widely accepted cutoff for "acceptable" intercoder reliability in the literature is lacking (Campbell et al., 2013; O'Connor & Joffe, 2020), 70% agreement (Fahy, 2001) and 80% agreement (Miles & Huberman, 1984) have been used as an acceptable agreement level previously with some researchers suggesting more leniency is allowable in exploratory research (Campbell et al., 2013). Thus, I aimed to achieve 70% agreement and began by refining my definitions. In addition, we determined that a few of the codes were nested within others and so applied only "reference point in time" and "reference point in space" in our second coding iteration.

Again, we selected 10 pages from a different farmer interview. This time, as we compared, we achieved 50% total agreement when combining both codes indicating that our agreement worsened. This was likely due to two challenges. First, we noticed that it was not uncommon for farmers to make references in space and time simultaneously. Second, as coders, we often varied in deciding where an idea began and ended. As a result, one of us may split a quote into multiple codes while the other lumped them together as one code. Consistent segmenting is a known challenge in assessing intercoder reliability (O'Connor & Joffe, 2020). Therefore, in our third attempt, we further reduced our codes to a single "reference point" code, which included comparisons in space, time, or both, and we treated each segment of text from the farmer between interviewer comments as one single idea. This meant that in each idea, we determined whether the farmer was using any reference point or not, then assigned the code accordingly. With this approach, we achieved 76% agreement, and I coded the remaining interviews with a single "reference point" code on my own.

Once all interviews had been coded, all reference point examples were copied to a separate document for further analysis. From this subset of data, "barriers to grazing" emerged as subtheme relevant to how farmers conceptualize the "good farmer", my first research question, and the alignment between the "good farmer" and well-managed grazing, my third research question. I then observed four themes related to my second research question exploring dissonance between farmers' goals and practices. First, farmers' land stewardship identity seemed to be impacted by their negative perceptions of historic land management practices compared with positive perceptions of land management today. These subthemes were designated as the "moldboard plow era" and "row crop conservation", respectively. Second, farmers' perceptions of the social fabric and economic constraints of their agricultural region seemed to be impacted by their positive perceptions of historic farming styles compared with negative perceptions of farming constraints today. These subthemes were designated as "nostalgic farming" and "farming as a business", respectively (for definitions, see *Appendix A*).

Finally, while interviews were conducted at two locations, it seemed there were more similarities than differences across the two locations following coding and reflections from the farmer workshops. Therefore, while the quotations are linked to the state where each farmer resides, the data are illustrative of broad themes present in both places.

Results

Farmers are multidimensional

As farmers described their farming management and motivations throughout the interviews, it became clear that they were striving to achieve multiple goals at once. Of the four identities characterized by McGuire et al. (2015), namely "productivist", "conservationist", "civic-minded", and "naturalist", each farmer expressed sentiments from at least two identities. Common goals included growing the farm and improving efficiency (i.e., productivist) as well as protecting the soil (i.e., conservationist). Many recognized the important role that farmers played in supporting their communities (i.e., civic-minded) and expressed a desire to set up the farm for the next generation, which can relate to multiple identities. As an example of these different identities, one farmer shared sentiments aligning with both productivist and conservationist identities, respectively:

> "…we try and keep waterways mowed up. I mean, that makes you zero money...there's pride in having a clean bean field and a clean cornfield…" and "I think we take soil health into consideration with how we farm, and I mean we've come a long ways from the moldboard plow…you know, erosion, is you try and do the best you can." (Iowa farmer)

The occurrence of these different identities demonstrates the complexities of farming and contests the notion that farming is just about maximizing profits. While economics are certainly still important, the idea that economics are the only thing that matters in farming was critiqued by the same Iowa farmer outright, sharing, "If we [were] all about money, we'd be sitting in an office making six figures just having, enjoying our weekends, working eight to five but yeah, but you still have to make a living out here too." Economics are one part of the "good farmer" but saying that money is all that matters mischaracterizes the many values and goals farmers hold. This indicates that "good farming" was conceptualized more holistically.

Through exploring the multidimensionality of farming, I also started to uncover areas of alignment and misalignment between crop farmers' current practices and their long-term goals. Areas of misalignment, in particular, present opportunities for tension to arise between how the "good farmer" is conceptualized and farmers' long-term goals. As mentioned above, farmers often expressed a goal of preserving the land, and subsequently, seemed satisfied that their practices were contributing to that goal. On the other hand, several farmers expressed a desire to return to a more nostalgic view of agriculture (e.g., more small family farms) while recognizing how this conflicted with the present realities of consolidation and pressure to continue growing and increasing efficiency. Importantly, this sense of alignment between goals and practices, or lack thereof, seemed to be impacted by what farmers were using as a comparison for their current practices.

"Better than the moldboard plow": Farmers positively assess their environmental stewardship

Many farmers expressed a strong environmental ethic, whether it was "[wanting] to protect the dirt" (Wisconsin farmer), "[giving] the ground to our kids in better shape than we got it" (Iowa farmer), or sharing that they were "a believer in conservation practices" (Iowa farmer). When assessing their environmental impact, many farmers also described how their practices today were improvements relative to previous generations. In other words, they used comparisons in time as reference points. For example, they referenced how reduced tillage or no-till practices today were much better for the environment than moldboard plowing. This practice-based comparison seemed to give farmers a sense that they were sufficiently meeting their goal of caring for the land:

> I mean, just compared to what things…you listen to the generation that's retiring, and it was moldboard plow, and we went across every acre, flipped it over every year planting. And granted, there [were] less acres that were being farmed. But I think what we do to soil now is a lot better. And I think the no-till on the scale of it has made a big difference. (Wisconsin farmer)

Thus, by comparing no-till to the intensive plowing that used to happen on most farmland, this farmer felt they were doing a better job of taking care of the environment now through much less soil disturbance. Decreased soil disturbance, which is achieved through practices like no-till and reduced tillage, was part of being a “good farmer”. This same sentiment, that farmers take better care of the land now than they used to, arose across multiple interviews:

> I think most farmers care about their land anymore. You take 30 or 40 years ago, there was, everybody was plowing. There was a lot of ditches, big ditches. But that's all changed for the most part now. And I didn’t see that stuff, but my dad said that, you know years ago people…it was bad. (Wisconsin farmer)

Similarly, this farmer used examples of reduced plowing relative to several decades ago and the absence of severe erosion as evidence of sufficiently caring for the land today. These reference points are powerful because they give farmers a way to evaluate their desired goal to care for the land that relies on practices, and notably, visual changes. For example, in a note from the Dodgeville meeting, reference points for building soil health were “yield” and “visual: not seeing visible signs of erosion”. Thus, these references seem to be based largely on different practices and subsequent observations from those practices instead of measured environmental outcomes. This gave farmers a sense that they were achieving their environmental goals.

However, not all farmers used the same reference point to assess their environmental impact. One exception to describing current practices relative to the moldboard plow was a single farmer who instead made a comparison to the historic prairies:

> …all the prairie that was ripped up after we settled here…I've been told the, you know, what the ground used to look like, what their earthworm situation used to be and it's, [we’ve] got a long way to go to get back to that. (Iowa farmer)

What is profound is that this new reference point led the farmer to conclude that “[we’ve] got a long way to go” to return the benefits that the prairie provided, rather than seeing today’s practices exclusively as improvements for the environment. Also, it is key that only one farmer used the prairie as their reference, indicating how uncommon this perspective was within "good farmer" conceptions. Further, using outcomes associated with prairies as the comparison created tension between the environmental goals the farmer would like to achieve and the impact their practices were having currently. Therefore, compared to a different reference point, the assessment of the environmental impact of dominant farming practices completely changed. This approach by many farmers of referencing past practices like intense tillage to assess their environmental impact may explain why many farmers felt negative public perceptions of agriculture were misaligned with the actual impact of their practices.

"Farmers versus the public": Mismatched comparisons led to mismatched perceptions of environmental impact

Throughout the interviews and workshops, a strong reoccurring theme was that farmers felt misunderstood and criticized by the public for the environmental impact of their practices. In particular, farmers expressed that the public viewed them as environmental polluters and those perceptions were mismatched with their own goals and practices:

> …I feel like there's such a still to this day divide of 'oh farmers versus we're not farmers' or, 'yeah, farmers are stupid, they don't know what they're doing and they're just out destroying the ground.' Where in the heart of most farmers, they want what is best for ground and productivity… (Wisconsin farmer)

This quote highlights tension between farmers perceiving themselves as caring for the land and the assumed public perception of a lack of care. Farmers felt mischaracterized because despite supposed public criticism of their environmental impact, caring for the land was just as important to them as they believed it was to the general public. These contrasting perceptions of environmental impact could be explained by returning to the comparisons farmers are using to assess their practices.

Because farmers perceived that they were having a positive environmental impact today *relative to* the moldboard plow, it makes sense that they feel such skepticism towards public scrutiny of their practices. To these farmers, their reduction in soil disturbance and limited visual evidence of erosion communicated care, so if the public was critical of their practices, then the public must misunderstand. Therefore, farmers felt that their improved practices refuted any public criticism:

> Oh yeah, well then the media's, 'you guys are polluting the world.' What makes you think that? 'Oh, I saw it. I heard it on CNN.' Okay, who said that? Like, come out here. Let me, instead of like…when that conversation comes up [with] somebody, don't be like, 'Oh, screw you.' Be like, 'no, we're not.' Explain it to them…And we're doing it in efficient ways, so we're not polluting, like it's way better than it was 50 years ago. Better than it was 20 years ago. (Iowa farmer)

Here, the farmer concluded that if the public realized how much better their practices were today than they were a few decades prior, they would similarly understand that farmers are caring for the land. Farmers felt the public should recognize their relative improvements as environmental stewardship. Thus, farmers see current criticisms of their practices as an issue of the public being uninformed. However, the public may instead be using different reference points than farmers in determining what sufficient care for the land looks like, or focusing on outcomes-based evidence, such as meeting water quality or biodiversity goals. Despite farmers being adamant that they were caring for the land, farmers also acknowledged some negative environmental impacts through sharing blame with the public.

References to other practices in space were used to both avoid the notion that farmers were the only culprits of environmental pollution, while conceding that farmers might contribute some to environmental pollution. In particular, farmers recognized the public as polluters too. As an Iowa farmer outlined: “I guess I don't see a problem…I'm sure you can have some runoff that puts something somewhere it shouldn't be. But you can also have that with people fertilizing their yard in town.” This farmer acknowledged that farmers might be contributing to some pollution, but it was perceived as no different than the pollution also contributed by the general public. This is not to say that farmers do not want to be part of the solution, but that they see themselves and the public as deserving shared blame for environmental pollution:

> …so farmers tend to get defensive, and often times with good reason, because we get blamed for a lot of it. But we also get defensive and tend not, don't always look at some of the research or because we’re just ‘oh they’re out to get us.’ I think there's a responsibility to be on top of issues, using a little bit of common sense plus research, and being willing to accept some of the research to prevent issues…sometimes the urban sector doesn't realize that they also have responsibilities, even in their small parcels of ground that they deal with or the things that they do, or the concentration of wastewater they produce in town that has to be treated. (Iowa farmer)

Using urban people as a reference allowed this farmer to admit that there can be some environmental issues associated with farming because they were not framed as the only contributors. References to other people polluting today also reduced possible tension between “good farmer” conceptions and farmers’ environmental goals.

In summary, reference points matter for assessing farmers’ environmental goals. Farmers’ reference points shaped their perceptions of the current environmental impact of their practices and how farmers responded to assumed criticism from the public. This included both disagreeing with what farmers perceived as the public's negative assessment of agriculture's environmental impact and sharing the blame for environmental pollution with the public. These references seemed to relieve tension that might otherwise exist between what farmers shared to be their environmental goals and the outcomes of their practices. As a result, their reference points helped reinforce the current composition of the agricultural landscape, dominated by annual row crops and including some conservation practices, because the "conservationist" components of their "good farmer" conceptions were satisfied. However, comparisons were used not just to assess environmental goals, but social goals too.

"The business of farming": Challenges present in aligning economic and social goals

When thinking about what it meant to be a farmer today, farmers frequently described both a desire and a push to continue expanding their farms while also recognizing the value of many small farms with a diversity of practices. For some, this created tension in balancing these goals:

> …every farmer wants to be bigger but yet, you still want to have the family farm. So it's definitely a struggle there to balance that out. And yes, in 20 years, do I think you're going to have to have twice as much acres as we do now just to stay viable or economical or..? Yeah. I do. Because it doesn't seem to be going the other direction. (Iowa farmer)

In particular, the tension that this farmer described between bigger farms and fewer family farms seemed to be exacerbated by a comparison to the past, a different reference point in time, where there used to be more small family farms on the landscape. For example, as the same Iowa farmer continued to describe their desire for small family farms, they expressed that it would be nice to "go back to the way it was." Therefore, while farmers made comparisons to the past similar to how they assessed their environmental practices, here the reference point seemed to create conflict with the way agriculture used to be and what farming looks like today. Their goals to have small farms with diverse practices were not being met by the way they were farming today, creating tension between parts of the “good farmer” conceptions that emphasize growth and efficiency and the parts that emphasize community cohesion and vitality.

Despite experiencing this tension around small family farms, however, farmers also expressed a lack of belief that an alternative to continued growth was possible. In particular, they felt that with the current economic context of farming, small farms could not be viable:

> …our dads, you know, farmed three, four or 500 acres. And they made good livings off that. Well, now a 1000-acre farmer is somewhat small…part of it is the equipment's gotten so expensive, you can’t afford to own a $700,000 combine and go through, you know, 1000 acres. It just doesn't pencil out. (Iowa farmer)

This farmer, as well as others, recognized that input costs have increased. Simultaneously, margins have decreased, which left farmers feeling like they must maximize efficiency. This resulted in approaches such as farming more acres, getting animals to market more quickly, and becoming expert at only a couple enterprises, even if small, diverse farms were preferrable. Becoming efficient was framed as response to economic challenges:

> …given as the years go by, less margin, the farmer has to figure out ways to be more efficient. And part of that is with genetics. Part of that is with management. Part of that's with inputs. Part of that’s with feed, all sorts of different things. And if you're [going to] try to raise the cattle on pasture, well, what's the way to get more efficient? Grow some corn, which you can grow really good corn, feed it to the cattle, cattle get to market quicker, then you can fill up the feedlot again quicker. So I think that's just overtime,

that's probably just how it's morphed. Because if everyone could, if we could go back to everyone having 350 acres, and just having a variety of livestock on your farm, that'd be awesome. But I just don't think that's feasible… (Iowa farmer)

Because of high input costs and narrow profit margins in farming today, farmers felt that getting bigger and more efficient was the only solution. If they cannot control prices, farmers instead tried to take advantage of efficiencies of scale, selling more crops and more animals more quickly. These challenging financial circumstances reflect the current construction of our agricultural system. Under this construction, farmers cannot fathom how they could make a profit on fewer acres when the current approach to staying profitable is getting bigger. Thus, returning to smaller farms felt impossible.

While an interest in small farms could be a reflection of farmers' desire for a more manageable and different type of workload or a nostalgia for the way the landscape used to be, discussions of smaller farms also seemed to be related to a larger purpose of returning to a greater sense of community. In particular, the lack of many small farms was thought to have negative impacts on community vitality:

> If I could see 20 years from now, I'd love to see it go back to that way where there were smaller farms. The rural areas I think have suffered a lot, because it's just the health of Main Street is a lot dependent on number of farms. And now when you just have a few bigger farmers doing what maybe 20 smaller guys used to do. It's changed that way. So yeah, nostalgically, I'd love to see it go back to that, where you helped your neighbors out doing chores and other things. And now it's kind of every man for themselves type of thing. (Iowa farmer)

Smaller farms meant more people on the landscape to support local communities. Smaller farms also meant more bandwidth to invest in relationships and community. That improved sense of community could help facilitate the future that farmers want to see. As one farmer reflected on how to support the future they desired, they saw a lack of close community as a barrier, which was affected by the heavy workloads farmers manage today:

> …communities aren't as tight knit as maybe they once used to be. There's a little more narrowed focus of, I need to focus on mine, because I'm so stressed on whatever's going on in my world that, where before maybe I didn't and I would have stopped doing what I was doing because my neighbor needed a quick hand this afternoon, whatever it might be. That stuff still exists, but that would be a barrier. You know, there's just not as much time, not as much idle hands sitting around as there may have been in the past. (Iowa farmer)

In other words, this farmer saw a close relationship between how farmers were doing and the future of their community. Having many small farms is important for meeting farmers' social goals, yet pressure to get bigger and do more just to stay afloat financially might limit the capacity farmers have to engage in their communities and with their neighbors. There was tension between how farmers felt they needed to farm to remain viable with the social outcomes they desired.

Despite some of the challenges with fewer and larger farms on the landscapes, it is worth acknowledging that many farmers also reflected on how changes in agriculture have come with positive outcomes. This included better care for the environment, as previously described, and improvements to the safety of production. Nevertheless, given that farmers may be feeling constrained by their current circumstances, it warrants exploring how rotational grazing perennial pastures might serve as an alternative solution.

“The economics…are not there”: Grazing not perceived as a viable practice

When asked why grazing was not more prevalent on the landscape, farmers often expressed concerns about the economic viability of grazing. Within these explanations, farmers commonly used comparisons elsewhere in the world, i.e., reference points in space, to relegate grazing to poor ground only, or in other words, to where you cannot grow good row crops anyway. They suggested that marginal ground was the only place that grazing made financial sense:

> …the return on investment isn't there unless you go to like, for this region, if you go down south where, or even out west where they have 7000 acres of grass, you know that that's all it's good for. Then they're on the other side of it. They're making way more money off cattle being on grass than they can off corn and beans. In this region, we just, if we can grow corn and beans, we're going to. And if the land isn't suitable for it, then we'll go to pasture. (Iowa farmer)

Farmers believed that growing corn and soybeans was a better use of the land, and only when environmental conditions, like limited rainfall or steep hillsides, limited row crop production, did grazed pasture become more profitable. Prioritizing row crop production was part of good farming and employing grazing on land suitable for corn and soybeans was not viewed as good farming nor economically viable. This suggested that farmers saw the lack of grazing on the landscape as largely an economic issue:

> I mean it’s all how you look at it, I guess, but I do think it's economically driven. If we go north of here, then there's some land that I look at the opposite. And I see it in row crops,

> and I think, 'Boy, that'd be a lot better pasture ground for cattle to run on whether it's too hilly or timber, whatever. So I think it's an area. You know, you go to Kansas, and parts of Kansas, and they just don't get enough water to grow a crop…Right, wrong or indifferent, I think economics played into it was cheaper to dry lot cattle in this area. (Iowa farmer)

Grazing was only justified when you cannot do something more "productive" with the land, such as growing row crops. While some farmers did point to other concerns, such as labor and years spent taking fences out in the movement away from livestock on pasture, overall farmers were skeptical of the economic viability of grazing.

However, it is important to note there is evidence to suggest that grazing can be profitable (Winsten, 2024) as well as evidence suggesting that row crops can be unprofitable (Brandes et al., 2016)—in some places most years—especially with increasing input costs (Burchfield et al., 2022). Thus, grazing could be a strategy to meet farmers' financial goals *and* there is likely more at play here than just economics. Farming practices are social and cultural. Practicing grazing often requires a mindset shift:

> …and I guess you could call it a mindset thing too. We have been conditioned as farmers to always get more milk, you know, get more bushels per acre, get more tons per acre, get more of everything, and the way you do that is not in a grazing system. (Wisconsin farmer)

This farmer recognized that rotationally grazed pasture systems were not oriented towards maximizing production, which is a stark contrast to row crop systems where increased production of commodities is a central tenant. A mindset shift, or rather a reference point shift, is needed for many of these farmers to see grazing as viable. While grazing might require farmers to prioritize different things, to find new reference points, this can and does still include economics.

In addition to grazing aligning with different priorities, farmers might also experience ridicule or skepticism for choosing to put flat, productive farmland into pasture:

> …everyone in the area complains that they're ruining good crop grounds for pasture. Because I have that example within my area of a farm that was highly productive crop ground, and everyone says, 'that's the best crop ground in the county. And now it's in pasture and they're wasting it.' (Wisconsin farmer)

Because grazing was often thought of as a practice for marginal land, using ground that could be cropped for grazing seemed like a faux pas as this farmer described it. Farmers who plant pasture on ground suitable for row crops are acting in contradiction to regional norms, i.e., against "good farmer" conceptions. Acting "out of place" in this way can seem like a transgression against those who are acting in alignment with normalized practices. Staying within the status quo and continuing to plant row crops on flat, productive ground avoids tension with current "good farmer" conceptions. The strong reaction to the farmer planting pasture illustrated how outside of the norm rotational grazing is.

Finally, perceptions of grazing also intersected with perceptions of land stewardship. As previously mentioned, it seemed that farmers felt they were sufficiently taking care of the land when comparing their practices to previous generations. Therefore, they may not be motivated to try to a different practice, such as grazing, which touts many environmental benefits:

> I think we're doing a good enough job with soil health in our current crop rotation that I can, I know it would be better to pasture something and then rotate it back into crop. But

> we're doing a good enough job and the economics of pasturing land that can be cropped are not there. (Iowa farmer)

The statement of "doing a good enough job" implied the farmer was making a judgement call in comparison to some alternative scenario, perhaps a scenario without a crop rotation at all. Critically, their unspoken reference was reaffirming that they did not need to change their practices to meet their environmental goals. When they used pasture as the reference point instead, they acknowledged that pasture offers a better option for meeting environmental outcomes in comparison to row crops. This farmer's continued commitment to annual row crops reiterates that farmers likely will not believe a sustainable agriculture transition, which could include grazing, is necessary if they already feel that their practices are sustainable per their current reference points, and the alternatives are outside the norms of the region.

However, some farmers did see grazing as an important and necessary part of the agricultural landscape. Some farmers contested the idea that row crop agriculture must be normalized as the dominant way of farming within the region. For them, economics were still an important consideration, but with specific acknowledgement that our agricultural system propped up corn and soybean production more than pasture systems:

> …corn and beans have a subsidy that kind of puts a floor in for them where you don't see that on the hay in the pasture ground. And yet we talk about clean water issues and some of those other things that kind of seems ironic to me that we don't support more of the putting the ground that, and not all of it, but a lot of the ground that could go back into the, rotated at minimum, but permanent pasture hay ground at best. There's very little support for that economically. (Iowa farmer)

This farmer called out the uneven playing field that made planting pastures challenging despite what they saw as clear environmental benefits from doing so. Specifically, they critiqued how our agricultural system was *constructed* to favor commodity row crop production, which was antithetical to environmental goals, like clean water. If our agricultural system was constructed differently where clean water and other environmental benefits were normalized and incentivized in the same way as row crops currently, perennial pastures could become much more competitive and widespread across the landscape.

Discussion

Despite "good farmer" environmental ethic, reference point norms diminish need for change

Farmers valued profitability in addition to conservation and community within conceptions of good farming, which has been demonstrated here and in numerous other studies with Midwest farmers (Comito et al., 2013; Leitschuh et al., 2022; McGuire et al., 2013; Strauser & Stewart, 2024). This suggests that the values Midwest farmers have assigned to the "good farmer" already align well with outcomes from sustainable agriculture, such as well-managed rotational grazing, which can promote environmental as well as social outcomes (Spratt et al., 2021). Therefore, there does not seem to be a mismatch between farmer values and sustainable agriculture. Rather, there appears to be a mismatch between the outcomes that farmers desire and the likely outcomes from an agricultural system constructed to favor and normalize annual row crop production.

Despite farmers' belief in the environmental benefits associated with conservation interventions within their row crops, they likely will not achieve soil health, water quality, and biodiversity improvements that would leave "the ground to our kids in better shape" as an Iowa farmer previously stated (Chaplot & Smith, 2023; Johnston et al., 2025; Ren et al., 2022). Even if row crop conservation practices moved farmers closer to their environmental goals, no-till and cover crop adoption remain low with considerable disadoption rates (Bowman et al., 2025; Plastina et al., 2024). In addition, these farmers' current practices are antithetical to other stated goals, such as managing smaller farms, which created some tension for farmers, yet they perceived alternatives as unobtainable. This inability to imagine a shift in dominant agricultural practices aligns with previous work characterizing how farmers were unable to imagine alternatives to the industrial agricultural system (Houser et al., 2020), and also reflects the "monologue" within industrial agriculture that leaves no room for imagining what could be instead (Bell, 2024). The inability to sufficiently achieve environmental goals and tension with meeting social goals could provide starting points for discussions on envisioning a new future of agriculture that better aligns farmers' long-term goals and practices. However, many farmers believed they were meeting environmental goals currently with the way "good farming" has been conceptualized.

In alignment with these farmers' perceptions of their environmental impact, there is strong evidence to suggest that practices, such as no-till, are better for soil health than moldboard plowing (Nunes et al., 2020). Reducing nitrogen application rates through improved efficiency also has been demonstrated to reduce reduced nitrate leaching and nitrous oxide emissions (Gu et al., 2023). However, these are *relative* comparisons between *practices*. No-till is better than the moldboard plow, and less nitrogen application is better for water quality than more, but that does not mean that soil health and water quality are reaching desired levels under these practices; transformational change is needed (Campbell et al., 2022; Chaplin-Kramer et al., 2023; Wepking et al., 2022). Despite how these reference points to past practices have been normalized, they do not allow farmers to assess if they are actually meeting their environmental goals (e.g., Sanderman & Baldock, 2010). Instead, to ensure the land is left "in better shape", an effective assessment is one that establishes clear outcomes paired with measurements to assess progress, and thus, allows for better alignment between the "good farmer" environmental ethic and the construction of our agricultural systems.

A focus on outcomes can align construction of agricultural systems with "good farmer" goals

Outcomes-based environmental goals improve clarity and reduce uncertainty, which may align farmer and non-farmer perceptions of the environmental impacts of agriculture. Throughout this work, farmers expressed that the public was unfairly critical of their practices, including arguing that non-farming folks are also contributors to environmental pollution, which has been captured in other research (Carolan, 2006). In Carolan (2006), deflection of blame to "the public" was explained by the lack of clarity between pollution sources and resulting water pollution. Given this challenge to seeing direct environmental costs of farmers' practices (Carolan, 2006), farmers and non-farmers could be relying on different evidence of environmental care. Therefore, while farmers reported that the impact of their practices now compared to previous practices was "good enough", relying more on outcomes-based metrics, especially those which more directly impact the public, like water quality, could be helpful in creating a more unified vision for what agriculture should be.

This is not to say that the comparisons farmers are making are wrong. It seems quite logical to reference one's own experience or the experience of a family member or previous mentor, but it is important to acknowledge the impact of these reference points. Comparing the practices of today to the farming practices of a generation or two prior disregards the ecosystem services historically provided by a prairie-dominated landscape, which could be regained following more perennial agriculture (Wepking et al., 2022). However, with such little prairie remaining on the landscape, it is not surprising that prairie was not used as a common reference point. In Iowa, <1% of the tallgrass prairie remains in the state, but it is estimated that prairie once comprised ~80% of the landscape (Heggen, 2017). A similar percentage of prairie remains in Wisconsin (Southern Driftless Grasslands, n.d.). The loss of prairie reduces familiarity with prairie functions and may perpetuate environmental degradation through the phenomenon known as “shifting baseline syndrome” (Soga & Gaston, 2018), which affects the reference point in use.

“Shifting baseline syndrome” (SBS) characterizes how each new generation adopts a new “baseline,” i.e., reference point, for environmental degradation informed by their own more immediate experience (Soga & Gaston, 2018). Soga and Gaston (2018) concluded that this shifting baseline contributes to new social norms for accepted environmental degradation because younger generations do not consider how the environment once was, accepting the current environment as an appropriate reference. Even if farmers adopt an outcomes-based focus, this shifted baseline could affect what are seen as reasonable environmental goals. Within these interviews, because erosion was more prevalent with the moldboard plow, that becomes the baseline farmers are referencing instead of how soils looked under historic prairies. Notably, SBS can lead to positive outcomes when environmental improvements serve as a new baseline. While evidence of this phenomenon has largely been explored in fisheries, it may be applicable here in explaining both why farmers felt positive about their row crop conservation efforts today and why they felt tension with the decline of small family farms and lack of diversity in crops that used to dominate the landscape. This explanation aligns with the impact of reference points described by Feola et al. (2023), but their research additionally recognizes that the parts of the past we choose to compare to is a reflection of our social groups and social norms.

Specifically, this perspective of comparing current farming practices to the moldboard plow was common across most farmers, such that only one farmer made a reference to the prairie instead, as noted in the results. This held true across farmers both in eastern Iowa and southwest Wisconsin, indicating this framing was widely held. In fact, while I initially speculated that farmers located in southwest Wisconsin might conceive of the "good farmer" differently than farmers in eastern Iowa due to topographical differences, overall, there seemed to be mostly consistent perspectives. I recorded nearly identical comments from farmers in these two places, demonstrating the transcendence of these farming narratives. The similarities between farmers in these two locations may arise from widespread messaging that reinforces the sufficiency of relative, practice-based assessments of environmental impact.

Broadly, narratives in the Midwest US uphold the idea of farmers as environmental stewards. For example, a persistent "myth" is the tautological argument that farmers must be good caretakers of the land because they are historic land managers, which fails to acknowledge poor environmental outcomes of past farming and caring for the land by past generations, including indigenous land managers (Hall, 2024). Here the specific parts of the past that are "remembered," i.e., settler farmers' historic land tenure only, affect their understanding of their present stewardship, aligning with Feola et al. (2023). Framing by farmer organizations that the public misunderstands the negative impacts from farming, rather than acknowledging that farmers' practices may cause some harm, also contributes to this collective understanding that farmers are practicing sufficient environmental stewardship (Rissing, 2021). Farmers across broad geographies are receiving messaging that confirms they are taking care of the land as intended.

Confirmation of environmental stewardship continues when examining payments for practices. For example, the USDA's Partnership for Climate-Smart Commodities (2022) lists cover crops, low-till or no-till, and nutrient management, which were common practices mentioned by farmers in these interviews, as the first examples of practices "that provide [greenhouse gas] benefits and/or carbon sequestration". Then, as one of the USDA's Climate-Smart Partners, ADM, a major grain elevator in the region, offers payments to farmers for cover crops, nutrient management, and tillage practices for commodity grain farmers (ADM, n.d.). Similarly from the University of Wisconsin-Madison Division of Extension webpage titled "Agriculture Water Quality", cover crops and no-till are promoted on the first page as strategies to improve water quality and soil carbon accumulation (Schwert, n.d.). Notably, these claims are relative to row crop fields with no cover crops as well as full tillage systems, not perennial agriculture systems. While these examples continue to promote a practice-based focus rather than an outcomes-based one, this is reflective of the way most soil health research likewise is conducted.

Research comparing practices in space to determine impacts on soil health are common in the literature (Cai et al., 2022; Chaplot & Smith, 2023), including my own research (Becker et al., 2022). However, the impact of conservation practices particularly on soil organic carbon (SOC), which is one metric of soil health, can differ when practices are compared to one another rather than compared to starting values over time, as was observed by Dietz et al (2024). In particular, their work showed that perennial agricultural systems that appeared to gain SOC over time were instead only maintaining carbon when assessed with more rigorous, comprehensive methods, i.e., sampling to a meter deep and tracking changes over time. At the same time, row crop systems appearing to hold onto SOC over time were instead losing SOC when rigorous methods were used. Similarly, a meta-analysis of the effect of cover crops on SOC accumulation also found that conclusions varied based on the methods used, with more comprehensive methods suggesting a much smaller potential for SOC accumulation than initial analyses suggested (Chaplot & Smith, 2023). Messaging that continues to promote row crop conservation practices as having positive environmental effects on SOC does align with research using certain methodologies and continues to support current, practice-based "good farmer" conceptions. However, for "good farmer" conceptions to meaningful support caring for the land and communities in practice, we should be cognizant of how different reference points shape understandings and constructions of places.

Intentional community visioning of agriculture can explore different place constructions

When farmers use different reference points from researchers or other community members, it contributes to different understandings of what places mean (Feola et al., 2023; Soga & Gaston, 2018). Meaning and materiality within places are constantly interacting, changing, and shaping those places (Cresswell, 2015), so different understandings of place contribute to different ideas about which practices should dominate the landscape. Those different perspectives then make it very challenging to reach consensus on and coordinate around necessary change to achieve a more sustainable agricultural system. In this work, "good farmer" conceptions normalized the continued use and dominance of row crop production with in-field conservation practices through reference points that depicted farmers as environmental stewards. Since most farmers were satisfied with their environmental stewardship based on those reference points and subsequent understandings of their region in meeting environmental goals, calls for a change to more sustainable practices might elicit skepticism from farmers, as heard in these interviews, rather than engagement. Thus, efforts to reimagine agriculture should include discussions of reference points as a key part of constructing better places.

Intentional community discussions could create an opportunity to engage various community members, including farmers, in a co-design process where space is made to explore different perspectives (O'Donnell et al., 2025), including reference points and conceptions of places. One approach is Participatory Scenario Planning (PSP), which involves working with diverse groups to reflect on the past, characterize the present, and envision the future, including pathways to get there (Galang et al., 2025). This approach recognizes that engaging with the past is a necessary step in reaching a shared understanding of places today and shared visions for the future (Feola et al., 2023). A similar approach is taken within the USDA-funded Grassland 2.0 learning hubs, where community members, from farmers to local business owners, spend time discussing and agreeing upon the current status of the community and where they want to be in the future (Grassland 2.0, n.d.). These community-based conversations are critical to creating consensus around where communities are and where they hope to go, so that they can act collectively to construct new places with new norms that better serve them.

Farmers care deeply about the environmental impact of their practices as is demonstrated in their conceptions of the "good farmer" here and in previous work (Leitschuh et al., 2022; J. M. McGuire et al., 2015; Shipley et al., 2022; Strauser & Stewart, 2024). Therefore, the problem in realizing a more sustainable agricultural system is not the lack of a farming environmental ethic. Disrupting the status quo is challenging outright (Cresswell, 1996; Houser et al., 2020), yet an additional barrier to sustainable agricultural transformations identified in this work is how reference points in agriculture lead to contrasting conceptions of places. Creating spaces where community members can talk *with* each other and explore different reference points will be necessary to support new “good farmer” conceptions and construct better place together.

Chapter 4. "Is the juice worth the squeeze?": Exploring soil carbon as a metric to align farmers' practices and long-term goals

Introduction

Maintaining and accumulating soil organic carbon (SOC) in agricultural soils is important to soil health (Cotrufo & Lavallee, 2022). SOC likewise has received considerable attention as a potential climate change mitigation and adaptation strategy (Lal, 2004; Paustian et al., 2016). As a result, researchers have been exploring and debating SOC accumulation potential and limits (Begill et al., 2023; Cotrufo et al., 2019; Poeplau et al., 2024). I am one of those researchers, as illustrated throughout this dissertation. Beyond the interest of researchers, implementing practices that accumulate SOC could align with farmers' own goals as they strive to care for the land, which is a goal captured both in Chapter 3 and prior literature (Leitschuh et al., 2022; Roesch-McNally et al., 2018; Strauser & Stewart, 2024). However, as also outlined in Chapter 3, farmers seemed to largely rely on references to prior practices to assess their environmental impact, such as comparing no-till practices today to moldboard plowing previously. While transitioning away from moldboard plowing can result in relative soil health improvements (Nunes et al., 2020), this practice change is likely not building SOC (Dietz et al., 2024), and therefore could be insufficient at meeting environmental goals depending on how they are defined. Thus, for farmers and soil health researchers to come together to collectively create a better agricultural system, it is valuable to make space for understanding different conceptions of environmental impacts and goals. Reaching a shared understanding of what caring for the land looks like could enable both groups to coordinate on efforts to achieve desired environmental goals. To begin, it is valuable to interrogate why SOC measurements may not be commonly used by farmers.

Co-benefits may motivate conservation; soil organic carbon may not

First, the nature of SOC might limit its use as an assessment of environmental impact for farmers. Because SOC change is slow, taking years to centuries for measurable differences, and context-dependent, driven by environmental and management interactions, farmers may doubt the credibility of this metric (Ingram et al., 2016). These characteristics of SOC change may also limit identification of an SOC loss problem, and problem identification can be a critical precursor for believing change is needed (Liu et al., 2018; McGuire et al., 2013; Roesch-McNally et al., 2017). In addition, Ingrahm et al. (2016) note that SOC and its relationship to addressing climate change politicizes SOC measurements, which could be another deterrent for farmers. Apart from SOC itself, carbon markets, which incentivize SOC-building practices, are criticized and controversial. Row crop farmers have critiqued uncertainty in the carbon calculations and payments and expressed concerns that carbon credits would further support large farms (Barbato & Strong, 2023). Therefore, farmers might have negative connotations associated with SOC and carbon markets, limiting their interest and engagement with SOC measurements.

These negative associations with SOC mirror reactions characterized by Herndl et al. (2011) to use of the word “sustainability”. In their research, farmers and community members in Iowa exhibited strong negative reactions to the use of the term, while simultaneously identifying with alternative terms such as “conservation” and “stewardship” and expressing goals aligning with sustainability. This suggested that similar sustainability goals could be achieved by using language accepted by the audience, and this approach can be applied to SOC discussions. Ingrahm et al. (2016) raised this issue by acknowledging that soil organic matter, which is made up of about half SOC (Pribyl, 2010), is a more familiar and meaningful term to farmers than

SOC, and Midwest farmers identify organic matter as an important soil health metric (Irvine et al., 2023). Fortunately, numerous co-benefits associated with SOC accumulation (Cotrufo & Lavallee, 2022) and carbon-accumulating agricultural practices (McGuire et al., 2022; Spratt et al., 2021; Wepking et al., 2022) allow for alternative terminology.

For example, in a study where soil health tests were run on farmers' fields in Michigan and compared to the farmers' designation of their "best" and "worst" fields, soil organic matter was significantly higher in the "best fields" (O'Neill et al., 2021). When farmers shared how they assessed which fields were best, they used metrics such as yield, drainage, and their perception of how well the soil worked for them. Therefore, the differences in organic matter, and consequently SOC, were translating to observable benefits they cared about, which could be emphasized to farmers instead. In another study by Singh et al. (2024) where Ohio farmers discussed soil health results from their "best" and "challenging" fields, the farmers expressed interest in the relationship between management and the soil health indicators shared with them. They were interested both in how management could lead to improvements in the soil health metrics and the outcomes associated with changing soil health metrics. Soil health indicators, including SOC, become valuable when tied to meaningful benefits. Rebranding agricultural impacts on soil health with more palatable language that makes connections to important agronomic outcomes could be an opportunity for improved science communication.

Researchers face trust as a barrier in promoting SOC and its co-benefits

Researchers might not be the best messengers to promote co-benefits of SOC to farmers. While there are few significant, consistent predictors of individual practice adoption (Knowler & Bradshaw, 2007; Prokopy et al., 2019), current research has demonstrated the value of personal, trusted contacts and local examples of best management practices in motivating practice change.

From semi-structured interviews with farmers in two European countries (Rust et al., 2022), researchers learned that other farmers are the most trusted source for soil health management information, and it is well-documented that trust mediates knowledge transfer (Arbuckle et al., 2015; Malka et al., 2009; Rust et al., 2022). However, seeking out and gaining information is not the same as motivating a change in practice. Having a local farm serve as a proof of concept of a new practice can help motivate practice change (Pires et al., 2024; Rust et al., 2022). The value of farmer-to-farmer learning has been observed in practice too, with a recent evaluation of Sustainable Agriculture Research and Education (SARE) projects between 2016 and 2019 suggesting that this method of learning improved project outcomes (SARE Outreach, 2025). Similarly, an emphasis on farmer-to-farmer learning has been attributed to the success of organizations like Practical Farmers of Iowa (Asprooth et al., 2023).

SOC researchers, however, may struggle to connect with farmers and engage with them in the learning process. Farming knowledge is “cultivated” through social relationships, rather than reflecting facts provided (Bell, 2024; Thomas-Walters et al., 2024), as is true for knowledge generally (Toomey, 2023), and rural people generally have colder feelings towards scientists, which can be a proxy for trust (Krause, 2023). While some research found that agricultural producers trust University Extension for providing soil and water quality information (Mase et al., 2015), other survey work with Midwest corn farmers found that University Extension was less influential on farmers’ decision-making than chemical and seed dealers, crop consultants, and bankers (Prokopy et al., 2014). If less trusted, university researchers may face hurdles as promoters of SOC and its co-benefits to farmers as part of conversations around necessary agricultural change for meeting environmental goals, especially if participating farmers value different goals or hold different understandings of soil health.

Thinking beyond the farm better motivates collective action

While reflecting on trust between farmer and university researchers is critical for SOC discussions, perhaps researchers should avoid a narrow focus on SOC, which can limit more holistic thinking about agricultural systems (Buck & Palumbo-Compton, 2022) and center individual action over collective action (Atwell et al., 2009; Iuliano, 2024). As Atwell et al. (2009) demonstrated, Iowa farmers prioritized building soil and minimizing erosion as their way of caring for the land, which focused their attention on fields and farms, rather than watersheds. As argued by Iuliano (2024), focusing on soil health further perpetuates notions of individualism in our agricultural system, which then fails to address concerns that require coordinated management, such as water quality, biodiversity and community health and well-being. Given these limitations, Gottschalk-Druschke (2013) argued for using watersheds as places that can promote collective action among land managers. Other work has suggested using the "peopleshed", the people and farms in the countryside that farmers already conceptualize, to motivate conservation at the appropriate scale (Atwell et al., 2009). The magnitude and scope of problems associated with the dominant agricultural system require coordinated efforts (Glibert, 2020; Johnston et al., 2025; Thaler et al., 2021). Thus, it is critical not only to explore what motivates land management on individual farms, but also what motivates farmers to work collectively to address shared problems.

As described in Chapters 1 and 3, there are many drivers that shape and coordinate land management efforts across the Midwest. Specifically, normative place meanings, or the shared understanding of what is considered socially acceptable within a place (Cresswell, 2015), have shaped and perpetuated a landscape dominated by annual row crops through many iterations of these place meanings. These meanings are then reinforced through narratives of "feeding the world" (Hall, 2024), conceptions of the "good farmer" (Leitschuh et al., 2022), and policies supporting annual row crops over grazed perennial pastures (Rissman et al., 2023). To reimagine agricultural landscapes in ways that meet the outcomes farmers and researchers in a place desire, researchers should make space for understanding farmers' conceptions of a place, which includes exploring farmer goals and how they assess them. These conversations are foundational to promoting collective, goal-directed action. To begin this process of understanding farmer priorities in a place and how they align with goals from SOC researchers, like me, my research questions were:

1) What environmental *outcomes* are important to farmers and how do they align with outcomes upheld by SOC researchers?
2) What goals do farmers hold that could underlie community conversations about agricultural transformations?

Methods

Data collection

A subset of farmers interviewed for the research in Chapter 3 were contacted via phone and invited to participate in a follow-up interview. In total, I interviewed 7 farmers, including 5 from Iowa and 2 from Wisconsin, with two farmers participating in the same interview. These farmers were compensated an additional $40 to participate. Interviews lasted ~1 hr and were audio-recorded with the farmer's consent. Recordings were transcribed using the Microsoft Word transcribe feature, then edited by the research team. The follow-up interview question guide appears in *Appendix A*.

Data analysis

Follow-up interviews were an opportunity to explore further emerging themes from Chapter 3. In particular, I previously heard two themes from farmers relevant to this chapter: 1) reference points shape farmers' management decisions and perceptions of their practices, including supporting their understanding of being good environmental stewards, and 2) farmers' perceived intense scrutiny of their practices by a public that they feel does not understand their decisions. To build on those observations, I now explored specific metrics farmers use to assess their environmental impact, barriers and opportunities to incorporating SOC measurements, and goals farmers' believed could be shared among other community members. Exploring SOC as a metric of environmental impact was emphasized most heavily given the perceived mismatch between the farmers' and researchers' perspectives on the impact of row crop agriculture on soil health.

I identified subthemes within the themes above that help us better understand the perspectives of these farmers. However, I did not formally define codes for these follow-up interviews or have multiple coders to assess the intercoder reliability. Instead, I used these conversations to add nuance to the emerging themes from Chapter 3 and continue to inform agricultural transformations. Therefore, these quotes are meant to be illustrative of farmers' perceptions without claiming to be representative, and some quotes from the initial interviews outlined in Chapter 3 are included.

Results

It's not just about comparison: Farmers provide evidence of caring for the land

From the interviews in Chapter 3, while farmers evidently were making comparisons to previous practices to determine their environmental impact, it was unclear if they also relied on other metrics. Furthermore, SOC did not appear important to farmers in their decision-making. One Iowa farmer in their initial interview shared, "…we're not at a point where organic matter's driving a ton of decisions. Usually there's other dominoes to fall before that becomes an issue." Of note, even in this interview, "organic matter" was the language used to talk about impacts to the soil, not "soil carbon." Therefore, throughout these follow-up interviews with farmers, I intentionally explored what farmers were specifically paying attention to when trying to assess their environmental impact.

Farmers pointed to visual assessments, commonly focusing on soil erosion, with a couple farmers also mentioning the importance of seeing earthworms as part of their assessment:

> …the first one that comes to mind is, is the soil staying in place? Because in my opinion, that's probably the easiest one to verify whether it is or it is not. And so, whether the soil is, so making environmental sense is whether the soil is staying in place and then I guess another one would be, like, say, when we're planting and we're doing a lot of digging out in the field just in the top few inches to like, look at the seeds, look at the roots, you know, we like to see earthworms. We think earthworms are a big indicator of soil health. (Iowa farmer)

While this farmer may not have mentioned SOC, their explicit mention of "soil health" and proxies for soil health demonstrated that their effect of their practices on the soil were still top of mind. In particular, they were emphasizing soil health metrics that they could see and verify for themselves.

In addition to these visual assessment, farmers also looked at nutrients from soil tests as a more quantitative assessment of how they cared for the land:

> …we do soil sampling of our farms. So then that in return, we put that in a spreadsheet, and we put, bring that back and that in return tells us, you know what we've put into the land, what, how we've reserved, you know, what different levels of NP&K that we've looked at. And then obviously we go back to the harvest part of it and see how in the last well, you know two or three years it's panned out and played out. So I think that in a case is how we would measure what we've done, you know as far as taking care of the land. (Wisconsin farmer)

The soil tests helped farmers ensure that they were replenishing nutrients taken off with the crops or lost from the soil. Therefore, replacing nutrients was a practice perceived as good land management. This was reinforced through farmers critiquing those who undercut the system and did not replenish nutrients. In the initial interviews, an Iowa farmer shared, "And then they just cut back their fertility to save money... But in the end, that's doing a disservice to the land, because you're not replenishing the fertilizer that you're using." Similarly, another Iowa farmer negatively described farmers who do not apply sufficient nutrients, saying, "we call them groundhogs around here that are paying $450 to $500 an acre, but they're not putting fertilizer down." Farmers who return nutrients to the land were perceived as good land stewards, and farmers who do not were perceived negatively. This further supports that farmers care about their environmental impact.

While a focus on nutrients, like nitrogen, phosphorous, and potassium, is not the same as focusing on SOC, some farmers did perceive organic matter as important. In fact, two Iowa farmers both emphasized organic matter as an important metric to their management without prompting in the follow-up interviews. Notably, one of these farmers was the one who compared our agricultural systems today to the prairie, as highlighted in Chapter 3, to conclude that today's practices needed to be improved. After prompting, organic matter seemed to be relevant to other farmers as well.

Soil organic matter is important in the context of yield

The relevance of soil organic matter to farmers emerged in the context of maintaining and increasing yields. Farmers viewed higher organic matter as key to having higher yields:

> …organic matter in our world is, yes, it's probably one of the biggest things that we gain yields off of, but…it's not something that we sit down and, it's not a data set that we have in front of us or that we use on a on a yearly basis… (Wisconsin farmer)

This highlighted that the priority for the farmer was achieving high yields. Organic matter gained importance because it supported yields, rather than being a metric that was sought after outright, such that organic matter was not regularly examined. To highlight a similar prioritization, one farmer described how caring about organic matter was nested within the priority of high yields:

> But our goal is, number 1 is yield. And then it would be, and it doesn't mean yield is like the only thing we care about, because it's yield, and then, is the soil in place? Are earthworms good? And that doesn't mean we're doing yield and if these things get, and then the last one would have been organic matter. It doesn't mean we're only thinking about yield and these things are afterthoughts. No, because they, I think if we got them proper, then yield is going to be OK, or we've done everything we can to try to help yield be OK and as good as it can be. So it doesn't mean we lose sight of these other things, but I think yield is what's most important. That's what our goal is. It's not the other way around. You know we’re not focused on if we can only get this organic matter higher, you know, and how do we do that? We come at it, well, we’re after yield and then go the other direction. (Iowa farmer)

These farmer perspectives demonstrated that taking care of the environment was believed to allow them to achieve high yields, and yields were what mattered most. Achieving high yields were also interpreted as an indicator that farmers had taken good care of the environment. Therefore, successfully pushing yields higher could reinforce farmers' perceptions of themselves as environmental stewards even if yield gains were driven by some other factor, such as improved varieties.

Even for a farmer that already cared about organic matter for other reasons, they suggested that connecting organic matter explicitly to yields could motivate sustainable practice adoption:

> Yeah, if somebody was coming out and saying, hey, with 4% organic matter, I'm getting, you know, 270-bushel corn, rather than, you know, 2%, I'm getting 230. You know, if there's those stark differences, which I think over time there's a lot of benefits, but maybe it doesn't show up every year that there's that difference. (Iowa farmer)

Yield increases make organic matter increases meaningful and worth considering. At the same time, this farmer recognized that benefits from increased organic matter are often a long-term investment. A lack of obvious change year to year in yield benefits from preceding organic matter accumulation could deter farmers from seeing its importance.

Slow, uncertain change makes soil organic matter a challenging metric

Soil organic matter, and therefore SOC, is slow to accumulate, which was one reason farmers gave that made it difficult to prioritize. The timescales of SOC accumulation were misaligned with farmers' decision-making timelines. An Iowa farmer acknowledged that the time to accrue beneficial outcomes was important when speculating why many farmers were not relying on organic matter for management decisions, sharing, "one of the things that I would say is you don't see immediate benefits." This was reiterated by another Iowa farmer stating, "I mean we can track organic matter, but it's such a small, it's you just don't see a lot of change to that necessarily."

Organic matter also differed from the other metrics farmers listed in that it was more difficult to track changes oneself. While looking for earthworms and visually checking for erosion were assessments farmers could make themselves, organic matter required sending off tests or investing in specific equipment:

> …we had a precision plane sensor that was supposed to map organic matter as you were going across the field. Well, we got a farm, you get south of the highway here, the soil changes from sand to heavy, heavy black dirt. And it does not, it didn't change as much as we thought it did on the map. Now, whether that was a sensor problem, so it would be where like carbon, you know, and organic matter, you know, they, you almost got to go to the lab to check that somewhat. (Iowa farmer)

This farmer was skeptical of the carbon output from the instrument they installed because it was misaligned with their visual assessments of soil color and knowledge of soil texture. To get more accurate estimates, they would need to send soil samples to a lab instead of viewing the data themselves, which would shift the data tracking away from the farmer. Sending soils off for analysis is routine for nutrient testing, which many farmers readily talked about and participated in. Thus, rather than the inability to collect the SOC data themselves being a problem, it seemed there was something unique about SOC specifically.

Organic matter perceived differently than soil organic carbon

While most farmers spoke comfortably about organic matter, the connection between organic matter and SOC was not obvious to all farmers. As I introduced my own interest in SOC within agricultural systems and described it as part of soil organic matter, one farmer reiterated the importance of and often overlooked nature of that connection:

> Iowa farmer: I wish more people would say that connection.
>
> *Researcher: Relating [soil organic carbon] to organic matter?*
>
> Iowa farmer: Yeah, because that makes it so much more relatable to a farmer. You know, because that, everybody knows what their organic matter is, or they should, or they've had a soil test that said it so then it makes it more personal. Because yeah, if you tell me about carbon levels in my soil and like there's a whole bunch of levels in my soil that I don't know anything about, you know, because we measure what we want to know to correct for crops. If it's not in that, we don't measure it, so then that ties it back to something we do measure.

Organic matter was meaningful to farmers, and if farmers did not realize that SOC was a part of organic matter, SOC was not meaningful to them. Similarly, this same sentiment about the lack of awareness of the relationship between soil organic matter and SOC was expressed by another farmer:

> …when you say soil carbon, to me there is a disconnect there with organic matter. But if you say organic matter, that's a whole different, that's in my mind. And you know, they might be one in the same thing and you maybe said they were. I'm just not sure. I hadn't heard that before. But organic matter is really important. (Iowa farmer)

These comments suggested that the relationship between SOC and organic matter was not understood widely among farmers, and for some, the idea that building organic matter builds SOC was completely novel. While concrete knowledge of that relationship may be lacking, these perspectives again illustrated positive associations with organic matter.

Recognizing the disconnect between organic matter and SOC is especially important given that farmers may have negative feelings associated with SOC that are not associated with organic matter. In particular, discussions with farmers about carbon specifically seemed to raise some scrutiny. One farmer, who previously noted the value of organic matter for their yields, was much more skeptical of carbon markets:

> I think as a farmer, we're all still, I don't know if skeptical is the right word to use, but that's the word I'm going to use, of the parameters that they're setting out there for what, for what carbon is. I don't know if that's right to say what carbon is, because I mean, obviously we know what carbon is. But I guess what we produce for carbon credits… (Wisconsin farmer)

The skepticism was not necessarily of the existence of carbon, but in how it was measured, monitored, and compensated. Carbon markets providing carbon credits were not trusted. Another farmer described carbon markets as the “Wild, Wild West” due to the lack of regulation. One farmer also shared that estimates of SOC change can feel “made up” to farmers.

More broadly, these comments raised the issue of farmer trust. For example, in one conversation, a farmer was expressing skepticism about the need to build SOC, which could reduce carbon dioxide in the atmosphere:

> And so I just would love to know, do we have too much carbon dioxide in the air, or do we not? I don't know, and if I knew that, then I could maybe be like if I'm sitting there with that guy from Stanford, I could be like, yeah, you're right. We do have too much. And I would know that. But just because he says it like, I don't know if I believe it, honestly. I don't know if I believe him. (Iowa farmer)

Ultimately, this farmer did not trust the Stanford scientist, who was advocating for sequestering carbon to reduce carbon dioxide. Because the farmer did not trust the researcher, they were also distrustful of the claims the researcher was making. This skepticism was reinforced by the crowd's response afterwards. The farmer shared that after questioning the scientist about what happens to our crops if we decrease carbon dioxide, "…I had like 12 people in line to talk to me. And that guy from Stanford, nobody was talking to him." While just one example, this skepticism aligned with the concerns and critiques of carbon markets above.

Aside from the critiques of SOC, discussing organic matter exclusively does not mean researchers and farmers are talking about the same thing. While soil health researchers may view soil organic matter as inherently good, one farmer referred to organic matter as a "burden" for some farmers:

> Organic matter is a, what do you want to say, a situation where people have to deal with it. You know they have to, if you have a lot of organic matter, some farmers are just using it as a burden, you know, and it's just like they don't take in consideration of how much it does. It does cost some money to manage it, if you do it the right way. And farming is all on a budget. (Wisconsin farmer)

In clarifying these negative feelings about organic matter, the farmer expressed that they think about organic matter only as plant material on the surface of the soil, not as *soil* organic matter, which encompasses decomposed plant material that is part of the soil. This conception of organic matter did not come up in the other interviews but is noteworthy as we were using the same language but with two different meanings.

Disinterest in soil organic carbon is about more than economics

Concerns about the relationship between soil health and yield, slow accumulation of SOC benefits, and skepticism around carbon market payments implied that farmers are concerned about the economics of SOC. For example, because organic matter accumulates slowly, it may seem less economically advantageous to adopt practices for the sake of building organic matter, at least short-term, as one farmer shared:

> …maybe it takes 20 years to see big increase in your organic matter, in your carbon in your soil and you're making decisions with tight margins today it's like, is the juice worth the squeeze to get here? (Iowa farmer)

Despite awareness of potential long-term benefits associated with SOC accumulation, farmers felt they could not make choices that jeopardize current profits. Narrow profit margins within the current agriculture system did not offer flexibility to await a potential future payoff. These economic concerns were initially expressed in Chapter 3, and arose again in follow-up conversations:

> …it's a lot easier to lose a little bit of yield when the prices are higher than when they're lower. You know your margins are so thin like now that you just like, oooh. You know, the experiments are not as much fun as they were at $8 corn. (Iowa farmer)

With little room for failure, trying new practices that merely have the potential for some payoff through SOC accumulation seemed less enticing to farmers who were already experiencing economic strain. The current agricultural system does not support experimentation that does not have immediate payoffs.

However, as also explored in Chapter 3, management decisions are not only influenced by economics. In particular, social norms also affect management. As such, even if the economic calculations for a practice were not favorable, the need for change may not seem obvious as challenging economics were the norm for many farmers. One farmer considered how having an off-farm job enlightened them to the uniqueness of the economic uncertainty within farming:

> I guess when I started this seed business, I thought you know if it grows really slow, that's fine. You know, I just want to do it correctly and help the people I'm dealing with the best I can and then this year especially, I'm like, you know, if this was 10 times the way it was, it would be 10 times more work, but I would gladly do it because it's so consistent compared to farming. So I guess your brother's probably felt that too. He's like, corn can go down two dollars, but I'm still going to make the same amount on this job. You know, and it's, until you're in that business, you don't realize how volatile the farming is because you've made money farming every year, but once you feel a consistent business, you can feel what you were missing before. (Iowa farmer)

Until this farmer gained a new reference point, they did not realize how different their economic circumstances could be. At the same time, another farmer had discussed diversifying their operation with their family but had not yet made a change. Previously, they had shared that market volatility is a normal part of farming that serves an important role, and now, considered that maybe they would not pivot to something new until the economics got even worse:

> But those are some things that I say, you know, maybe we're not desperate enough. Well, who knows? Maybe we need to have a few more years of, like, bad years farming and then be like, well, we got no other choice. Let's try something. And I'm not saying that we have to get to that level before we would do it, but, I don't know. We haven't done it yet,

so maybe we do need to get to that point. We're not there yet. So, that's kind of how we see the current state of affairs, not super optimistic with this year, but I guess probably it's a job of a farmer is to be eternally optimistic. (Iowa farmers)

These quotes highlighted that social norms within farming may be quite different than other sectors. Financial uncertainty and variability is a given in farming, and these farmers seemed to be considering pivots within the system rather than transforming their farming operation. Even among farmers that were exploring getting more livestock back out on the landscape, they also recognized the financial hurdles. As one farmer asked, “how can we put more pasture down back into our landscape while competing economically?”. Farmers were not rewarded financially for using rotational grazing.

Another component of social norms that may work against the adoption of SOC accumulating practices are narratives around production. Specifically, the narratives that were accepted among farmers seemed to reinforce maximizing production as a priority over other environmental goals. In response to one farmer conceding that today’s farming practices were not like the prairie, we had the following exchange:

Researcher: Do you feel like it's useful to try to aim for the prairie or is that just something that's unobtainable, but we're doing a good job with the way things are?

Wisconsin farmer: Depends on how many hungry people you want in the world.

This farmer referred to farmers’ role of feeding the world, which is used to justify farming practices that are less environmentally friendly than the prairies used to be. Other farmers made similar comments about “feeding the world” in both Iowa and Wisconsin, which demonstrated the broad range over which these narratives are shared.

Farmers feel their conceptions of farming differ from non-farmers yet see shared values

Farmers across locations similarly shared a narrative that the public negatively viewed and misunderstood farming. From the initial interviews, it became clear that farmers felt the general public misunderstood their practices and their relationship to caring for the land. Therefore, these follow-up conversations explored farmers' perspectives on potential shared goals between farmers and the people living in nearby towns and cities, which could underpin dialogues about transforming agriculture. Goals shared by farmers that extended beyond the scope of their individual farms included having enough safe, affordable food and good water quality. However, while farmers identified goals which they believed could provide common ground with the public, they anticipated disagreement on how to achieve those goals. For example, good water quality was perceived to be a goal farmers and the public could agree on but defining "good water quality" and agreeing on and implementing practices to achieve that goal were thought to be considerably more challenging. As one farmer shared, it could be challenging to determine where the "goal post is", continuing:

> I think everybody would be like somebody told me [nitrates in water] is an issue. We need to lower it. Where is lower? Somebody would need to tell everybody where lower is and then agree on a goal. (Iowa farmer)

Beyond identifying potential shared goals around water quality and access to food, the general sentiment emerged among these farmers that the struggle to identify shared goals was reflective of farmers being misunderstood by the public, which was a key theme in Chapter 3. This misunderstanding was expressed by farmers suggesting that those farming the land need to better communicate their practices to the public, such as with social media, as well as noting that fewer people being connected to farms was to blame for this problem:

> …the misunderstanding is growing just because the lack of kids originating from farms and that was just obviously a natural way to know where things come from and know how things are grown, you know. (Iowa farmer)

One farmer echoed this sentiment by recognizing that it would be difficult to identify shared goals in the first place given the disconnect between farmers and non-farmers. Another farmer distinguished between their small local community, who they currently felt supported by, and their understanding of public perceptions in larger cities farther away. For them, it was nearer to more urban areas that they felt there was greater misunderstanding about farming. Regardless, there was a clear sentiment in these interviews that farmers believed they had different understandings of agriculture than non-farmers, even if theoretically, they might share some big-picture goals.

Discussion

Soil organic matter and soil organic carbon are not the same to farmers

Farmers often use visual assessments to determine their environmental impact, in addition to relative comparisons as outlined in the Chapter 3, but these metrics leave ambiguous how farmers are moving towards their long-term environmental goals. However, measuring SOC changes over time is not likely to be the solution. While we know that soil organic matter is composed of roughly half carbon (Pribyl, 2010), and thus, accumulating soil organic matter increases SOC, there is at least a subset of farmers where the connection between SOC and soil organic matter is unfamiliar. Similar to research by Ingram et al. (2016) with European farmers and advisors, soil organic matter was much more common and meaningful to these farmers than SOC. If soil health researchers aim to communicate the importance of building SOC to farmers, then it is important to be mindful of these differences to communicate more effectively.

Practically, these results suggest that it may be valuable to avoid discussing SOC with farmers, especially because there are numerous co-benefits that can be emphasized instead (Cotrufo & Lavallee, 2022). Using alternative language, such as only talking about organic matter changes, can be an effective strategy to avoid negatively charged language while still meaningfully discussing environmental impacts (Herndl et al., 2011). Alternatively, only discussing SOC in direct connection to other metrics farmers care about, such as yield, nutrient availability, protecting the land for the next generation, or even organic matter, could also be a better approach. Connecting information to what is important to your audience is a good science communication practice across disciplines anyway (Arbuckle et al., 2015; Krause et al., 2020; Malka et al., 2009). Discussing co-benefits may provide a more holistic framing that avoids narrowing the focus to any one component of the farm, while additionally encouraging practice adoption (Buck & Palumbo-Compton, 2022). Thus, knowing that soil organic matter and SOC are conceptualized differently is important for science communication efforts, but it is likewise worth further considering why such a distinction exists.

Since farmers already seem familiar with focusing on maintaining, or even accumulating, organic matter, thinking about building up SOC could, in theory, be an easy transition. However, one reason for the distinction between concepts may be that these farmers readily tied the concept of organic matter to yield, which is meaningful to them. Their assessment of this link is supported by literature demonstrating that more soil organic matter is related to higher yields (Crookston et al., 2022; O'Neill et al., 2021; Oldfield et al., 2019), though results are also context-dependent (Cotrufo & Lavallee, 2022; Crookston et al., 2022; Oldfield et al., 2019). While yield may not be the only meaningful metric of success to farmers (Leitschuh et al., 2022; Strauser & Stewart, 2024), yield and maximizing production has been and continues to be an important component of the “good farmer” identity (Burton, 2004; Comito et al., 2013; Hall, 2024). Organic matter, therefore, gained meaning through its relation to a metric important to farmers, but the same was not done for SOC, despite the assessment of both metrics through soil health testing. Farmers may not care to focus on SOC because they lack trust in who and what SOC is associated with.

As outlined by Barbato and Strong (2023), U.S. farmers did not trust carbon markets because of uncertainty in both payments and carbon calculations. This mirrors the uncertainty and distrust among farmers in these interviews. Another element of distrust around SOC specifically could involve the competing narratives about agricultural practices that can sequester carbon among scientists. For example, in a critique of the methodologies used to claim cover crops can sequester carbon, Chaplot and Smith (2023) argue that one consequence of miscommunicating the impact of agricultural practices on SOC is an erosion of trust in scientists. Of note, how this uncertainty within science is framed can affect whether it is positively, negatively, or neutrally interpreted by the public, but in particular, classifying this uncertainty as conflict between researchers is more often associated with negative effects on trust in the information (Gustafson & Rice, 2020). Therefore, as scientists debate the potential for practices to sequester SOC, this could exacerbate confusion and distrust among farmers in the science and scientists if not framed appropriately.

Farmers may already be hesitant to trust those who are promoting SOC accumulation. First, other research has demonstrated that farmers are most trusting of other farmers for soil health (Rust et al., 2022) and conservation information (Witzling et al., 2021), but farmers seem to be talking less about SOC. As for information from non-farmers, focus groups with Vermont farmers captured the importance of relationship-building for those working with farmers in order for the information they shared to be perceived as trustworthy (White et al., 2022). Other research has suggested that trusting the information source is important for motivating practice adoption (Ranjan et al., 2019; Rust et al., 2022) and informing agricultural risk perceptions (Arbuckle et al., 2015). Research outside of agriculture also demonstrates that trust in the messenger can even be more important than the message itself (Malka et al., 2009), and recent research found that rural people have colder feelings, and therefore potentially reduced feelings of trust, towards scientists (Krause, 2023). Without sufficient relationship-building upfront, university researchers or extension agents who emphasize SOC accumulation may be less trusted and perceived as outsiders, such as how the Iowa farmer did not trust the Stanford scientist. This indicates that it is not just the information that matters, but the relationship to who is communicating it. Time for relationship-building with farmers may not be sufficiently supported by how universities prioritize and reward outreach efforts currently.

Universities must support relationship-building and community dialogue to identify shared goals

Outreach has long been part of the mission of land-grant institutions (Jischke, 1998) and the University of Wisconsin-Madison is no exception. Today, the university's Extension Agriculture Institute website (*University of Wisconsin-Madison Extension: Agriculture*, n.d.) states:

> We support individuals, communities, and businesses by providing trusted resources to Wisconsin farmers, gardeners, agriculture and horticulture producers, and industry members. Our mission is to advance practices that are economically sustainable, socially responsible, and environmentally sound.

Here, outreach is conceptualized as sharing "trusted resources". However, critiques have been raised in how university outreach is conducted.

In particular, Bell and Lewis (2023) unpacked how university reward structures and norms often worked against community-engaged scholarship, which involves relationship-building and collaboration with community members. Gottschalk-Druschke (2022) shared this critique and outlined the importance of taking the time to build relationships to engage in community-based research ethically, even though this might be counter to university goals of faced-paced, high-output work. Greater community engagement has also proved successful in agricultural work. For example, working with farmers to set up on-farm research trials resulted in a major increase in practice adoption (Pires et al., 2024), which likely reflects the impact of locally-relevant information (Rust et al., 2022) as well as relationship-building (White et al., 2022). Bell and Lewis (2023) differentiated dialogue with the public as "engagement", which encompasses a bidirectional relationship, from one-way "outreach", which is much more one-sided. Therefore, if universities want to have a positive impact on their surrounding communities and effectively carry out their mission to connect with the public, they should invest in and reward researcher efforts to build relationships and collaborate with community members.

A potentially untapped role for researchers interested in supporting sustainability transitions is discussion facilitation among community members (Loeber & Kok, 2024). As a throughline in my initial and follow-ups interviews, there seemed to be a common perception among farmers that farmers are misunderstood by non-farmers, and this narrative of farmers pitted against non-farmers is not new (Hall, 2024). Here, the conflict seemed to center on environmental critiques, where farmers felt they cared for the land better than non-farmers perceived. To reach a unified vision on what change should occur in a place and how to get there, relationship-building might be needed among community members to promote understanding of different perspectives as a precursor to collective action. Researchers could play a more active role facilitating this relationship-building. At the very least, the need for relationship-building and open dialogue suggests that events bringing community members together can be important investments, especially as places to explore shared goals.

One potential shared goal that farmers identified to motivate collective action was water quality, though with acknowledgement that determining specific water quality goals could be a challenge. Farmers' view of water quality as a potential shared goal aligns with survey research in the Midwest exploring farmer and non-farmer perceptions around water quality (Hu & Morton, 2011). In particular, Hu and Morton (2011) found that farmers and non-farmers both valued clean water, but discrepancies arose when comparing perceptions of water quality and the source of water quality harm. Emphasizing water quality could be impactful because Gottschalk-Druschke (2013) concluded that focusing on the watershed scale might better motivate collective action over in-field soil health metrics. Similarly to Hu and Morton (2011), a study in Ireland found farmers and non-farmers had shared levels of environmental concern, though with different perspectives on the appropriate uses of the land (Howley et al., 2014). Thus, there is nuance in the environmental goals of both farmers and non-farmers, yet despite farmers' strong perceptions of being misunderstood, there may be some alignment with non-farmers.

For example, in a survey of U.S. adults by the American Farm Bureau Federation, most respondents reported high trust in farmers generally, and more than half of respondents positively rated farmers' sustainability practices (American Farm Bureau Federation, 2020). According to a poll commissioned by the John Hopkins Center for a Livable Future, surveyed voters strongly conveyed agreement for government support of small and mid-sized farmers as well as for sustainable agricultural practices (Greenberg Quinlan Rosner, 2023). These survey results indicated public support for farmers. Perhaps what could be contributing to perceived tension between farmers, non-farmers, and even researchers, are different framings of the same place.

Place-framings are partial representations of a place and are part of the place-making process (Martin, 2003). These framings can be used to motivate change through creating shared understandings of what a place is and what it can become (Murphy, 2015) and delineate local actions to address broader scale issues (Martin, 2003). Importantly, these place frames are also relational (Murphy, 2015), and thus influenced by the context around them, from university research to agribusiness narratives. This context includes framing farmers as heroes who feed the world (Comito et al., 2013), as stewards of the land (Hall, 2024), or as water polluters (Armstrong et al., 2019). Currently, farmers and non-farmers may hold different place frames as suggested by farmers' perceptions of the public's misunderstanding of their practices. Farmers viewed industrial row crop practices as a necessary approach for feeding people that sufficiently take care of the environment. Do non-farmers see these same practices as harming the environment and contributing to rural community decline? Having different understandings of how our agricultural system is functioning makes it difficult to come together on specific goals and pathways to pursue within sustainable agriculture transitions (Duru et al., 2015), but agreeing on representations of a place could instead help to identify pathways to change. While constraints imposed by industrial agriculture can make it challenging to imagine a different agricultural future (Houser et al., 2020), university researchers can offer a counter balance by creating spaces for people to come together to identify shared place frames that reflect shared goals.

Imagine how impactful university research would be if universities invested their resources in bringing people together to collaboratively discuss the future of their communities.

Our work could then be more responsive to communities around us and reflect true *engagement*. After all, if the goal is to create "economically sustainable, socially responsible, and environmentally sound" practices (*University of Wisconsin-Madison Extension: Agriculture*, n.d.), who better to include than the people we are creating change for.

Chapter 5. Interdisciplinarity as a strategy to transform agricultural research

Reflections from an interdisciplinary researcher

When I started seriously thinking about what I wanted to go to college for, I can vividly recall what a struggle it was to pick one thing to be. In part, I believe my struggle came from longing for a mixture of multiple careers. At the same time, I believe I lacked examples of careers that embodied the skills and experiences I most desired, which included the flexibility to be more than one thing. In an effort to gain some clarity about who I wanted to be, I recall one car ride with my mom as we played this game where she would list careers, and I would consider whether they seemed a viable option for me. For most propositions, my answer was "no, because…", but I do remember one career that finally got a "maybe": pharmaceutical liaison. Now, regardless of what it actually means to be a pharmaceutical liaison, I still remember the appeal of what I thought a pharmaceutical liaison could be. I wanted to be the *bridge* between pharmaceutical companies and doctors. I wanted to be someone who could both understand the complex science and then translate it in a comprehensible way to other people. While I certainly had never considered the word "interdisciplinary" at this stage in my life, I believe this was my first moment of feeling called to interdisciplinary work.

Since that moment, I have actively pursued an interdisciplinary focus throughout my college education. During my undergraduate studies in particular, I found myself in the fortunate circumstances of having time to explore different interests. This exploration is reflected in everything from the minor degrees I chose to my senior-year research project, where I considered both the environmental impacts of incorporating prairie strips into farm fields and barriers to prairie strip adoption. My interest in combining natural and social sciences continued into graduate school. A major strength of pursuing my MS in the Nelson Institute for

Environmental Studies at UW-Madison is that interdisciplinarity is a core degree requirement, and a requirement that my research includes both natural and social sciences is a dream for me. I thrive on variety and want to solve big problems, which requires research that reflects the complexity of the world. As I now push towards the finish line as an Environment and Resources PhD candidate exploring SOC accumulation, place-making theory, and the sociology of science, I pursued the exact blend of interests I longed for. However, in my drive to pursue such breadth, I have had to grapple with the question: What is my expertise?

It seems inevitable that seeking scientific breadth comes at the cost of scientific depth, at least within a finite timeline. For me, this means that while my dissertation research has included natural and social sciences, I would not consider myself an expert in any explicit field. While this feels antithetical to the supposed expertise I should have gained by earning a PhD, I have never wanted my expertise to be siloed within a single discipline. My pursuit of graduate school was not to become a soil scientist or a sociologist or a communications science expert. Rather, I built “expertise” in the ability to bridge disciplines, the role I first found so enticing as a teenager. However, cynicism of interdisciplinarity and challenges to its implementation remain, with many of my sentiments captured in other literature exploring challenges to interdisciplinarity in practice.

Interdisciplinary research is challenging

Interdisciplinary research (IDR) integrates across disciplines to create new knowledge (Kobilka, 2025; Vladova et al., 2025), though definitions are debated and varied (Hofmann et al., 2025; Louvel, 2022), and conducting IDR comes with additional challenges not borne by disciplinary research. First, engaging in IDR successfully is slow and deliberate (Kovacic & Marcos-Valls, 2023; Vladova et al., 2025) given barriers in communicating disciplinary jargon, methods, and epistemologies across disciplines (Christensen et al., 2021; Russell, 2022; Vladova et al., 2025) as well as developing necessary expertise to communicate and understand those differences (Kovacic & Marcos-Valls, 2023; Russell, 2022). In addition, the physicality of research institutes might hinder collaboration on IDR, with universities often spatially-structured around disciplines (Vladova et al., 2025), yet even research institutes and programs centered on interdisciplinarity face structural and cultural barriers in implementing IDR in practice (Kovacic & Marcos-Valls, 2023; Woiwode & Froese, 2021). Researchers who prioritize IDR may experience tradeoffs in developing disciplinary expertise and publishing academic journal articles (Vladova et al., 2025) or reduced likelihood of receiving grants (Bromham et al., 2016), which are key metrics of success in academia (Kobilka, 2025). As such, under publishing and time constraints, as well as a lack of institutional support, researchers may return to a more disciplinary research focus (Kovacic & Marcos-Valls, 2023; Woiwode & Froese, 2021). In particular, interdisciplinarity can be a challenge for young researchers, such as during graduate programs (Kovacic & Marcos-Valls, 2023). Thus, engaging in IDR can be risky (Christensen et al., 2021; Kovacic & Marcos-Valls, 2023; Vladova et al., 2025; Woiwode & Froese, 2021), but at the same time, it is a highly important endeavor for addressing the complex problems facing our world.

Interdisciplinary research is critical

Calls have been made for an interdisciplinary approach (Crockett, 2025; Jacquet et al., 2022), and even a transdisciplinary approach (Ong et al., 2024), which brings in non-academic expertise (Kobilka, 2025), to address issues with our agricultural systems and support agricultural transformations. While disciplinary research can also be very impactful in creating change (Louvel, 2022), interdisciplinarity captures the complexity needed for reshaping *places*, which is foundational to transformational change (Binz et al., 2020). My expertise might look different than graduate students with a more disciplinary focus, but I believe that I am well-equipped to bridge across disciplines as well as among researchers and the public, a critical skill for successful interdisciplinary research (Kobilka, 2025).

My training at UW-Madison opened my eyes to a plurality of perspectives, made me a better science communicator, and enabled me to ask thoughtful socioecological questions. This training provided the unique opportunity to recognize parallels between soil science methodologies and social science theories as someone with a foot in both worlds, and seeing connections across disciplines is recognized as a strength of interdisciplinary research training (Kobilka, 2025). Perhaps the biggest strength of being an interdisciplinary researcher, however, is that I am constantly aware of the limits to my knowledge as I explore a breadth of research questions and ways of knowing. This has made me a more inquisitive and thoughtful listener, and ultimately, a better scientist. I am proud to have stayed true to the younger versions of myself, who first dreamed of a new kind of agriculture, then strived to be a communicator between people and disciplines, and finally, the bright-eyed, bushy-tailed graduate student who chose to pursue all her interests together.

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Appendix A

Figures

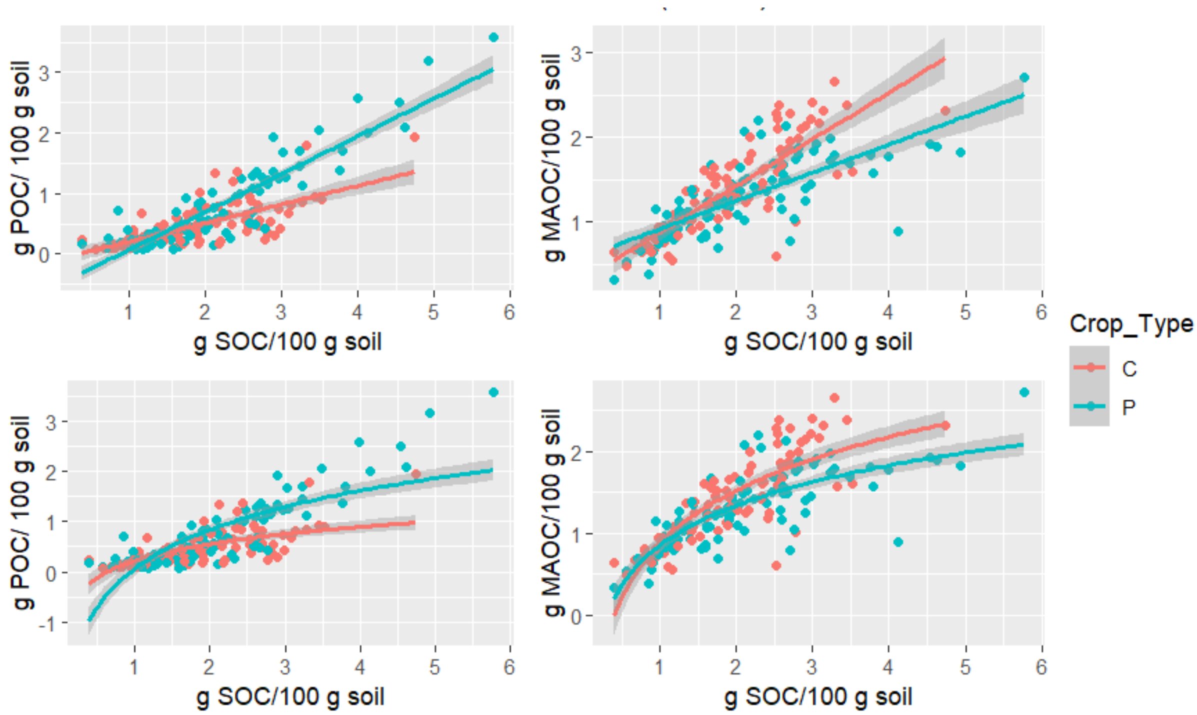

Figure S1. Scatterplots of POC concentrations and MAOC concentrations by SOC concentrations in the bulk soil in both the 0 to 15-cm and 15 to 30-cm soil depths for annual row crops (C) and perennial pastures (P) with linear and logarithmic models depicted.

Tables

Table S1. Masses for carbon analysis based on anticipated C concentrations in soil samples.

%C	**%N**	**Min. sample wt. for C (mg)**	**Min. sample wt. for N (mg)**
0.05	0.01	180	225
0.1	0.025	90	90
0.25	0.05	36	45
0.5	0.075	18	30
0.75	0.1	12	23
1	0.2	9	11
1.25	0.3	7.2	7.5
1.5	0.4	6	5.6
1.75	0.5	5.1	4.5
2	0.6	4.5	3.8
2.25	0.7	4	3.2
2.5	0.8	3.6	2.8
2.75	0.9	3.3	2.5
3	1	3	2.3
4	1.1	2.3	2
5	1.2	1.8	1.9
6	1.3	1.5	1.7
7	1.4	1.3	1.6
8	1.5	1.1	1.5
9	1.6	1	1.4
10	1.7	0.9	1.3
20	1.8	0.45	1.3
30	1.9	0.3	1.2
40	2	0.23	1.1
50	3	0.18	0.75
60	4	0.15	0.56

Interview documents

Initial interview guide

1. Tell me the story of your farm. How did you get to where you are now? What is your farm like?
2. Why do you farm?
3. What do you want the legacy of your farm to be?
4. What do you like about your own farming operation? What changes would you make?
5. What practices do you use to protect the soil and clean water?
6. How has the agricultural landscape changed in this region over time?
7. What do you think makes a good farmer? When you see another farmer's land, how do you know if they are a "good farmer"?
8. Why do you feel a practice like rotational grazing is not a dominant agricultural practice in this region?
9. What would you like agriculture to look like in this region 20 years from now?
10. What role do you see your farm playing in the health of your community?
11. What would you like your community to look like 20 years from now?
12. How do you imagine we could move towards the future you envisioned? How could the agriculture industry support that change?

Initial interview theme definitions

1. *Reference point in time:* referral to some timepoint, past, present, or future, as comparison to this farmer's practice/activity in some other point in time
2. *Reference point in space:* referral to some practice/activity/concept elsewhere in space as comparison to the farmer's own practice/activity/concept in the same time period
3. *Ag system determinism:* expression that some aspect of agriculture is pre-determined, unable to stray from the present course, or simply is the way it is
4. *Ag system disruption:* expressed disagreement or dissatisfaction with some aspect of agriculture, that extends beyond a criticism of an individual; a call for change
5. *Conservation:* any behavior, sentiment, or value related to sustainability

Reference point sub-theme definitions

1. *Nostalgic farming*: sentiment that farming historically involved smaller farms, more farmers, a greater sense of community, straightforward economics/greater profit margins, and/or more diversity in operations, which are viewed positively
2. *Farming as a business*: sentiment that succeeding in farming today requires running it like a business and is more reliant on desk job work, e.g., crunching numbers, tracking markets, adopting new technology, rather than getting hands dirty with physical management; may be expressed through describing pressure of narrower profit margins, need for efficiency, maximizing ROI, how tightly farmers are squeezed
3. *Moldboard plow era*: sentiment that historic farm management had a negative impact on the land, especially relative to farming practices today OR use of moldboard plow in specific contrast to farming today
4. *Row crop conservation*: sentiment that practices to reduce soil loss and improve soil health within crop fields are an improvement in how farmers care for the land
5. *Barriers to grazing*: sentiment that grazing is not a viable choice (includes both internal and external factors)

6. *Negative public perception*: sentiment that the public doesn't understand farmers, are overly critical, have misplaced judgement, etc.

Follow-up interview guide

1. Previously, you shared with me that your goal was (insert quote of environmental goal). How will you know if you've achieved that goal?
    a. For me, paying attention to soil carbon is an important way to measure your impact on the land because…What I was hearing from these interviews is that soil carbon might not be something you are really monitoring. What are you paying attention to instead?
    b. I'm someone that thinks a lot about soil carbon and carbon markets. How do you feel about carbon markets? Do you trust them?
        i. What information have you heard around soil carbon? Where did you hear that from?
        ii. You shared that you were tracking SOM%. If you saw that your SOM% was decreasing, how would that affect your management decisions?
2. Previously, you shared with me that your goal was also (insert quote of economic goal). I know markets are variable, but corn prices aren't looking great. Can you help me make sense of how you deal with that? Would you ever consider growing a different crop?
3. Previously, you shared with me that your goal was also (insert quote of social goal). How do you think we make progress towards that goal?
    a. For me, this sounds like it would require farmers and community members working together. How do you feel about that?
4. You shared with me that X, Y, and Z are important goals to you. I also believe those are important goals. What research question could I be exploring that would be important to you and help you achieve those goals?