Agricultural Carbon Offset Market Development:

Barriers & Opportunities from the Farmer Perspective

University of Michigan School for Environment and Sustainability

Master's Capstone Project In Partnership with Carbon Yield

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Thank You

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The University of Michigan's School for Environment and Sustainability Land Acknowledgement

"The School for Environment and Sustainability acknowledges the university's origins through an 1817 land transfer from the Anishinaabek, the Three Fires People: the Odawa, Ojibwe, and Bodewadami as well as Meskwahkiasahina (Fox), Peoria and Wyandot. We further acknowledge that our university stands, like almost all property in the United States, on lands obtained, generally in unconscionable ways, from indigenous peoples. In addition, our research on environmental science and sustainability has benefited and continues to benefit from access to land originally gained through the exploitation of others. Knowing where we live and work does not change the past, but understanding and acknowledging the history, culture, and impacts of colonial practices is an important step towards the creation of an equitable and sustainable future."

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1 Executive Summary

In partnership with Carbon Yield, a company that promotes the adoption of regenerative agriculture practices, this project studies the role of agricultural carbon credit markets as a driver for farm revenue and climate change mitigation. The project specifically aims to understand the barriers to farmer participation in agricultural carbon credit markets, quantify the carbon price that would best incentivize farmer participation, and develop practical recommendations for improving the opportunity for farmers, thereby increasing participation levels and reducing greenhouse gasses (GHGs) in the atmosphere.

Carbon credit (or equivalently carbon offset) markets enable buyers who desire to reduce the amount of CO_2 in the atmosphere to pay suppliers to remove this carbon. This project focuses on agricultural carbon credits for carbon removal, which are generated when a farmer decides to change their farm management practices in a way that adds carbon to the soil over time. Carbon Yield is a project developer for these credits, working with farmers who are making changes to help them quantify the carbon sequestered (or stored) in the soil and then find a buyer for the resulting credits.

Agricultural carbon credit markets are nascent and dynamic. This project is organized around three guiding research questions to help Carbon Yield design their approach for success: (1) What is the state of knowledge on agricultural carbon sequestration in soils as a climate change mitigation opportunity? (2) What are the barriers to farmer participation in nascent carbon offset markets, and how can Carbon Yield help overcome those barriers? (3) What characteristics currently make a farm or farmer a strong candidate for this opportunity, and how can agricultural carbon offset markets be designed to better support diverse groups of farmers? Section 4 elaborates on our research questions and metrics for impact from this project.

Our methods included a review of online resources and peer-reviewed literature, a survey of 48 farmers, and an immersive experience working with growers as "data managers," during which our team assisted a cohort of nine farmers through the process of quantifying their potential carbon credits using Nori, one of the agricultural carbon credit registries. We also interviewed each grower at the conclusion of the data management process to understand their perspectives on the experience. After working with the student team, growers had the opportunity to work with Carbon Yield to seek a buyer for their carbon credits, if desired. Section 6 provides a more detailed description of our methods.

Existing research on-farm management practices suggests that practice changes do have the potential to sequester carbon in soils, though some uncertainties remain. The global food system accounts for approximately 30% of annual GHG emissions (Clark et al. 2020). Due to the loss of historic soil carbon from agricultural systems, soils also have the capacity to reduce GHGs in the atmosphere by returning carbon to the soil. The potential for soil carbon sequestration as a climate change mitigation strategy is closely connected to farm management practices. Practices including crop rotations and cover crops, no-till and reduced-till, irrigation, manure use, and nitrogen management choices can have a strong influence on soil carbon stocks. Cover crops and diversified rotations generally have the highest potential to increase carbon inputs to soil and

thus soil organic carbon (SOC) levels. Reducing tillage intensity can increase SOC, though there is continued debate on the quantity of this reduction. Irrigation can increase crop productivity, but the energy demand for delivering the irrigation may often produce additional CO_2 emissions. Manure use increases SOC, but does not typically result in a net GHG benefit unless the manure would not have been applied elsewhere. Nitrogen fertilizer application has been shown to increase nitrous oxide emissions and also implies embodied carbon emissions from fertilizer production, both of which make it highly debated whether nitrogen application represents a net carbon sink. Section 3 provides a detailed summary of peer-reviewed literature related to carbon sequestration in soils.

As agricultural carbon credit markets continue to develop, it is critical for market participants to be aware of past injustices in the agricultural system and to build justice considerations into their strategic plans. Between 2012 and 2014, 98% of American farmland was owned and 94% was operated by white people (Horst and Marion 2019). These statistics are a result of a long history of systemic discrimination against Black, Indigenous, and People of Color (BIPOC) farmers, and our recommendations consider ways to ensure that the benefits of carbon credit markets are more justly distributed. We also consider strategies to help small farms derive benefits from carbon credit markets. In 2012, the top 7.4% of farms operated 41% of farmland and earned 80% of total agricultural sales. The bottom 80% of farms sold less than $100,000 annually, and most of these farmers relied on other streams of income (Host and Marion 2019). There is a risk that carbon credit benefits, due to economies of scale, could go mainly to the largest farms. Section 3.3 provides more detail on historic injustices and how they relate to the current market.

Section 7 presents the results of our data management experience. The nine growers who participated in our data management cohort grew primarily row crops, such as corn and soybeans, but also produced wheat, hay, popcorn, and cattle. Farms were an average of 1500 acres, mostly non-organic, and operated by White male farmers with 15 to 40 or more years of farm management experience. Most had some exposure to carbon markets as a concept but had limited direct experience with the opportunity and were curious to learn more, especially about the potential for income. A subset of participants was also initially skeptical of the markets.

Four of the eight participants who completed the process rated it a seven or less out of ten when asked whether they would recommend working with Carbon Yield to a friend, neighbor, or family member, while three rated the process a nine or ten. Our cohort of farmers was evenly split on the difficulty of the data collection and modeling process, but all felt that a data management partner was essential to using the Nori tool. Key findings from our experience included that results should be communicated in dollars per acre ($/acre) rather than dollars per ton of sequestered CO_2e ($/ton), that answers should be given more quickly about the likelihood of a viable project, and that the current profitability level is too low to properly cover the costs and risks of practice changes. Farmers desire a profit of $50/acre to make carbon credits worthwhile. From the data management perspective, we concluded that the process currently takes too long and that data managers need more troubleshooting resources from Nori to assist in the model-building process. Ultimately, two out of our nine participants decided to move forward with Carbon Yield to register carbon credits in the Nori marketplace at this time.

Section 8 contains the full narrative of our recommendations and supporting evidence, including a discussion of the farmer survey results, which are integrated with our recommendations. We surveyed 48 farmers about interest in carbon markets with the goal of identifying a clear subset of farmers best suited to carbon markets. Our sample included farmers in a range of age groups and farm sizes, with mostly White male farmer respondents. Websites and social media were the most common primary news sources. For carbon market information, 34% of farmers most trusted agricultural extension offices, with carbon credit brokers a distant second at 23% of farmers. 51% of respondents had a mix of digital and paper records, while 22% had only paper records, and the remainder had digital records. Participation in other ecosystem service programs, especially EQIP, and pre-existing use of reduced tillage were the strongest indicators of interest in carbon market participation, though we were unable to associate any of these findings with demographic factors that would make it easy to identify candidate carbon market participants.

Section 5 summarizes our recommendations, with a more detailed discussion and supporting evidence in Section 8. We organize our recommendations into five categories. First, for improvements to the Carbon Yield grower engagement process, we recommend creating a pre-feasibility study profitability screen, streamlining the process for growers who move forward with modeling to include more resources up-front and investing in soil testing to verify a subset of early projects. Second, for the Nori model-building process, we recommend continued investment in resources to enable data managers to be more independent and continued refinement of the carbon modeling tool's user interface. Third, related to marketing, we recommend that Carbon Yield incorporate education into the feasibility process, with a focus on communication about trust, flexibility, financial security, and ease. We further recommend focusing on early adopters as suppliers and on companies with robust, evidence-based climate mitigation plans as buyers. Fourth, we recommend a target carbon credit price of $100/ton given our research on farmer profitability goals and costs to store carbon by changing practices. Finally, with respect to justice, we recommend that Carbon Yield use its premium carbon credit strategy to help BIPOC farmers tell their stories and receive high prices for their carbon credits while passing on any additional profit margin to the farmers themselves. We further recommend that Carbon Yield use farmer cooperatives to aggregate small farm projects so that small farms are not left out of the opportunity to benefit from carbon credits.

In conclusion, we note that the carbon credit opportunity may differ significantly for certain types of growers, such as highly diversified or perennial farming operations, or for farmers in different regions with unique circumstances. Our project is based on the experiences of commodity row crop producers and will be transferable to farmers with similar practices. Nonetheless, we encourage readers to consider our recommendations critically and to conduct further research when forming opinions and making decisions about carbon credit markets.

2 Introduction

Climate change is projected to further disrupt life on earth as greenhouse gasses (GHG) accumulate in the atmosphere. The warming of the atmosphere and ocean is well documented, along with robust observations of other changes such as sea-level rise, snow and ice decreases, and the increase in greenhouse gas concentrations (IPCC 2013). In 2019, GHG emissions grew for the third year in a row, and even though the COVID-19 pandemic may reduce emissions in the short term, it is unlikely to significantly contribute to emission reductions by 2030 (UNEP 2020).

Globally, the agriculture sector represents a significant portion of global GHG emissions (UNEP 2020, see Figure 1). While the majority of global GHG emissions are the result of fossil fuel combustion, roughly 30% of the total is attributed to food systems, including land clearing and deforestation, production and use of fertilizers, enteric fermentation, and fossil fuels used during agricultural production and supply chain logistics in the food system (Clark et al. 2020).

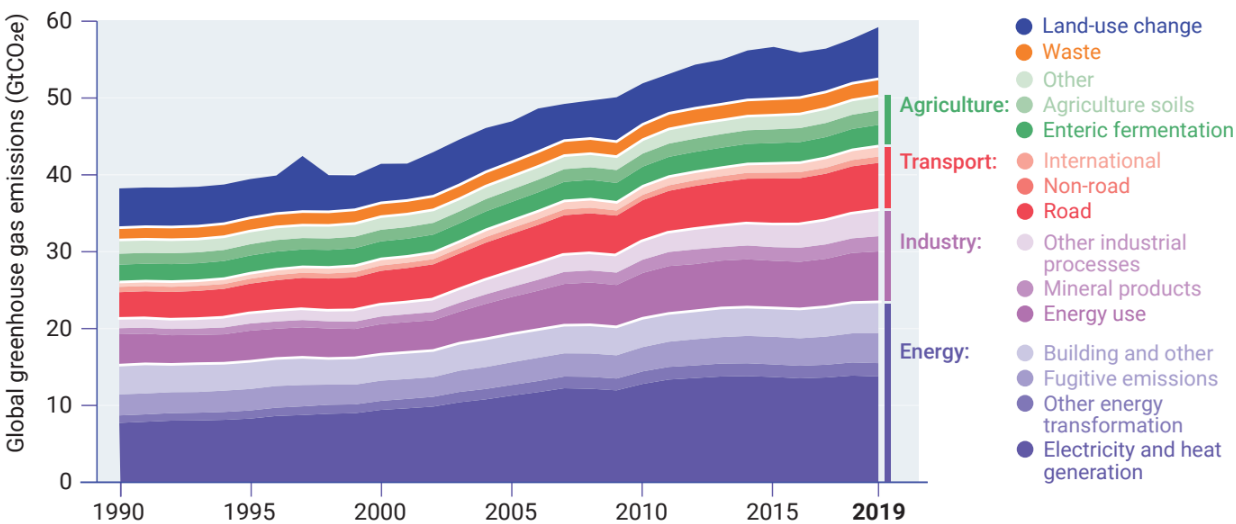

Figure 1. GHG emissions at the sectoral level. Reproduced from the UN Environment Programme Emissions Gap Report (UNEP 2020).

Though agricultural soils are estimated to have lost 50 to 70% of their original carbon (C) stocks (Lal 2003), there is also strong potential for carbon sequestration in soils. Estimates of global soil carbon sink capacity range from 30 to 60 Pg (Lal 2003). Robertson et al. (2014) investigated this potential for distinct cropping systems in the Midwest. Over 25-years of this long-term experiment in Michigan, the authors found that cropping systems could be managed to contribute to a variety of ecosystem services including greenhouse gas mitigation. Specifically, a conventional management system contributed 101 grams of CO_2e per square meter each year whereas a no-till annual plot had a net impact of -14 grams of CO_2e per square meter due to increased carbon sequestration in the soil. The greatest mitigation potential among the annual cropping systems studied was a USDA certified organic cropping system, though it is noteworthy that the yield of corn and wheat was respectively 20% and 40% lower than conventional practices, while soybean yield was virtually identical to conventional practices (Robertson et al. 2014).

Farmer willingness and ability to adopt practices is a key factor in realizing soil carbon sequestration potential. A carbon credit market would provide financial incentives to change management practices by offering a new stream of revenue to both large farms and small diversified operations that struggle to compete in current market conditions. However, agricultural carbon markets are still underdeveloped, and it will be important to build a clear understanding of the barriers and opportunities influencing farmer participation for farms with different management practices and scales. An example can be seen in Figure 2, reproduced from Robertson et al. (2014), which found that while mitigating global warming was not of high importance to the average Michigan farmer, increasing soil organic matter was quite important. This suggests that specific communication strategies are critical in recruitment efforts for carbon offset markets.

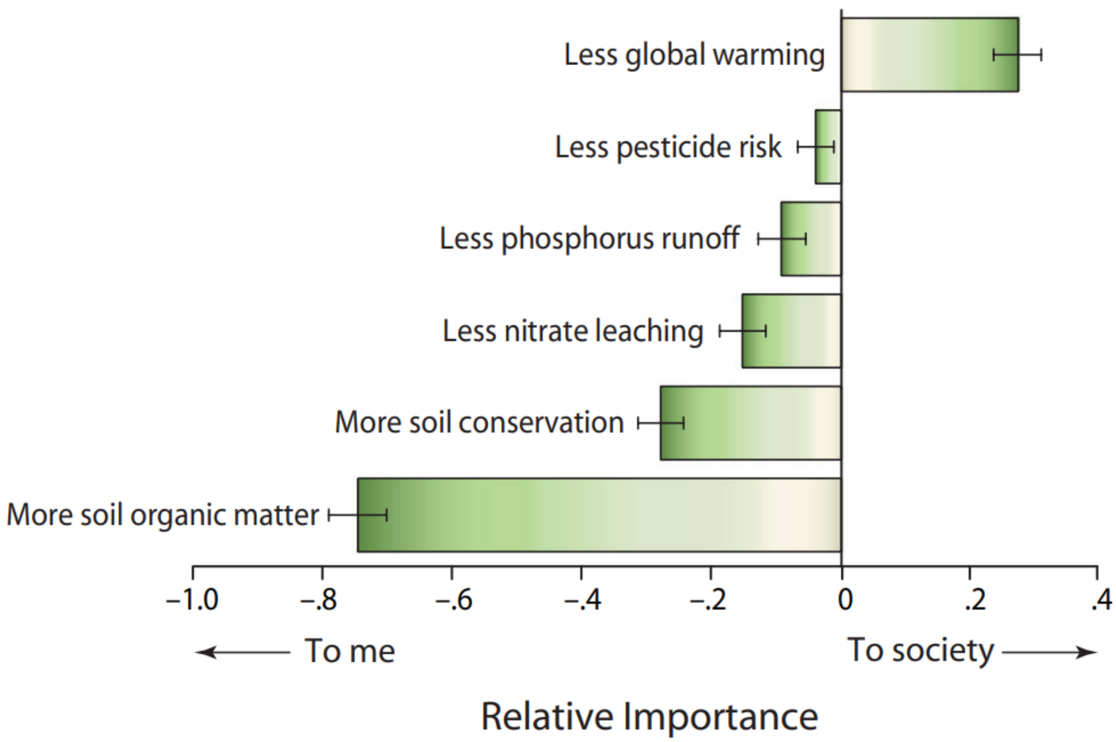

Figure 2. The relative importance of environmental issues to Michigan farmers. Increasing soil organic matter is very important to the individual Michigan farmer, while less global warming is seen as relatively unimportant. Reproduced from Robertson et al. (2014).

Building on this prior research, we seek to address existing challenges to farmer participation in agricultural carbon markets and answer the question of how Carbon Yield can develop carbon offset opportunities for diversified, organic, and regenerative cropping systems in the Midwest.

3 Background

3.1 Agricultural Carbon Sequestration Potential

The science behind soil carbon sequestration as a climate change mitigation strategy is still actively developing. To successfully create and sell agricultural carbon offsets, business leaders, farmers, and scientists must understand the biological, chemical, and physical processes that underlie carbon sequestration. Both practical knowledge and scientific research will inform which management practices farmers choose to use to increase carbon sequestration. These farm management practices can include diverse crop rotations (such as perennial crops and cover crops); reduced tillage and no-till practices; irrigation; manure and compost use; and nitrogen (N) management (Eagle et al. 2012). While there is still a debate on a precise definition of regenerative farming practices, the practices above are all relevant to regenerative agriculture in different contexts.

Through regenerative farming techniques, carbon can be sequestered in the soil by increasing the quantity of soil organic carbon (SOC). SOC is dynamic, and the amount of time organic carbon remains in the soil is dependent on complex physical, chemical, and biological interactions and processes within the soil ecosystem (Schmidt et al. 2011). Many ecosystem services, including retention and cycling of water and nutrients, depend on SOC (Lal 2016). Therefore, one of the goals in adopting regenerative farm practices is to increase SOC.

The physical environment of soils consists of minerals in the form of sand, silt, and clay, as well as water, gasses, and organic matter. Approximately half (42%) of soil organic matter (SOM) is carbon (Brady and Weil, 2008). Organic matter is composed of living and dead compounds, such as microorganisms, roots, decaying plants, and highly processed organic material. The accumulation of soil organic matter in a given field or farm, and its constituent SOC, is determined by the balance between carbon entering and leaving the soil. Carbon inputs to soil begin with photosynthesis, whereby plants assimilate CO_2 to build the carbohydrates and proteins necessary to grow. On farms, a portion of this plant tissue (typically grain) is harvested and exported from the system. While the plants are growing, some carbon enters the soil through rhizodeposition (the exudation of substances from plant roots into the soil), but the remainder enters the soil as crop residues, at which point microbial and physical processes mediate the amount of SOC accumulation. Carbon can also be added to fields through amendments such as compost, manure, and mulch. Like other heterotrophs, microbes use carbon for energy to power their growth and reproduction. Their metabolic activity releases much of the carbon back into the atmosphere as CO_2.

The total amount of SOC in the soil is a combination of different fractions of soil organic matter with different turnover times, typically referred to as a stable carbon pool, the actively cycling pool, and the living biomass of plant roots and soil organisms. Due to its fast cycling between plants, microbes, and the atmosphere, the portion of SOC that is easily accessible to microbial decomposition is referred to as labile, or active SOC. There is also a much larger pool of stable SOC, which persists in soil for up to thousands of years. Some carbon is stabilized by forming tight chemical associations with soil minerals, while some is physically protected from microbial breakdown within soil aggregates, where it is less likely to be exposed to oxygen (which accelerates decomposition). These long-term pools of carbon build up slowly over time but can be highly resistant to decomposition. Management practices typically have the largest impact in the short term on the living and active SOC fractions. For example, perennial crops increase living root biomass and microbial processes that contribute to aggregation, whereas tillage breaks up aggregates, thereby exposing more stable SOC to oxygen and losses of C from fields through decomposition.[1]

Finally, when assessing changes in SOC levels across multiple studies the measurement methods are important. It can take several years or more to detect changes in the total SOC concentration or stock, depending on soil type, thus measurements of active SOM fractions can be helpful indicators of the potential for long-term SOC accrual. Generally, for robust assessments, studies should measure SOC at multiple time points to soil depths of 30cm or greater, while accounting for changes in bulk density when quantifying SOC stocks (Leifeld and Fuhrer, 2010; Tiefenbacher et al., 2021). In addition to understanding the sequestration of carbon within soil, a thorough analysis of the offset potential of agricultural systems must also consider other greenhouse gas emissions in the form of fuel for machinery and the production of synthetic fertilizers. The potential substitution of forests and natural grasslands for agricultural land must also be assessed.

3.1.1 Diverse Crop Rotations and Cover Crops

The study of crop rotation diversity has revealed several important benefits with regards to SOC. Gregorich et al. (2001) found that a crop rotation of maize, oat, and alfalfa increased soil C by about 20 Mg C ha^{-1} compared to a maize monoculture, and that including legume forages in rotation increased soil C retention by 40% beneath the plow layer compared to monocropping. Crop residue quality was also found to play an important role in increasing the retention of soil C (Gregorich et al. 2001).

King and Blesh (2018) conducted a meta-analysis of long-term experiments to test the connection between crop rotation diversity and SOC concentration as it relates to plant functional traits—the physical traits of a plant (root, leaf, and shoot morphology; plant tissue quality, etc.) that determine its contributions to ecosystem function (water quality, nutrient cycles, etc.). They found that the strongest driver of SOC accrual was the C input to soil associated with specific functional traits of crops in a given rotation. To increase SOC levels, the authors found, an increase in diversity within crop rotations should include either perennial crops or cover crops, because these crops increased the total carbon and root carbon input into the soil. On average, the percentage increase in SOC levels was 6.3% (or approximately 2.9 Mg C/ha) for rotations with cover crops and 12.5% (approximately 5.7 Mg C/ha) for crop rotations with perennial crops (King and Blesh 2018).

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[1] The mechanisms of SOC cycling in this section is based on lecture materials from Prof. Jennifer Blesh's Agroecosystem Management Course at the University of Michigan School for Environment and Sustainability, January 25, 2022.

A similar, earlier meta-analysis conducted by McDaniel et al. (2014) synthesized 122 studies that examined crop rotation effects on total soil C and N and found that going from monoculture to two or more crops in rotation increased total soil C by 3.6%; when that rotation included cover crops, total C increased by 8.5%. Explanations for the positive effect of cover crops on SOC is that they increase total C inputs to soil compared to rotations with only cash crops, including greater levels of belowground productivity, and the C inputs are more continuous (i.e., if the cover crops are grown in the "off-season" in temperate climates) (King and Blesh, 2018; McDaniel et al. 2014). The fact that many cover crops never fully mature and are grown in seasons when temperatures are generally lower and light is less available could also promote high root to shoot ratios (McDaniel et al. 2014).

Taken together, this research suggests that cover crops and perennial crops will be important to the success of agricultural carbon markets. King and Blesh (2018) also emphasize the remaining uncertainties that will be important to consider. Of note, rotations with cover crops and perennial forages in the legume family sometimes have increased SOC levels compared to less diverse rotations, even when they have lower total C inputs to soil, which may potentially be explained by the effects of increased biochemical quality and diversity of carbon from legume sources on microbial metabolism (Cotrufo et al. 2013, Kallenbach et al. 2015).

3.1.2 Conservation Tillage

Tillage practices may also affect SOC accrual. Conservation tillage can be broadly defined as a tillage method that leaves crop residue in place to cover 30% or more of the soil surface after planting. While initial research suggested that conservation tillage sequestered carbon (so much so that the defunct Chicago Climate Exchange facilitated transactions to pay farmers for conservation tillage), the hypothesis is now being called into question (Baker 2007).

In their meta-analysis, Eagle et al. (2012) found that switching from conventional practices to conservation tillage, excluding no-till, reduced GHG emissions by an average of 0.70 t CO_2e ha^{-1} yr^{-1}, however these results were inconsistent across geographic regions with distinct climate conditions and soil types. No-till management has a larger soil C sequestration potential, averaging 1.47 t CO_2e ha^{-1} yr^{-1}, however continuous no-till is not common in the United States and much of the sequestered carbon can be released if the soil is tilled even once. Biennial tillage may result in maximum C storage in the cooler and wetter soils of Minnesota and Wisconsin (Eagle et al. 2012).

Subsequent studies (Baker et al. 2007, Powlsen et al. 2014) have argued that many of the initial studies on the effects of reducing tillage did not sample soil deeper than 30 cm and that when researchers have sampled to deeper levels, there is little evidence that conservation tillage sequesters carbon. The studies that took samples to 30 cm or shallower depths may simply have been measuring the redistribution of carbon in the soil profile rather than a net positive C gain. In other words, the C gain in the topsoil is offset by C loss in lower soil horizons beyond 30 cm (Baker 2007).

Some long-term studies that measured soil C to depth with continuous no-till management have found gains in SOC over time (Robertson et al. 2014). In practice, however, no-till practices are often not continuous, and farmers may till every few years to incorporate crop residues. A single tillage event can nullify the effects of carbon capture from previous years. If a high percentage of no-till farmers have some level of tillage in order to maintain optimal productivity, then those soils may not reliably retain C (VandenBygaart 2016, Powlsen et al 2014). What is not in dispute is the other ecosystem services, such as reduced erosion and fuel use, that conservation and no-till practices provide to farms.

3.1.3 Irrigation

Approximately 18% of cropland is irrigated globally (Smith et al., 2008). This additional water helps to improve the soil's ability to retain carbon thanks to better productivity and crop residue returns. Irrigation can increase crop biomass production both above and below-ground, therefore, converting dry cultivated land to irrigated land could capture more carbon in the soil through greater residue inputs. However, estimates vary significantly by crop and regional conditions (Eagle et al. 2012). Notably, a review by Tiefenbacher et al. (2021) concluded that irrigation is likely to have a neutral or even negative effect on SOC storage because the carbon emissions from pumping water often exceed the additional SOC obtained from increased biomass production. Michigan has some irrigation, but it is not very common, with most of the activity taking place in the drier, southwest portion of the state.

Additionally, too much irrigation can also be an issue. Excess water in the soil can speed up the decomposition of SOC (Matteau et al., 2021). This leads to a strong interest in precision irrigation to make sure the right amount of water goes to the right place at the right time.

3.1.4 Manure

The American agricultural system produces a large amount of livestock manure. Increases in soil C sequestration potential have been measured by several studies after application of manure, averaging between 0.18 and 5.10 t CO_2e ha^{-1} yr^{-1} (Eagle et al. 2012).

However, these improvements are not without issue. The overall GHG mitigation potential must account for what would have happened to that organic matter if it had not been used on a specific farm. For example, simply moving the manure from one location to another sequesters carbon in a different location, but the net change for the entire system is the same. There is no net gain unless the manure would not otherwise have been used to fertilize croplands or pasture. In the US, the majority of manure is already applied to agricultural land (Eagle et al. 2012).

3.1.5 Nitrogen Management

Nitrogen (N) fertilizer is used to increase crop productivity, which can lead to greater SOC via residue inputs to soil. It could therefore conceivably be a GHG-mitigating practice. However, this would only apply to N limited areas, the majority of which are outside the US considering most domestic crops already receive surplus quantities of N fertilizer. Since American cropland is not N limited, adding additional N fertilizer has little impact on SOC (Eagle et al. 2012) and could exacerbate N_2O emissions from soil, as well as the embodied GHG emissions in fertilizer production. The C cost of fertilizer production, including manufacture, distribution, and transportation is estimated by West and Marland (2002) to be 857.54 kg C Mg^{-1}. In other words, there would be upstream GHG emissions savings with any *decrease* in N fertilizer rate, while increasing N fertilizer rates would likely increase net GHG emissions.

3.1.6 Organic Practices

Due to market conditions and regulations, organic farmers may have unique constraints that influence their ability to participate in carbon offset opportunities. For this reason, it is important to understand the organic practices most likely to drive net gains in SOC, as well as the wide variation in specific practices used on certified organic farms.

The goals of organic practices include "maintaining or enhancing soil and water quality; conserving wetlands, woodlands, and wildlife; and avoiding the use of synthetic fertilizers, sewage sludge, irradiation, and genetic engineering" (USDA AMS 2015). The USDA Organic standards also specify the use of crop rotations and mechanical or biological methods to control pests and weeds (USDA AMS 2015). Practices that affect decomposition rates or organic matter inputs to soil, such as tillage, cultivation, and organic fertility amendments, are directly related to the change in SOC content and associated carbon offset credit potential.

On a broad level, the literature shows potential for carbon sequestration and avoided emissions on organic farms. For instance, fossil fuel energy inputs for organic crop production were about 30% lower than for conventional corn production (Pimentel et al. 2005), and organic farms have been shown to have greater SOC stocks despite equal or somewhat lower yields (Roberston et al. 2014; Pimentel et al. 2005). This increased level of soil organic matter helps conserve water and enhance other aspects of overall soil health.

There has been some debate about the role of animal manure as a driver of SOC accrual from organic management practices. In a review of studies reporting organic and conventional SOC levels, Leifeld and Fuhrer (2010) noted that while studied organic fields had greater increases in SOC percentages than conventional fields when they received *larger* amounts of organic fertilizer than the conventional fields, when organic fields and conventional fields received the *same* amount of organic fertilizer, there was no difference in SOC percentage increase. They further noted that most reported SOC gains in organic over conventional systems were in systems where organic fertilizer was applied at greater than necessary quantities (for crop productivity) in the organic system. The authors suggest, therefore, that the SOC gains attributed to organic systems are more related to organic fertilizer is applied in excess of productivity needs than to the other organic management practices. In contrast to this finding, Blanco-Canqi et al. (2016) reported results from a long-term comparison of typical organic and conventional crop rotations in Nebraska, finding that organic cattle manure (soybean-maize / sorghum-soybean-winter wheat) and green manure-based (alfalfa-alfalfa-maize-winter wheat) systems *both* increased SOC more than a non-diversified conventional system (maize-soybean-sorghum-soybean). The manure-based system also accumulated more SOC than a diversified conventional system (maize-sorghum-soybean-winter wheat).

Tiefenbacher et al. (2021) conducted a review of the relationship between a broad range of agricultural management practices and cropland SOC stocks reproduced in Figure 3 below. On average, organic farming as a management system, as well as individual practices commonly associated with organic production, have positive carbon sequestration potential. Tiefenbacher et al. (2021) conclude that organic amendments (such as manure and compost) are most beneficial when they are derived from a source that would otherwise be wasted (such as food waste), so as to ensure net SOC addition, rather than simple transport from one place to another. The authors further note the benefit of diverse crop rotations to increase SOC stocks, especially for deep rooting crops and cover crops (often called “catch crops” in Europe). The review emphasizes organic fertilizers, diversified crop rotations with legumes, and cover crops as the most influential practices for SOC stock increases on organic farms, calculating an incremental carbon sequestration potential rate for organic practices of 287 +/- 102 kg ha^{-1} yr^{-1} greater than the rate for conventional farming systems. The authors noted the uncertainty surrounding the carbon sequestration potential per unit yield when studying organic systems, which may be of interest to carbon markets as it relates to leakage (incentivizing more organic fields of lower yield could have unintended carbon emissions if other land use must adjust to maintain overall yields). The conclusions from Tiefenbacher et al. (2021) overall suggest that organic farmers have significant potential to store carbon in soils through typical organic practices.

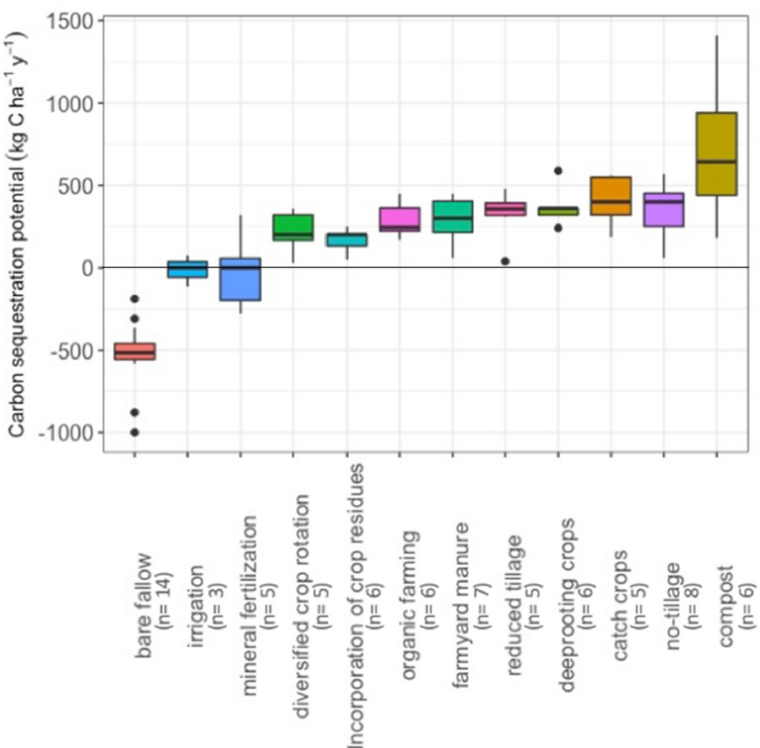


Figure 3. Carbon sequestration potential of various management practices. Compost from sources that would otherwise go un-utilized, continuous no-tillage, and catch crops (also known as cover crops) were found to have the highest C sequestration potential. Reproduced from Tiefenbacher et al. 2021.

Research on the use of conservation tillage to sequester carbon on organic farms is less conclusive. Littrell et al (2021) used data from the Rodale Institute’s long-term Farming Systems Trial to investigate SOC levels in organic versus conventional systems that used conservation tillage (no-till for the conventional system and, in the organic systems, rotational no-till where tillage occurred in years prior to oats and wheat). The study found that SOC concentrations increased 16-132% more over ten years in the organic systems versus conventional systems, with the highest increases in the organic system that incorporated hay and manure (Littrell et al. 2021). This study demonstrates that rotational no-till can facilitate carbon sequestration. Blanco-Canqi et al. (2016), in the same study mentioned above, measured SOC down to 1m depth and noted that SOC accumulation was primarily in the top 0-15cm of the soil.

This reinforces the Baker et al. (2007) conclusion that conservation tillage may simply redistribute C, including in organic operations.

Knowledge of regional variation in organic practices will also be important to fully understand the carbon offset opportunity. For example, Brock et al. (2021) conducted a study of over 850 certified organic corn growers (⅓ of all US organic corn growers, representing over 20% of US organic corn production) in Indiana, Michigan, Ohio, and Pennsylvania, describing the specific set of organic practices common to this region in 2018. The practices recorded are numerous, but each one affects SOC accumulation and would be relevant to a farmer's eligibility for carbon credit markets. Specifically, the authors found that 54% of respondents were dairy farms that raised corn as feed for their cows. 27% sold only corn/soy/small grains as their source of income and ⅔ of respondents used horses for fieldwork and were likely Amish farmers. Over ⅔ of respondents incorporated hay into their corn rotation for either 2 or 3 years of a 4-year rotation. About 40% of respondents used a cover crop prior to corn planting, with about 50% using grasses and about 20% using legumes. Figure 4 reproduced below summarizes some of these results.

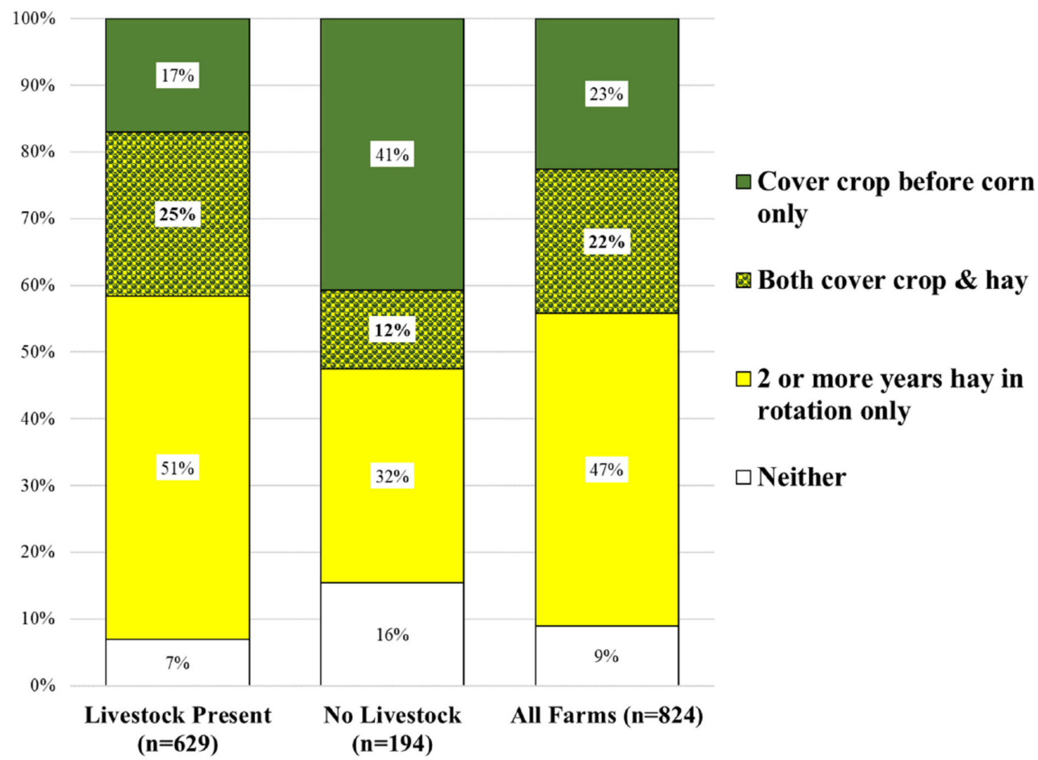


Figure 4. Example of rate and variation of cover crop usage on a subset of U.S. organic corn farms. When livestock is present, farms more frequently grow cover crops and hay than when livestock is not present. Reproduced from Brock et al. (2021).

About 90% of respondents applied manure and about 40% applied some form of organic-approved commercial NPK fertilizer. 20-25% used an inoculant or microbial additive. 94% of respondents said that building organic matter content of their soils overtime was very important or important to them. There are extensive differences between the practices described above and those studied in the long-term experiments in Litrell et al. (2021) and Blanco-Canqui et al. (2016). This marked contrast demonstrates the importance of further research on SOC accumulation for a broader range of organic practices, of careful SOC measurement and modeling for soil carbon offset markets, and of direct farmer engagement to correctly model each farm's unique practices.

Ideally, a well-functioning agricultural carbon offset market would most incentivize the practices highlighted in this section that lead to maximal SOC accumulation. However, other practices still have important environmental or health benefits beyond carbon sequestration potential. Policymakers and organic or transitioning growers should consider the trade-offs between prioritizing carbon offsets versus other goals and ecosystem services, as well as areas of overlapping benefit.

3.2 Soil Carbon Sequestration Science

The scientific uncertainties associated with understanding and predicting SOC accrual in agricultural soils constitute a major barrier to the adoption of carbon offset markets. Current soil carbon protocols for estimating changes in SOC with different management practices rely on the DayCent, DNDC, and COMET-Farm models, but not all include soil sampling for direct farm-level measurement of SOC stocks. In general, the more complex or diversified a farm's practice the less effective these models are inaccurately predicting SOC accumulation. To the degree that uncertainty remains in the underlying models, there is a risk that carbon markets will be unreliable for farmers, that credits will have lower value, and that efforts to mitigate climate change through agricultural carbon markets will be ineffective or even counterproductive.

Nonetheless, as carbon offset verification protocols and registries evolve, we expect there to be increasing clarity as to the types of practices that maximize carbon sequestration while meeting other environmental and societal goals. Our assessment of the opportunity for farmers and businesses and our recommendations incorporates the latest available science.

3.2.1 Soil Science Implications On-going Debate

The scientific basis for soil carbon sequestration as a viable method for climate change mitigation is not yet conclusively understood and is still debated. For example, the World Resource Institute (WRI) published an opinion article online in May 2020, asserting that soil sequestration on agricultural land cannot amount to any significant climate change mitigation factor and that other opportunities should be prioritized instead (WRI May 2020).

The WRI post points out several issues. First, WRI argues that there are uncertainties in the scientific literature around no-tillage practices, highlighting that studies to date have not sufficiently demonstrated net gains in SOC from no-till.

Second, WRI states that the reduction in yield from regenerative agriculture ultimately leads to the need for further expansion of agricultural land to compensate for losses. Additionally, SOC retention requires N in the soil, which could raise the demand for N fertilizer inputs, an ongoing source of environmental degradation in waterways. However, this second argument is potentially based on a problematic assumption because the planet's current agricultural system already produces enough calories to satisfy human caloric needs, but most calories are then fed to animals for livestock production (Tilman and Clark 2015). To be sure, distribution and equity challenges still cause food insecurity, but to assume lower yields will need to be offset by increasing the area in cropland is faulty logic when changes in diet (not to mention reductions in food waste) are another option.

Finally, farmer skepticism on the adoption of cover crops due to the significant change in management practices required is cited as further evidence that these practices are unlikely to be adopted or maintained given current policy and market conditions (WRI May 2020).

Several scientists published dissenting opinions following WRI's post, stating that WRI had improperly defined the parameters of regenerative agriculture, and grossly underestimated its potential (Paustian et al. 2020). The rebuttal consists in part of pointing out where WRI undersold the volume of published research into no-till, cover cropping, and perennials as contributors to SOC build-up and retention, as reported in the meta-analyses summarized above.

The argument that regenerative agriculture will result in reduced yields is also disputed. Evidence is provided to suggest that regenerative agriculture only experiences a brief yield reduction before rising again and providing substantially greater yield stability than conventional agriculture. On the matter of excess N inputs needed to increase SOC retention, the dissenting authors point out that many studies have already affirmed that regenerative agriculture could supply its own N via leguminous crops in rotation and retain that N better via cover cropping so that no increase in the use of synthetic N would be needed (Paustian et al. 2020).

Ultimately, the authors agreed with WRI that there are many opportunities for climate change mitigation within agriculture, and that regenerative agriculture is likely to have many environmental benefits aside from carbon sequestration, but they disagreed on the magnitude and most promising practices, stating that all of these benefits need to be explored.

Cover crops can reduce the need for external N inputs, and are likely to build SOC, but this is an area where additional research is needed. Global studies of carbon sequestration potentials in different soils are also criticized for being inconclusive and based on too many assumptions around the adoption of practices that would reduce production to below current market expectations.

In the end, WRI maintains that the current interest in rewarding farmers for making management changes goes too far in assuming that those recommended changes have the potential to make a significant impact on climate change. They caution against over-relying on this option and foregoing the greater opportunities such as developing more use of perennials in food production and landcover (WRI August 2020).

While the science of regenerative agriculture and SOC sequestration is still in progress, climate change is already harming ecosystems and lifestyles worldwide. Scientific investigation and inquiry into regenerative agriculture must continue and its conclusions should inform agricultural carbon markets but these markets are acting now to slow climate change. Ultimately, this project is concerned with developing a carbon market based on regenerative farm management practices to mitigate climate change, with a focus on barriers to farmer adoption and participation.

3.3 Agriculture Justice

3.3.1 Racial Inequity in Agriculture

In the United States there are significant disparities in farming by race and gender. Between 2012 and 2014, 98% of American farmland was owned by and 94% of farmland was operated by White people (Horst and Marion 2019). People of Color farmers, including Black, Asian, Native American, Pacific Islander, and Hispanic, are generally more likely to be tenants and own less land. This disparity is found between genders as well, with 86% of farm operators identifying as male (Host and Marion 2019).

These striking numbers are the direct result of structural discrimination and patriarchal White supremacy. We first provide a brief and admittedly over-simplified history of U.S. agriculture as it relates to colonization, racism, dispossession, and the exclusion of women and minorities. Before the Columbian exchange, millions of Native Americans lived in what is now the United States before European contact and colonization. Each tribe had its own culture and food system, but as European settlers arrived, starting in the fifteenth century, they implemented a system of land recording which popularized buying and selling land. Native Americans were systematically dispossessed of their land base often through the use of physical violence and manipulation with the support and legal backing of the U.S. government. This dispossession played out differently across geographies and time, but the result was that White settlers obtained land while non-Whites were excluded (Greer 2012).

Throughout the late nineteenth century and early twentieth century, a series of laws referred to as the Homestead Acts were enacted by congress that further redistributed land from Native Americans to U.S. citizens at no or very low cost. Legal and financial barriers prevented many non-White households from taking advantage of the redistribution leading to the vast majority of beneficiaries being White (Host and Marion 2019). In 1881 Native American-held land had already declined to approximately 156 million acres and by 1934 held only 50 million acres (Dunbar-Ortiz 2014).

In the Southern United States, the enslavement of Black people allowed massive wealth accumulation for White plantation owners and operators. Slavery was essential to U.S. agriculture in the South and has been well recorded but for brevity will not be discussed here. After abolition, former slaves often lacked resources and the federal government failed to provide 40 acres and a mule to freed slaves as it had initially promised. The best soil for farming had also already been claimed, therefore many former slaves became sharecroppers or farmworkers (Host and Marion 2019). However, by 1890 14% of U.S. farmers were Black and owned 15 million acres (Williams 2006). In 2012, after decades of continued structural racism and policies that favored large-scale heavily capitalized farming, roughly 2% of farmers were Black (Host and Marion 2019).

Asian American immigrants faced similar structural racism as laws at both the state and federal level prevented Asians from owning land, including the Chinese Exclusion Act and Alien Land Law. During World War II Japanese people were incarcerated and struggled to regain farms and land in the aftermath. Less than 2% of farmers in 2012 were Asian despite making up 5% of the population (Host and Marion 2019).

USDA has, at least historically, been a major perpetrator of the structural racism experienced by farmers of color. This includes discrimination in lending practices, English-only paperwork processes that are onerous for non-native speakers, and exclusionary racist treatment at local and federal offices (Minkoff-Zern 2016). The net result of structural racism, dispossession, and exclusion embedded in the United States' agricultural system is the low number of People of Color in farming, particularly as owner-operators.

3.3.2 Consolidation and Market Power

At the same time that structural racism cemented the racial inequities in farming, government policies, and market forces also shifted the U.S. agricultural landscape. Until the early 1900s, the typical American farm was a small-scale family farm with diverse crops, but beginning with the New Deal, farms began to consolidate and rapidly industrialize. There was a 14% decline in the number of farmers, regardless of race, between 1930 and 1950 (Rosenberg and Stucki 2017). The trend then continued to accelerate. In 1950 the United States had 5.4 million farms operated by 5.3 million operators comprising 1.2 billion acres. In 2012, farming acreage was 915 million but had only 2 million farms and 3 million operators. (Host and Marion 2019). The median farm size has nearly doubled from 1987 to 2012, from 650 acres to 1201 acres (MacDonald et al. 2018).

This consolidation affected White farmers and farmers of color differently. Because of the issues outlined above, as farms consolidated, owners and operators were likely to be White men. Black-owned farm loss in the last 50 years is estimated to be at twice the rate of White-owned farm loss (Ayazi and Elsheikh 2015). In 2012, the top 7.4% of farms operated 41% of farmland and earned 80% of total agricultural sales. The bottom 80% of farms sold less than $100,000 annually, and most of these farmers relied on other streams of income (Host and Marion 2019).

Just as farm size has changed so has the market power of actors within the value chain. Today, many U.S. farmers have only a single or a handful of sales channels, giving procurement markets and intermediaries market power, which they use to extract most of the profits from the value chain (Saitone and Sexton 2017). The result of these market forces has been to largely squeeze small family farms out of existence, and few remain without additional off-farm income. The market power for procurement intermediaries keeps profits low for farmers further accelerating consolidation as farmers seek cost reductions in economies of scale.

The United States agricultural history is one of dispossession and exclusion based on race and other marginalized identities (such as gender) leading to an industry dominated by White men. Simultaneously, farms have consolidated and industrialized leading to fewer, larger farming operations (primarily owned by White men) whereas smaller farms struggle to compete with the economies of scale. The market power exercised by procurement intermediaries further shrinks profits for all farmers.

In understanding the barriers farmers face to participation in carbon markets it is essential to understand the historical and ongoing injustices different demographics face. All commercial farmers must face the market forces that squeeze the profits of their commodified crops and incentivize consolidation. This means that farmers are often pressured by larger buyers to make changes, potentially including management practices that sequester carbon. Larger farming operations are likely to benefit from economies of scale when it comes to carbon markets as well because verification costs can be spread across more acreage. We have also seen those who own and operate farms are disproportionately White men, making carbon markets yet another mechanism in our society that would disproportionately benefit this demographic and perpetuate racial and gender inequities.

4 Objective

Carbon credit markets, referred to equivalently as carbon offset markets, enable buyers who wish to reduce the amount of CO_2e in the atmosphere to pay suppliers to remove carbon or equivalent compounds. The unit of trade in this market is a carbon credit, which represents one metric tonne of CO_2e removed from the atmosphere. These tokens can derive from many GHG-reducing practices and can be issued for the removal of carbon from the atmosphere or for avoided emissions. The focus of this project is on agricultural carbon credits for removal, which are generated when a farmer decides to change their farm management practices in a way that adds carbon to the soil over time.

The goal of this research was to investigate barriers to farmer participation in agricultural carbon offset markets and then to define strategies for the successful development of the market with increased grower participation. A large portion of our project involved working directly with nine farmers in the Midwest to help them complete a feasibility study for potential carbon credits based on a model of farm management practice changes. Our project explored the potential benefits and costs of the management practices these farmers used, assessed the process of data modeling with existing soil carbon measurement protocols, and generated recommendations for successful market development. Section 6 includes a detailed discussion of our methods.

4.1 Project Partners

Our primary partner on this project is Carbon Yield, a company that promotes the adoption of regenerative agriculture practices in part by serving as a project developer for these credits. Project developers, like Carbon Yield, work with farmers who are making changes to help them quantify the carbon sequestered (or stored) in the soil and then to find a buyer for the resulting credits.

Our supporting partner is Nori, an agricultural carbon credit registry and online marketplace, whose modeling system we used to perform the feasibility studies.

4.2 Research Questions

The motivating question for this study was: "How can we develop an agricultural carbon offset opportunity for a subset of diversified, organic, and regenerative cropping systems in the Midwest?" Our research centered on three key questions:

1. What is the state of knowledge on agricultural carbon sequestration in soils as a climate change mitigation opportunity?
2. What are the barriers to farmers to farmer participation in nascent carbon offset markets, and how can Carbon Yield help break down those barriers?
3. What characteristics currently make a farm or farmer a strong candidate for this opportunity, and how can agricultural carbon offset markets be designed to better support diverse groups of farmers?

4.3 Hypothesis

Our hypothesis focused on our second question: We expect that farmers face multiple, and potentially surmountable, barriers to participating in carbon offset markets. Specific barriers for farmers are likely to include: knowledge of market opportunities, time and skill to enter the data needed to enroll, and lack of adequate compensation. Similarly, barriers for carbon market businesses are likely to include: upfront investment in feasibility studies for farms, time for data management, seasonal farm cycles slowing the pace of data entry, uncertainty in the science of soil carbon models, and competition from other businesses. Barriers for carbon offset buyers are likely to include: a lack of supply and concerns about the long-term credibility of purchased offsets. We did not have a hypothesis for question three, leaving our research and analysis open-ended.

4.4 Impact

This project aims to increase Midwest farmer participation in carbon credit markets by assisting in the development of those markets with our project partners to address farmers' specific needs and barriers to participation. Ultimately this will contribute to more sustainable agricultural practices, added carbon sequestration, and resultant climate change mitigation.

Specifically, the project will have four practical impacts:

1. **More Farmer Participants**: Increase the number of farmers pursuing carbon sequestration offsets.
2. **Better Models**: Contribute recommendations to increase the ease of use of carbon measurement tools from the farmer perspective.
3. **Reduced Barriers for Farmers**: Assess the socioeconomic barriers to farmer participation in carbon offset markets, and recommend next steps to help reduce these barriers.
4. **Increased Market Access**: Increase the ability of row crop farmers to participate in existing sustainability programs and pilots that are designed to increase carbon sequestration.

The recommendations will inform future business development and farmer engagement strategies at Carbon Yield and help to improve the carbon credit registration process at Nori. The partner organizations have identified the operationalization of carbon offset opportunities to farmers as a barrier to more sustainable practice adoption, and they are excited to put study findings to practical, commercial-scale use to increase incentives for farmers to adopt climate-friendly practices.

4.5 Measures of Success

The primary measure of success for this project will be a reduction in barriers to farmer participation in agricultural carbon markets, which is associated with increased soil carbon sequestration and increased climate change mitigation. To unlock this metric, secondary measures of success include: the number of farms assessed for Nori Removal Tonnes (NRTs), appropriate pricing discovered for carbon credits and ecosystem services, and the number of farms and magnitude of potential carbon sequestered.

4.6 Audience

The target audience for our recommendations is Carbon Yield, with a subset of our report tailored more specifically to Nori. Our secondary audience includes all other readers with an interest in agricultural carbon credit markets.

4.7 Study Limitations

While most of our recommendations are transferable across a gradient of farm types and sizes, we do note that our findings related to the barriers and enabling elements of the carbon credit process derive from a sample size of only nine growers, concentrated in Michigan. Our methods in Section 6 and our results and discussion in Sections 7 and 8 provide more detail about the demographic and farm characteristics of our study participants. We focused mainly on the experiences of commodity row crop producers. The carbon credit opportunity may differ significantly for certain types of growers, such as highly diversified or perennial farming operations, or for farmers in different regions with unique circumstances. We encourage readers to consider our recommendations critically and to conduct further research when forming opinions and making decisions about carbon credit markets.

5 Summary of Recommendations

The sections below provide a brief overview of our recommendations on each topic. For the full discussion of supporting evidence and details on the recommendations, please refer to Data Management Results (Section 7) and Discussion (Section 8).

5.1 Carbon Yield's Grower Engagement Process

As demonstrated by the results of our data management exit interview, many aspects of Carbon Yield's grower engagement process are already strong. However, we recommend a few ideas for improvements:

- **Strong Relationships:** Continue to focus on trust, transparency, and farmer-centric results.
- **Speedy Process:** Reduce turnaround time for building models. Consider hiring someone who can become very familiar with modeling and focus on this full-time or part-time.
- **Introductory Resources:** Create an FAQ that would be shared at the start of the grower relationship to head off concerns about contract length, data security, etc, and to explain in detail what to expect from the process. A checklist of required data would also be useful early in the process.
- **Accuracy and Credibility:** Strive to ensure maximum accuracy in the Nori model and maximum credibility of the carbon credits. Incorporate soil tests if farmers have results from prior tests, and if not, consider adding soil sampling to some or all projects. Have the Nori Supply Account Manager review every model before the farmer sees any results.
- **Feasibility Study Refinement:** Simplify the feasibility study process by starting with one field per set of farm practices and by developing benchmark NRT results that are likely with various practice changes in a given region.

5.2 Nori's Carbon Modeling System

While serving as data managers for the cohort of farmers participating in a feasibility study, we worked closely with multiple Nori team members who were generous with their time and knowledge as we learned how to build models in Nori's system. Our recommendations for Nori, therefore, focus on the soil carbon credit modeling spreadsheet and its usability for both data managers and farmers.

- **Customer Service:** Continue to prioritize fast and excellent customer support to stand out from competitors.
- **Data Management Efficiency:** Evaluate the pros and cons of hiring internal data managers versus partnering with external data managers as it relates to cost, efficiency, and farmer relationships.
- **Data Manager Support Resources:** Create additional support resources for external data managers to ensure models are built correctly. In our experience, small changes in

entry format could significantly change the outcomes. This caused us slight worry that data managers were correctly inputting data. Furthermore, we're concerned that incentives may exist for model manipulation that would reduce accuracy.

- **Improved Application User Experience:** Continue to fine-tune the Nori carbon model application with improved user experience, simplified features, and elimination of bugs.
- **Dollar per acre as a Farm Profitability Metric:** Communicate credit values in $/acre terms and relative to practice changes. For example, instead of highlighting the NRTs per acre, instead, share that the farmer would receive $15 per acre per year for a shift to cover crop over ten years.

5.3 Marketing

5.3.1 Recruiting Farmers

Throughout our research, we had many touchpoints with row-crop growers to better understand their viewpoints. We analyzed data formally collected from the broad quantitative survey and data management exit interviews, as well as reviewed our notes logged from initial recruitment through completion of the feasibility study. Unsurprisingly, we found the farmer awareness of carbon markets to be quite low, which tracks with the nascence of these market-based solutions. We suggest marketing to farmers along with the following recommendations:

- **Educate on Markets**: Infuse feasibility study and other aspects of the on-boarding process with educational touchpoints that can dampen some concerns that growers may have when engaging in a new potential revenue stream, specifically fairness, ease, security, and flexibility.
- **Target Those More Likely to Pursue Enrollment**: Early-adopters and those motivated by profit were shown to be more likely to pursue additional revenue streams at this time.; Seek early adopters
- **Alignment with Trusted Sources**: Hire tech-savvy farmers during the off-season to quickly input data and be a resource to answer questions about the markets. Form partnerships with the Agricultural Extension Office in high-priority states.

5.3.2 Buyer Acquisition

While this research centers on the farmer's perspective of carbon markets, we'd like to highlight points regarding the half of the market that drives demand: the carbon credit buyers. Carbon Yield sells carbon credits that tell the human story of farmers using natural systems to take carbon out of the atmosphere. The critical attribute to be aware of is trustworthiness. We, therefore, recommend that the firm selectively screen customers for genuine commitment and authenticity to reducing carbon emissions along these guidelines:

- **Showcase Strengths**: Carbon Yield's small size enables them to be agile, provide personal attention, and authentically show their genuine interest.

- **Highlight Product Differentiation**: The firm's de-commodified carbon credit can be humanized with the farm's story.
- **Align with Customer Need**: Choose consumer branded companies that are agricultural-adjacent, such as cotton apparel.

5.3.3 Ideal Carbon Credit Price

We evaluated Carbon Yield's current pricing strategy relative to (1) a review of industry sources and scientific literature about the net income, revenue, and cost implications of transitioning to carbon-sequestering farm management practices (no-till, reduced till, cover crops, and soil health management systems), (2) farmer opinions about the profit level that would incentivize practice change, and (3) competitor prices. We recommend the following:

- **Seek High Prices:** Continue to seek the highest prices possible for high-quality credits, but use a $50/acre desired farmer profit as a guideline for determining pricing and profit margins for projects with varying carbon sequestration rates and sizes. We find that $100/ton is a justifiable price to charge to compensate farmers for the true value of their practices changes while providing Carbon Yield a viable revenue stream to continue developing projects.
- **Present Long-Term Income Impacts:** Work with farmers who are shifting to cover crops to present and discuss the long-term net income considerations for carbon credit payments to reflect the fact that cover crop profitability generally improves over time.
- **Present Feasibility Study Results in Dollars per Acre:** Present the carbon credit opportunity to farmers in $/acre. This is the metric preferred by a strong majority of the farmers we spoke with and the metric used by most farm economic sources.
- **Identify Locations Where Cover Crops Are Most Profitable:** To maximize the conversion rate from interested farmers to farmers with economically viable carbon credit projects, identify and recruit in locations where farmers experience the following situations that have been identified as contributors to increased cover crop profitability: (1) face severe herbicide-resistant weeds, (2) have access to grazing income, (3) have soil compaction challenges, (4) are also transitioning to no-till, or (5) are likely to face drought conditions. (SARE, 2019).

5.4 Justice

After centuries of injustice, Carbon Yield may not be able to solve every problem but is positioned to take action that would lead to more just outcomes. Directly rectifying injustices was not the original purpose of our study but the implications became impossible to ignore as we learned more. Our recommendations here are the result of innumerable conversations with a variety of stakeholders.

- **Market BIPOC Farmer Credits as an Additional Price Premium:** BIPOC farmers are underrepresented and less likely to see the benefits of carbon markets due to lasting racism. However, we believe that there is a market for these farmers to earn a higher price premium for their credits when marketed as one element of the human interest story. The

BIPOC farmer credits present a more compelling narrative to certain customers and this increased demand should mean additional value that can be captured with greater prices.

- **Rely on Existing Farmer Cooperatives to Spread Fixed Costs:** One of the largest barriers for small farmers to access carbon markets is the verification fee that is paid to audit and confirm reported practices. This is a relatively fixed cost making it a trivial sum for large operations that generate more revenue through sheer volume of credits but cost-prohibitive for smaller farms. This phenomenon is often repeated and cooperatives already exist to enable small farmers to combine resources and still compete. Using these existing cooperatives is a good way to spread the verification cost out and include more farmers in the market.
- **Include Regenerative Farming Leaders as Ambassadors:** Early adopters of regenerative practices are often unable to qualify for carbon credits as their carbon isn't additional. Those that have depleted their soil the most stand to gain the most from carbon markets. In the interest of fairness, we propose including early adopters as ambassadors for the management practices they already employ with financial incentives for their effort.

6 Methods

At the onset of the project, our goal was to understand the system, stakeholders, options, and constraints that shape agricultural carbon markets from a science, policy, economic, and business perspective. The methods we used for each piece of this background research reflect the most practical way to obtain accurate information and include literature review, internet research, stakeholder interviews, data management, and data collection through a broad qualitative survey and structured interviews.

We chose our mix of methods to provide a balance of scalable conclusions and in-depth investigation. Newing (2011), in Conducting Research in Conservation, defines three types of validity related to research design: internal, external, and context. Internal validity relates to experimental design and signals a high likelihood of “theoretical rigor”; external validity refers to “the extent to which the results can be generalized from the sample to a larger population”; and context validity indicates how well the research conclusions correspond to real life (Newing 2011, p. 51-52). For our study, we emphasize context validity by using semi-structured interviews, experiential immersion in existing carbon market processes, and collaborative work with our project partners; these methods involve a deep investigation of qualitative themes and causes. Our broad qualitative survey later in the project added external validity to our initial findings.

6.1 Research Question 1: State of Knowledge on Soil Carbon Sequestration

Our first research question is: *What is the state of knowledge on carbon sequestration in soils as a climate change mitigation opportunity?*

To understand the farm practices most likely to result in viable carbon offsets and credible carbon sequestration, we conducted a literature review of agricultural land management practices and their connections to soil carbon sequestration.

To understand the current carbon market ecosystem, we used news articles, industry reports, and other online sources as well as informational interviews with industry professionals to investigate (1) soil carbon sequestration quantification tools (DNDC, Century, Daycent, COMET-Farm, Cool Farm Tool), (2) additionality and its equity implications, (3) historical or existing carbon market structures, (4) existing agricultural policies, and (5) existing Payment for Ecosystem Services (PES) opportunities.

6.2 Research Question 2: Farmer Carbon Offset Participation Barriers

Our second research question is: *What are the barriers to farmer participation in nascent carbon offset markets, and how can Carbon Yield help overcome those barriers?*

6.2.1 Data Management Process

To understand barriers to farmer participation in carbon offset markets, we served as "data managers" for nine farmers in the Midwest, with a focus on Michigan, between April 2021 and March 2022. We assisted these farmers in using the Nori carbon registry system to determine how much carbon their farms could sequester and to offer our data management cohort the opportunity to work with Carbon Yield to market any resulting soil carbon credits. In partnership with Carbon Yield and Nori, we identified a set of criteria for this grower cohort: farmers had to be in Michigan, be over 400 acres in size, grow field or grain crops, own 50% or more of their land, have reasonably good data, have plans to or have recently shifted management practices, and be able, willing, and interested in participating. See Appendix 1 for a copy of our grower recruitment flier. Carbon Yield and Nori assisted us in identifying growers who would be responsive partners. Throughout the data management process, we kept a record of barriers, successes, and ideas for improvement associated with the process.

To experientially understand the work involved with enrolling a farm with the Nori carbon removal token registry, each researcher served as a data manager for one to three farmers in the Midwest. Growers participating in the study primarily produced row crops such as corn, wheat, and soy. Several of the other farmers grew additional crops, such as alfalfa. Participants were identified via inbound traffic to Carbon Yield or Nori, as well as connections from the Michigan State University Agriculture Extension Office.

The data management role involved gathering and consolidating land management history to produce results of the feasibility study. This is a process by which Carbon Yield assesses a portion of a farm for project viability. The role consists of conducting an initial interview, collecting digital and paper records, consolidating historical and future practices into Nori's data management model spreadsheet, confirming records with the grower, and providing a financial outlook based on findings. The COMET-Farm data model is used by Nori to estimate the amount of carbon sequestered based on the management of land in a particular part of the country. The results are then translated into Nori Carbon Removal Tonnes (NRTs), which represent one tonne of carbon dioxide equivalent sequestered by agricultural land management practices.

6.2.2 Data Management Exit Interviews

We asked participants in the data management process to partake in a post-data management exit interview after the completion of their feasibility study. These calls were conducted by the researcher who served as the data manager for that participant and were in some cases shadowed by a second researcher. We compensated participants $200 to complete the data management exit interview.

Each interview included a qualitative interview of 11 questions and a quantitative survey. The qualitative questions (Appendix 2), discussed the farmer's perception of carbon markets before, during, and after they engaged with Carbon Yield. The quantitative survey was identical to the one completed by the broad survey participants, which is described later in this section.

Interviews were primarily conducted and recorded using the Zoom video call platform. These calls were transcribed automatically using Zoom's speech-to-text service. The interviews were later organized into themes using the codes (Appendix 2) by referencing the recorded calls and transcriptions.

A few exceptions to the process are as follows: one interview was conducted by one researcher over the phone and notes were taken by hand, one participant refused compensation, and one participant did not return data in time to complete the process and therefore did not complete a post-process interview.

We chose to use the above semi-structured interview process for a few reasons. First, semi-structured interviews involve a pre-set list of questions or topics to cover, but also allow for fluid conversation with follow-up questions and can be tailored to each individual interviewee (Newing 2011, p. 101-103). Blair (2020) used semi-structured interviews in her master's thesis on how farmers use financial incentives to overcome barriers to cover crop adoption. She chose this option because it provided a more detailed understanding of farmer experiences than a survey (Blair 2020). Second, though other studies of farmer behavior have used focus groups to gather qualitative data (Roesch-McNally et al., 2018, for example), we used semi-structured interviews rather than focus groups because they avoid the group bias of focus groups while maintaining more structure than a simple conversation without pre-prepared questions (Newing 2011, Ch. 6).

6.2.3 Broad Survey

To assess whether the themes uncovered in our background research and data management process (both logs and exit interviews), are relevant to a broader group of farmers, we developed a qualitative questionnaire. The goal was to generate at least 35 responses from Michigan farmers. We conducted this broad survey to better quantify barriers, interests, and eligibility of growers to participate in carbon markets. We used Qualtrics to collect the survey data. The final questionnaire consisted of 30 questions with variations for specific practices (Appendix 3). The survey sought to identify practices the growers were currently doing or planned to and the costs required to switch. We additionally collected demographic and psychographic information to identify patterns. The farmer questionnaire used a "structured" interview format, in which questions are standardized for all participants and there is no follow-up conversation (Newing 2011, Ch. 7).

We initially collected data in person at the Great Lakes Crop Summit (GLCS) in Mount Pleasant, MI on January 26, 2022. We received 39 responses, which we later supplemented with 9 additional responses from our data management cohort. We asked attendees to complete the survey and compensated GLCS participants $10 in cash. Respondents primarily completed the surveys using their mobile phone. We analyzed the data using basic statistics, charts, and correlations between attributes.

6.2.4 Pricing Research

To understand the economic context and our hypothesis that low profitability of soil carbon credits is a barrier to farmer participation, we reviewed industry publications and peer-reviewed studies about (1) the economic costs and returns of regenerative practices (including cover crops, reduced tillage, no-till, and other soil health-building practices), (2) potential revenue streams from carbon or other ecosystem services payments, and (3) current soil carbon credit prices. We then compiled these benchmarks with the results of our interviews and survey to make a recommendation about the ideal soil carbon credit price Carbon Yield could target.

6.3 Research Question 3: Ideal Farm and Farmer Characteristics

Our final research question is: *What characteristics currently make a farm or farmer a strong candidate for this opportunity, and how can agricultural carbon offset markets be designed to better support diverse groups of farmers?*

The interviews and broad survey questionnaire that we used to inform research question two contributed greatly to our investigation of research question three. In addition, based on our notes from the experience working with farmers as data managers, we compiled (1) recommendations for how the process can be improved and (2) qualitative data about the farm management practices and farmer characteristics likely to lead to viable carbon offsets. We used this synthesis to inform our marketing recommendations.

To better understand justice considerations related to soil carbon markets, we conducted a literature review to identify key justice concerns in agriculture and then compared the results with our other study data to identify measures that could increase equity of access to the agricultural carbon offset market.

7 Data Management Results

7.1 Farmer Cohort

To experientially understand the work involved with enrolling a farm with the Nori carbon removal token registry, each researcher served as a data manager for two or three farmers. During farmer recruitment, we corresponded with 19 farmers. We ultimately began the data management process with nine farms and conducted an exit interview with eight farms, including a farmer and son pair. Growers participating in the study primarily produced row crops such as corn and soybeans. Some also focused on wheat, hay, popcorn, and cattle.

Participants were identified via inbound traffic to Carbon Yield or through connections from the Michigan State University Agriculture Extension Office. Most, if not all, were already engaged in some degree of carbon-sequestering practices before their involvement in this project, particularly with cover crops and various forms of reduced tillage. The size of farm operations varied from less than a couple hundred acres to a few thousand acres, with the average around 1,500 acres and the majority being one thousand or more acres. Less than half of the cohort had any certified organic land and those that did manage a minority of their land organically. Most were involved already in some cost share or ecosystem services program, but none were engaged in any carbon credit program. All of them were white and male, and most were between 45 and 75 years of age and had at least 15 to 40 years or more of farm management experience.

The data management role involved gathering and consolidating land management history to produce results of a feasibility study about whether a farmer was likely to have enough carbon storage to earn carbon credits. This consisted of an initial interview, collecting digital and paper records, consolidating historical and future practices into Nori's carbon model, confirming records with the grower, and providing a financial outlook based on findings. Nori uses the COMET-farm data model to estimate the amount of carbon sequestered based on land management in a particular part of the country. The results are then translated into NRTs, or Nori Removal Tonnes, which roughly translate to a ton of carbon sequestered in 10 years.

7.2 Barriers and Opportunities

This section presents key findings from our own experiences as data managers and from the set of data management exit interviews we conducted with each farmer after the model-building process concluded. Table A highlights the most commonly recurring themes across the farmers' responses to the standardized list of questions that made up the exit interview and Appendix 2 contains the comprehensive list of recurring themes, including those which were brought up less frequently.

Table A. The Most Frequent Themes in Cohort Exit Interviews (n=8)	
Theme	No. Farmers
Cost per acre is the meaningful metric	7
Had well organized records already	7
Cost of seed as major financial concern	6
Minimum price of carbon should be $50/acre	6
Minimal prior knowledge on carbon markets	6
Low time commitment to gather data (1-2hrs)	5
Opportunity for income by participating	5
Unclear on what ultimate benefit of participating would be	5

Nearly all of the farmers interviewed felt cost per ton is not as useful as cost per acre in communicating the value of participating in carbon markets. The only other theme that was brought up as frequently was the feeling that the farmers had all the necessary records ready to go to complete the data upload process. This might suggest an expected selection bias in having attracted participants to this project who were better primed and ready to participate than the average farmer. Six of the eight farmers suggested roughly $50/acre ought to be the minimum price of a ton of carbon for them to see much value in participating in carbon markets. As one farmer put it, "past $30, definitely $50 you got my attention." One final comment from this snapshot, particularly worth highlighting, is that while five out of eight farmers saw participating in carbon markets as an opportunity for income, the same number also was unclear on what exactly the financial benefit would be before they participated in this project. This seems to be a significant opportunity for improved messaging to help farmers better understand what the likely financial benefit is in participating before they put in all the effort to share their data.

7.2.1 Farmer Motivations

As indicated above in the summary table on the most frequently occurring themes in the data management exit interviews, most respondents felt they had minimal prior knowledge of carbon markets, but were generally aware of them. Half of the respondents were primarily aware of corporate payment-for-practices programs. Also as shown in the above summary table, the most common motivation for participating in this relatively new and less familiar market was the income opportunity. However, the second most common motivation, with half of the respondents stating it, was an interest in being an early adopter that came out of open-mindedness towards trying new things.

Before participating in this pilot project with Nori, only half of the respondents had made even a brief attempt at exploring other carbon credit registries. Three out of the eight said they had been directly contacted by other registries. The respondents typically described their limited experiences with these other registries in unfavorable terms: "I talked to one person, and they were going to a meeting and just three or four different times I talked to them and never really got any answers and got anywhere with them."

7.2.2 Carbon Yield Grower Engagement Process

Farmer's Perspective

As a result of our work, two of the nine growers in the data management cohort are currently proceeding with Carbon Yield to register and sell soil carbon offsets. Of those not proceeding, two had promising carbon credit numbers but chose to pursue other buyers or to wait, and one grower had borderline results but decided to wait rather than pursue the opportunity now. Four growers had NRT results that were too low to be financially viable, though one grower had not yet made any practice changes, which influenced their results. The final grower did not provide data in time to complete the modeling process. Though they could not be included in our results, they may still have the potential for a successful outcome if they choose to continue with Carbon Yield to complete their initial model.

Table B. Summary of the carbon market decisions of our data management cohort.

Result	Number of Growers
Proceeding	2
Not proceeding, good carbon credit numbers	2
Not proceeding, okay carbon credit numbers	1
Not proceeding, low carbon credit numbers	3
Did not complete data process	1

As a group, the growers in our data management cohort varied significantly in their assessment of the quality of the Carbon Yield process. Figure 5 below shows the range of responses to the interview question, "How likely are you to recommend the Carbon Yield process to your family, friends, or neighbors, on a scale of 1-10?". Three growers rated the process a 9 or 10, but three growers also fell in the 5-7 range. Given that these answers were relayed in person during an interview, it is possible the responses were inflated to avoid awkwardness. Of the two growers who responded "it depends", one was a conventional farmer who felt they did not use the right practices to be a good fit for carbon markets and therefore abstained from answering. The second grower elaborated that their response would be a 5-7 for a small farm and a 1 for a large farm, driven by their opinion that it would be more difficult for a grower to locate data for a large operation.

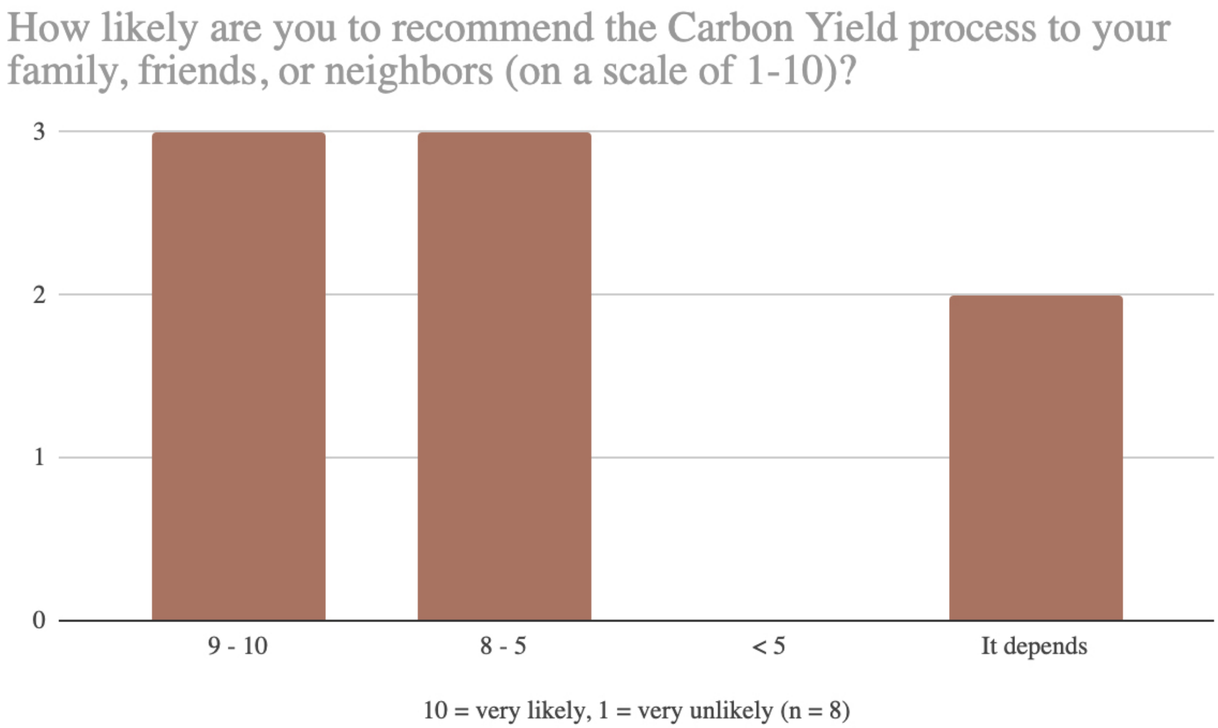


Figure 5. The bar graph above summarizes farmer opinions about how likely they would be to recommend the Carbon Yield process to a friend, family member, or neighbor where a 1 represents unlikely to recommend and 10 represents very likely to recommend. Some literal responses to the open-ended questions were "6 or 7" and "5 to 7".

Data Gathering Process

In addition to the ratings above, our data management exit interviews asked farmers to comment on the pros and cons of the process of working with us as representatives of Carbon Yield. As previously mentioned above in the summary table on most frequently occurring themes, nearly all respondents felt their farm management records were well organized and conveniently accessible for the data upload process with Nori. Five out of eight also felt the process was not overly lengthy, needing only a couple of hours to get most if not all of the work done in entering data. Half of them also felt the experience was a good incentive to learn more about carbon credits and appreciated that opportunity. A few respondents specifically mentioned that getting the data upload process done in the wintertime was ideal, and three respondents even said the process overall was enjoyable.

On the other hand, half also felt the process required them to invest too much time and effort before ultimately finding out that they stood to gain nothing from the program. This is a key opportunity to better communicate upfront how likely a given farmer is to derive value from the program or to find a way to more quickly communicate those chances once they express an interest. A few respondents suggested that simpler, more concise language should be used (e.g. "removing" carbon from the atmosphere instead of "sequestering"). Finally, and not surprisingly given the complexity of this market, three respondents felt they were still largely confused about carbon markets.

When asked to what extent they would feel comfortable using the Nori application independently, our data management cohort felt they would not be likely to do so. Four growers mentioned that the tool is too difficult to use for one-time use. Three interviewees felt they were not technologically inclined enough to use the Nori tool on their own. One stated, "if you want the farmer to input all that you're probably looking at more the millennials and younger people. I don't know if gen X or baby boomers [are going to] take the time for some of that." Three growers felt the Nori process took too long.

Carbon Market Perceptions

The responses to our data management exit interviews also identified more general barriers to carbon market participation that apply to the opportunity as a whole, and not just Carbon Yield as a partner. Three farmers in our post-data management interviews mentioned difficulty finding information about carbon markets as a barrier. One stated, "As a farmer you want to know [...] is it worth your time, what can I make, and what's it going to cost me, so that's really what you want to know, and I had trouble getting that from anyone from the start". A second grower stated, "What we were getting out of the deal, I guess, will be my main thing that was a little shy on information".

Skepticism about carbon markets emerged as a theme. Most of the responses related to skepticism emerged from the question regarding what interviewees knew about carbon markets before working with us. Though we recorded 16 sub-theme reasons for farmer skepticism, most of these came from only two respondents, and there were two other respondents who did not express any skepticism at all. Notably, three growers mentioned a perception that carbon market contracts are too long or restrictive, two expressed concern about the verification process, two felt that carbon credit buyer motivations were unclear, two felt that the system was not grounded enough in soil science, two felt carbon markets were unlikely to make a real impact, and two felt they had already adopted all of the practices that could generate credits and therefore had no further room to benefit.

Three growers mentioned other reasons for skepticism but were the only ones to express their specific reasons. For one grower, these reasons included concern about corporate greenwashing and power and the opinion that farmers are always asked to take on all the work and risk. A second grower's reasons included concern that farmers are currently forming strong opinions without real knowledge of the carbon market options, feeling that governments should be the entity making carbon payments, skepticism about the profitability of regenerative practices, concern that carbon markets would take advantage of farmers facing economic hardship, and concern that farmers are not asking for carbon markets. A third grower mentioned concern that carbon markets are just a fad.

Financial Considerations

Financial considerations were another theme related to farmer decision-making about carbon markets. As previously listed in our summary of most frequent themes, seven of eight of our growers mentioned that revenue per acre is a more relevant unit to them than revenue per ton of carbon. Three growers expressed concern that middlemen or non-farmers would end up making the money in carbon markets, and three growers expressed concern that carbon market profits are currently too low to motivate change in practices. In addition, one farmer mentioned concern about carbon market price variability, and one felt favorable that Nori's customization can lead to a better carbon price.

When asked about the costs involved in changing to regenerative practices, our data management cohort focused most on the risks and time involved in making the shift, in addition to the expected cost for cover crop seed. Four growers out of eight mentioned time spent coordinating the change as a major factor. One grower stated, "My time is worth more than actually $20 an acre […] the time is what's the killer for me, […] trying to get the logistics inline". Three growers mentioned weather complications as a potential cost, and three others listed a negative effect on yields as a cost associated with cover crops. One grower stated, "I'm trying to take the time to understand that it takes many years on to try to get a primary crop out of [...] a cover cropping or companion cropping system." Other financial considerations that received one mention each included the costs of no-till equipment and equipment wear and tear and revenue from cost-share programs.

Data Manager Perspective

Based on notes we kept throughout the data management process and based on two team reflection sessions, we identified strengths and areas of improvement for Carbon Yield.

Positive Elements of the Process

Carbon Yield already does many things well to help farmers navigate the process to successful carbon credit projects. A major strength is the Carbon Yield team of Claire Pluard and Sam Schiller. In their work with farmers, the Carbon Yield team conveys trustworthiness, transparency, and farmer-centricity. This is supported by the positive reviews Carbon Yield received from farmers on the initial data interview and final results meetings; in our data management exit interviews, farmers did not have many suggestions for improvement to the way Carbon Yield presented the opportunity, but rather focused on more general carbon market concerns or specific details of the data collection process.

As a business, we feel Carbon Yield offers a differentiated product. The individualized attention they provide to growers allows them to source high-quality carbon credits, and they are connected to a large network of entrepreneurs, funders, and potential carbon credit buyers, both of which enable them to offer farmers higher prices per ton than other project developers. In addition, as a small start-up company, Carbon Yield is agile, allowing them to respond in real-time to the changing carbon markets space.

Three elements of the farmer engagement process stood out to us as contributors to success. First, during grower recruitment, we found that almost every grower came to us through a personal connection rather than a cold email or call. Extension agents were particularly effective at recruiting growers. For example, the Michigan State University extension successfully helped us locate growers who they already knew and who fit our initial criteria. Second, we believe a few characteristics likely contributed to successful carbon projects: (1) a patient farmer, (2) a farmer with time available to meet, (3) large acreage, (4) openness to practice changes, and (5) data availability and good management practice records. To illustrate, in our log of farmers who had one conversation with us but decided not to participate, two of nine were too small, two were too busy, one was skeptical of the markets, and one had already switched to regenerative practices long ago. Third, as we gained experience conducting initial intake calls, we found that it was important to focus the first conversation on mutual goals. Starting the conversation with a general question about the farmer's operation was a good way to break the ice. The agenda we settled on for this introductory call with farmers (pre-data collection) included the following topics: (1) acreage, crops, and general management history, (2) recent practice changes or desire to change, (3) potential financial benefits to the farmer, and (4) overview of next steps including more specific data that would be required.

Barriers to Participation

Three of the barriers identified in our post-data management interviews also stood out to us as data managers: (1) difficulty finding reliable information about carbon market opportunities, (2) the need for a data manager to go through the Nori model process, and (3) the time and risk involved with regenerative practice implementation. In the section below, we describe how these barriers to successful carbon market participation manifested to us as data managers. In addition, we add data manager uncertainty to the list of barriers.

Our data management experience suggests that lack of knowledge is indeed a barrier to farmer participation. At one farmer field day we attended during our grower recruitment efforts, we heard feedback that our presentation was too advanced and that many in the farm community do not yet know the basics of carbon credits. As mentioned above, one grower in our data management cohort suggested using less technical terms: "If you could say sequester carbon or remove carbon out of the atmosphere, [...] I think people will view those as the same thing, but […] people are way more comfortable with the word removed."

We strongly agree with the farmer perspective that the Nori model requires a data management partner. As one grower stated, "To have the production farm do it themselves you're going to be kind of pushing a string. It's [going to] be hard to get them to do it and get it done unless you have a real close relationship with them or they're really motivated to do it." Even with excellent support from the Nori team, we each needed at least one, possibly two model-building experiences to feel confident using the application. In some of our early models, we also spent an unexpectedly long time trouble-shooting the Nori model. Though we eventually learned how to build successful models, we feel this lack of experience, if it becomes obvious to growers, could erode confidence in the system.

A major sub-barrier to us as data managers was the time required to build each model. The data collection process often took multiple follow-up interviews, emails, or calls. In some cases, it was difficult for farmers to find their data, for example: if a multi-generational farm had switched primary managers sometime in the historic data period. Growers also sometimes changed their estimates of historic practices from conversation to conversation, creating unnecessary re-working for the data manager. In general, we found it difficult to align on one best practice for efficiently gathering the data needed. Some farmers preferred pen and paper as a means to communicate data, while others preferred electronic forms.

At least two of our farmers were curious about carbon credits but had not yet made a practice change. With one of these growers, we modeled hypothetical practice changes and their carbon impact, but this was not enough to overcome the farmer's perception of the risks and time involved in making the practices changes.

A final barrier for us from the data management perspective is our uncertainty about the carbon impact of the final projects. This uncertainty has two root causes. First, some projects ended up having fields with positive carbon sequestration alongside fields with negative sequestration (positive carbon emissions). In such cases, farmers may proceed with just the positive fields, but we wonder what this means for additionality. If a farmer changes practices and this leads to carbon sequestration on one field but a discovery of carbon emissions on another field, should there be a process to ensure that any credits issued account for the net carbon storage across the entire farm? To some degree, is this part of the learning process to identify the practices that best store carbon in soils? Second, while we are confident in the accuracy of the underlying scientific model, we are uncertain about our ability, even with much assistance, to properly populate it with farmer information. On multiple occasions, we found that small variations in how we entered certain data made a big difference to the number of carbon credits generated. We expect this will improve with experience, but we see this as a major barrier to first-time data managers.

7.2.3 Nori Process

We identified strengths and areas of improvement for Nori's carbon modeling process in addition to those of Carbon Yield. Some of our suggestions are relevant specifically to Nori, while others apply to how Carbon Yield engages with the underlying Nori system.

Positive Elements of the Process

As data managers, there were a few general Nori strengths that stood out to us. First, Nori has a great customer support team. They are responsive, patient, and knowledgeable, both about the software application and about technical farm management practice questions. Second, we found Nori to be agile and open to feedback, which is an important attribute in the evolving soil carbon markets space. Third, we feel Nori is well-positioned to build confidence in carbon markets. Carbon credits are currently available for sale on Nori's website, which sends a positive signal to prospective suppliers and buyers. In addition, farmers can express interest via the website (two of our data management cohort came to Carbon Yield in this way), and the grandfathering system currently rewards early adopters, incentivizing market growth to lay the foundation for future success and even greater carbon sequestration.

We particularly appreciated some of the features of the Nori application. Smart defaults are a big time-saver for the data they cover, the Soil Metrics model is grounded in rigorous science, and the model allows for multiple collaborators. Despite some bugs and ways in which it could be improved, the model overall has a positive user experience, and it is flexible to accommodate a wide range of farm scenarios.

As we learned the system, we found two strategies most helpful to facilitate our interaction with the Nori application. First, we used a separate spreadsheet or another organizational system to keep track of the data we received from farmers to ensure accuracy in the model-building process. Second, we found the combination of Google maps and geojson.io to be an efficient way to create field boundaries. Farmers could send us an address or pin drop of their field location and an accompanying map or screenshot with the field outline, and this was enough for us to create a geojson to upload to the Nori application.

Barriers to Successful Models

In this section, we summarize our data manager perspective of the main barriers to success related to the Nori carbon credit modeling system.

First, it is difficult for new data managers to fully understand the assumptions behind the Nori application. For example, we did not initially understand Nori's emphasis on carbon removals and which practices would or would not create carbon credits. It was not clear to us after our training that the application only models soil carbon sequestration and not avoided emissions from tractor tillage passes or other fuel usage. We also found the historic information section of the Details tab confusing. For example, what does the model do with pre-2000 information if the baseline modeling period is only ten years? This confusion led to lower motivation to enter the fields in the Details tab.

Second, we often felt a lack of confidence about the accuracy of our models. This is not to do with the underlying scientific model, but rather with our ability to properly populate it with farmer information. This stems partly from our direct experience of small variations in how we entered certain practices making a big difference to the outcome. For example, improperly entering cover crop dates due to a lack of understanding of the model constraints led to major inaccuracies in one grower's final NRT numbers. To compound this lack of confidence, there is potential for loss of accuracy in the data translation process between the data manager and grower. Farmers often have to approximate dates and gloss over year-to-year variations in practices to make the process simpler, and even though we feel it is important to review the completed spreadsheet with the grower to be sure it is accurate, we found this review overwhelming due to the size of the model and time constraints.

Third, we experienced frustration related to a few elements of the user experience. These are summarized in the table below.

Table C. List of user experience issues we encountered as data managers.

Nori Application Feature	User Experience Issue
Setting up smart defaults	When you finish entering the smart defaults for the historic time period, there is no button to "continue on and enter future period smart defaults". Instead, you get a warning that you will lose your data if you re-enter smart default and must know to navigate back to the original "Set up smart defaults" button.

Entering dates	To manually correct a year in the date field, you must enter DD/MM/YYYY rather than just YYYY.
Updating smart defaults in the inputs tab	It is not possible to update certain parts of the smart defaults in the inputs tab if you make a mistake or if something changes. This can lead to time-consuming manual updates. For example, you cannot enter N lbs/acre or update manure lbs/acre in the inputs tab.
Using the crop data layer	The Crop Data Layer information was pretty inaccurate for 2000-2011. For one farmer, it showed a ten-year monoculture of the 2011 crop going all the way back to 2000. This is misleading because it conveys the impression that the information for later crop years might also be inaccurate.
Entering specialty crops	Some crops are not easily included in the models (green beans, succulent peas, multi-species cover crop mixes).
Entering manure	It is challenging to enter manure. Many farmers did not have a C:N ratio, so we had to use the default value for the closest manure type, even when we had customized other values for that manure type. This is concerning for accuracy.
Scenario planning	Growers often want to have different versions of their project to reflect hypothetical future scenarios but doing so is a time-consuming and mostly manual process for the data manager.

Finally, as we spent time using the Nori application, we compiled a list of bugs in the system. We have shared this list with the Nori development team.

- Any entry of a date in the year 2021 line makes it auto-populate to 2022, resulting in time-consuming manual fixes.
- One farmer had to recreate their Nori account three times, which caused frustration.
- One project we created simply did not show up on Nori's end of the system. We had gone all the way through smart defaults and had to completely re-create the project.
- When you update the spreadsheet and rerun the model shortly thereafter, the app often displays green checkmarks for all fields and displays the alert saying the model run is completed even though the NRT numbers have not changed. Logging out and back in after hitting "run model" seems to solve the issue. When you return, the app either shows an alert that the model is still running or displays new numbers. If the app is still running, 30 to 45 minutes is usually long enough for it to complete. Nonetheless, the green checkmark display before receiving new numbers is confusing.
- In row 378, column I, the date harvested year does not auto-update to the following year for a cover crop.
- Column BE in the irrigation section does not auto-populate the year when you enter a DD/MM date.
- The drop-down options for historic crop practices in some counties did not include the practices the farmer specified. For example, land that was known to be irrigated annual crops had only an option for non-irrigated crops.

8 Discussion

8.1 Carbon Yield Farmer Engagement Process Recommendations

Carbon Yield is a growing company acting in a quickly-evolving market space. We recommend a few key actions that will support the company's continued success while also meeting the needs of farmers and increasing the amount of carbon removed from the atmosphere.

Streamline the Farmer Engagement Process

While Carbon Yield already excels in building trust with farmers and successfully guiding them through the soil carbon credit development process, we have a few ideas for how this process could be even better. Recognizing that many farmers have incomplete carbon markets knowledge and perhaps even initial skepticism, responsiveness and clarity are very important early on in the process.

We recommend that Carbon Yield further develop its standard farmer engagement process and incorporate goals for the amount of time between stages of the process. We suggest conducting the initial data interview and model build in quick sequence, perhaps pre-scheduling the farmer interview, data manager time to build the model, a Nori office hours session, and a follow-up review call with the farmer, all in the same week. This would increase accuracy and customer satisfaction by reducing delays. On a similar theme, we suggest setting a standard (if it is not already in place) to respond within one business day to all farmer emails, even if it is simply an acknowledgment of data receipt.

We also recommend developing a more specific set of introductory documents that help the farmer prepare for the data collection interview. This would consist of two parts. The first part would be a detailed list or form to fill in that shows all specific data points necessary for the Nori model. For example, "commercial fertilizer broadcast rate in lbs/acre". This form would also instruct the farmer to send field boundaries at least two days ahead of the call (so the data manager can enter them). This step would help minimize follow-up calls. The second part of the introductory materials would be an FAQ list, introductory webinar, or introductory video that anticipates and addresses the questions and concerns farmers may have. For example, this could explain what to expect during the model building and registration process, the timeline for any credit payments, and how the contract provisions allow for unexpected changes. As an example, Figure 6 lists the questions one grower asked after Carbon Yield presented their carbon model results. One risk to be aware of with this recommendation is that some farmers might be overwhelmed; prefacing in the introductory call that these materials are meant to save time down the line might be helpful.

Figure 6. Example questions from a grower after seeing their model results.

- What do the NRT units mean and what are the carbon prices in $/acre?
- How do the payments come over the 10 years?

- What is the difference between fields that had positive numbers and negative numbers historically?
- To move forward, what data would you need to verify and how long would it take? Could you get kicked out of the program if something changed? Would you have to pay back the credit income?
- Can we change practices in any way to improve the numbers on fields that don't look great?
- How would Carbon Yield get to the $65/ton price? What are the odds of getting closer to $65? If the carbon market prices go up a lot, could I get that higher price later?

Continue to Invest in Accuracy

Given the early stage of the agricultural carbon offset industry, there is, a risk that the carbon credits for projects somewhere in the marketplace will at some point be invalidated due to inaccuracy or data that shows carbon was not properly stored in soils. To combat this risk, we recommend taking action now to ensure that Carbon Yield credits are as accurate as possible and as high quality as possible. We suggest three strategies:

- First, though it may be costly, we recommend adding a soil sampling step to some or all projects to enhance proof of carbon removal. This would provide evidence for anyone who asks that the models and physical sample data align. On a similar note, it may be helpful to develop internal standards for additionality, leakage, and permanence, given that Nori's carbon measurement protocol, like most others currently available, is not as rigorous as some buyers might desire (Zelikova et al., 2021).
- Second, we recommend having a Nori Supply Account Manager review every model for unintentional errors before meeting with a grower. In one case, we met with a grower prematurely and had to correct the results we had presented, and we worry that this could cause a reputational issue when the farmer shares their experiences with other interested farmers.
- Third, to build trust amongst farmers that they are creating real impact, we recommend adopting a vetting process for buyers that selects only those companies that have high quality climate goals and who are making progress towards climate change mitigation in ways other than offset purchases. One farmer quote expressed why this would go a long way towards building motivation to participate, "And it goes back to these big corporations and big businesses trying to put something on their Twitter page or their Google front page that they're green or that they're doing this to help the environment when in fact they really aren't doing anything other than following a government mandate and throwing money at something to make themselves look better when in fact they themselves aren't doing a thing, they're really offsetting."

Improve the Feasibility Study

We recommend developing a more standardized scope of work for the feasibility study. This will save time, provide faster answers to farmers, and help ensure that feasibility studies can be provided free of charge for as long as this remains economically viable. Specifically, we recommend using only one field of a given practice set for the feasibility study. This will reduce the time invested before knowing the potential of the project, for both the data manager and farmer. We also recommend creating a set of estimates for hypothetical carbon credit amounts that a farmer could receive if they were to make certain practice changes. This may require significant time or monetary investment to create, but we feel it would help to more efficiently identify promising candidates.

These hypothetical scenarios could perhaps be compiled over time from successful projects: "a corn-soy-soy rotation in southern Michigan that adds cereal rye as a cover crop every year may accrue XX NRTs per acre per year, subject to local variation". Grower comments from our post-data management exit interviews support this idea. One farmer stated, "[I'm] wondering why there isn't just some drop-down menu that downloads into Python or whatever and kicks out 'you're not going to be a viable candidate or you'll be a really good candidate' ". Another grower suggested, "either having a smaller sample so that you can get a quicker answer [...] or having set examples of [...] if you [...] do this thing this is kind of where you'd be. [...] If you're in the Midwest and you know you farm this way you know you might be in this range for capturing carbon or or not".

On the technical side, we feel there is also an opportunity to automate much of the data entry involved in the data management process via scripts for common data sources such as Climate FieldView or farmer Farm Service Agency (FSA) portals. For example, a web crawler script or integration could pull common data from various services to be populated into the Nori spreadsheet, or an internal replica, to save the tedious work of data management. Integration would require permission from the data platform provider, so this may involve a collaborative process.

8.2 Nori Model-Building Process Recommendations

To respond to the barriers we identified while building carbon models in the Nori system, we recommend three potential actions that could improve the data manager role.

Data Manager Efficiency

We recommend that Nori consider the pros and cons of using internal and external data managers. While partnering with external data managers likely reduces costs and allows for greater flexibility and relationship-building with farmers, we wonder if internal Nori-employed data managers might be more efficient given the learning curve for new external data managers. As our Nori Supply Account Manager can attest, our team had to ask many, many questions to be successful.

Additional Support Resources for Data Managers

We recommend creating additional support resources for data managers. This would reduce the number of questions addressed to the Nori customer experience team and contribute to greater accuracy in the model-building process. We suggest expanding the help resources to include the following topics (if not already included):

Introductory Resources

- A video training module with an example dataset for new data managers to work through, including common issues they might encounter.
- A guide that explains the purpose of each data field in the model as it relates to carbon quantification. For example, "irrigation affects carbon sequestration in soils because increasing moisture levels accelerate decomposition, which releases carbon from the soil back into the atmosphere as carbon dioxide".
- A step-by-step guide for how to fix common errors received when running the model. The existing documentation lists errors but does not always provide solutions.

Resources about Data Entry Fields

- A living guide to "odd" or uncommon crops and how to classify them. For example, we had to contact Nori to understand how to model green beans, succulent peas, and multi-species cover crop mixes.
- A guide to how to enter winter wheat given that it partially spans two crop years and requires tillage events to be in a specific year. This took us a while to figure out with our Supply Account Manager.
- A guide to when to choose the no-tillage and/or no-till planting option.
- A guide on how to enter grazing, including how to correctly model a perennial pasture (we did a planting start date in 2000 and then no further plant or harvest dates for any year 2000 to 2030).
- A guide on how to enter haying. For example, the guide might say, "A farmer says the field is hayed once per year on July 5, with 80% residue removed. In this situation, the spreadsheet line would look like this: [example screenshot]".
- A guide that explains how to interpret the many types of fertilizer information that data managers might receive from farmers. Fertilizer questions were the source of many emails and clarification meetings. The guide could include an explanation of the option to input N as total lbs product plus % N versus lbs N. There is a small comment in the spreadsheet header for Total lbs applied, but we felt this was not enough for a new data manager. The guide could also specify that fertilizer dates must be in chronological order to save correction time later.
- A guide about manure interpretation. It could also include how to convert liquid to solid manure. For example, our Supply Account Manager shared this equation, "For liquids and slurries ((gallons of liquid or slurry applied/acre) X (8.34 lbs/gallon) X (% solids as a decimal) = lbs dry matter)/2000 = tons".
- A guide that explains the lime options and how to clarify which one is closest to a farmer's information. For example, the Nori support team provided information upon request about the percent magnesium in certain lime options.

Resources for Model Finalization

- A guide explaining when and how it is acceptable to copy and paste for efficiency. As a new data manager, it was difficult to know what was "okay" and what would break the model and cause more issues later, though we did eventually learn by trial and error.
- A more detailed guide to common errors and how to do a quality control check on a completed model. For example, instruct data managers to ensure that fertilizer dates are in chronological order and that cover crop plant dates do not overlap with cash crop harvest dates.

Enhancements to the User Experience

We observed how Nori's application and processes evolved even in the year we spent as data managers. We recommend that Nori consider the following new features as they might integrate with their existing product development plans.

Simplification

- Remove the yield field if it is unnecessary and does not affect the model. Alternatively, create guidance to explain why the yield is not important to the NRT outcomes. Some farmers were surprised at not being asked for yields.
- If it is possible to remove the 2000-2010 years since they are earlier than the ten years required to generate a baseline, it would save a lot of time and uncertainty not to have to locate and enter data for these years.
- Review the Turbo Tax and Lemonade (renter's insurance app) platforms and consider whether customized questions such as those in these apps could help to streamline the Nori process in any way. One farmer we interviewed suggested the following improvement, "anything you can do to simplify the model and make it stupid simple, not because production farms are stupid, but just because that's what Turbo Tax does."
- Convert the spreadsheet data to a visual format using a timeline to display information according to the growing season and facilitate data entry to match the temporal order of events.
- Integrate the Nori application with farmer FSA accounts so that crop, plant date, harvest date, and yield are automatically uploaded into the Nori tool once a farmer has given permission for the data manager to access their FSA account, assuming the USDA also allows this type of data-sharing. This was suggested by a grower in their post-data management interview. Consider integrating with other farm data platforms as well.

Carbon Impact Strategies

- Enhance the model so it can account for intercropping, such as cereal rye interseeded with corn prior to harvest.
- Enhance the model so it can account for agroforestry, such as incorporating the carbon impacts of the official USDA agroforestry conservation practices, for example, silvopasture establishment, alley cropping, or windbreaks. One grower had many ineligible pasture acres because they contained too many trees to fit the model.

Usability

- Add the ability to run the model for a single field to see whether a trouble-shooting fix is successful.
- Create a button to advance directly to "set up future smart defaults" after you complete the historic ones.
- Add smart defaults for the grazing section.
- Add the ability to update manure lbs/acre and fertilizer lbs/acre in the inputs tab after smart defaults have run.
- Create an option in the fertilizer field that allows you to select "enter N in lbs/acre", which would then eliminate the confusing unnecessary fields for % N and % ammonium that should be blank when you use the lbs/acre method.
- Make the borders of the spreadsheet immutable.
- Add the ability to copy a spreadsheet from one project to another. For one grower with more than 25 fields (and therefore two projects), we wanted to duplicate information from a field within one project to the second project, but it created weird borderlines, and we manually copied the information instead.

8.3 Marketing Analysis and Recommendations

8.3.1 Broad Qualitative Survey Findings

There were two priorities in pursuing a broad qualitative survey of Midwest farmers. The first was to ascertain any useful identifiers for Carbon Yield and Nori to better find potential customers interested in participating in carbon markets, while the second was to help better understand the perspectives of that target audience. After conducting a literature review, speaking with several farmers at various events, and meeting for extended one-on-one data management upload sessions with individual farmers, we as a project team had come to suspect several trends that spoke to those two priorities. The broad survey produced several interesting correlations that generally add support to these anecdotal insights. Some correlations contradicted our suspicions.

The vast majority of the 48 survey respondents were White and male, with just one White female respondent and one male Hispanic respondent. Figure 7 shows the ages of survey participants. Ages ranged from approximately 25 to 75, with an average age of around 50. These survey respondents also include those individual farmers from the data management cohort, who were asked to fill out the survey as part of the end of the project interview.

Some of the survey results were as we expected they would be, while some were not. For example, the size of operation in acres showed no significant correlation with any of the other questions. This may be because respondents were too clustered on the smaller end, but then the question was also designed so that respondents managing over 2,000 acres could not enter a specific number of acres, but instead just select one of two ranges (2,000 - 5,000 acres and 5,000+ acres). There were also clusters of related questions that seem to have been overly redundant in their design. The primary example is age and years of farm management experience. It seems most farmers interpreted the second question as general farm experience, including their childhood helping on the farm, as opposed to management experience since they often answered both of these questions with the same or similar number.

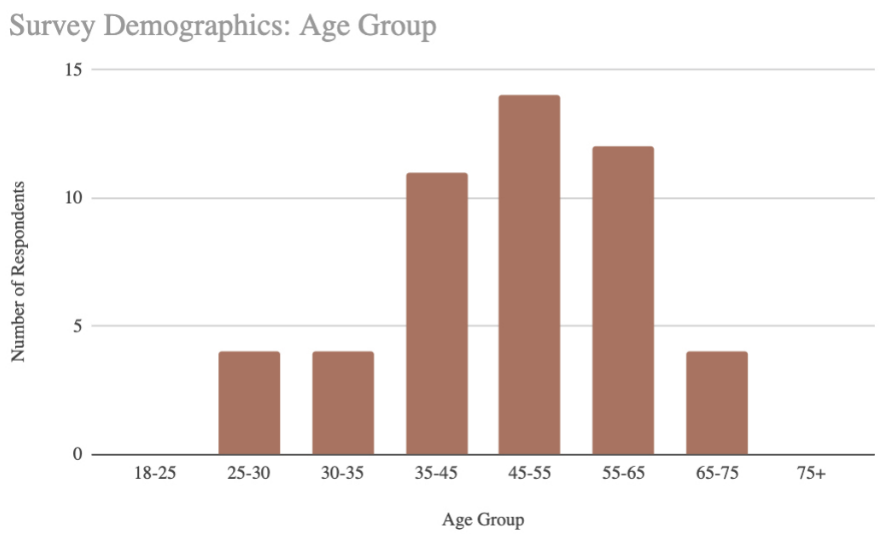


Figure 7. Ages of broad qualitative survey respondents.

The way the survey respondents managed information is also important to note. The majority of them relied primarily on either websites or social media for their information, as shown in Figure 8 below.

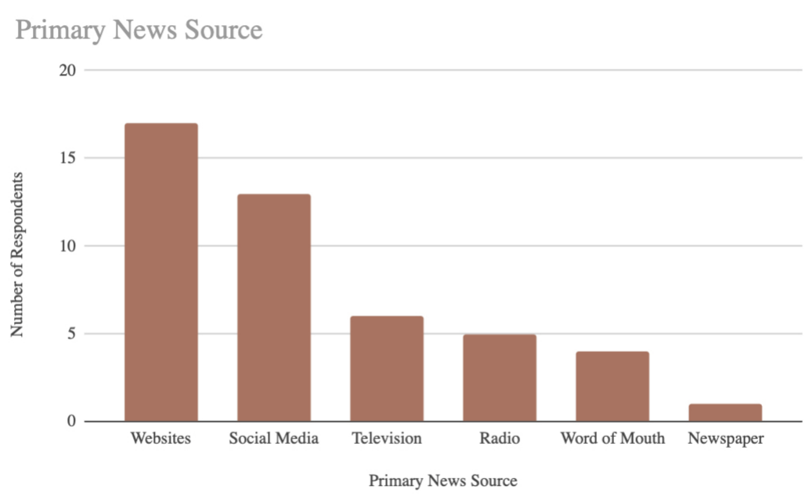


Figure 8. How survey respondents receive news.

Additionally, Figure 9 below shows the distribution of how the farmer respondents tended to store their own information when it came to farm management data. It is interesting to note that the more the farmer respondents had already digitized their data, and invested in outside support for maintaining it, the more likely they were to be interested in learning more about carbon markets, with a correlation of $r = 0.35$.

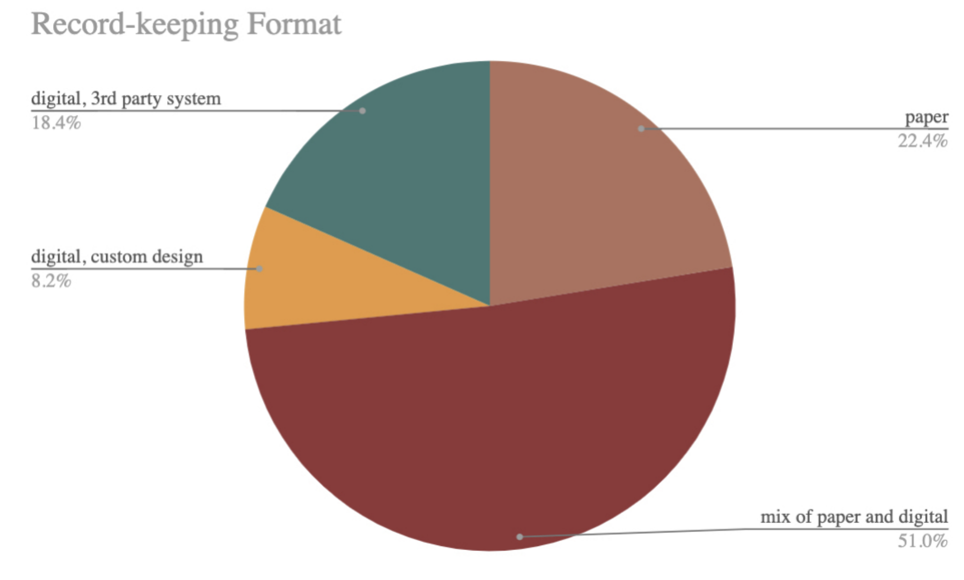


Figure 9. Three quarters of farmers surveyed still use some amount of paper records.

To address the first priority for this survey, there were three questions asked about carbon market participation, specifically respondents' preexisting knowledge, their interest in learning more, and their interest in participating directly in carbon markets. Essentially we considered those farmers who show high values on these three questions to be the target clientele because those are the minority of farmers already actively thinking about carbon credits and thus presumably more likely to be convinced to participate in carbon markets.

Identifying Key Potential Farmer Clients and their Perspectives

Perhaps the most anticipated correlation in identifying potential clients was that those farmers already engaged in greater soil-sequestering practices would be more interested in participation in carbon markets. The greatest commitments were in cover crops, followed by reduced tillage and no tillage practices, measured in terms of percentage of their stated acreage currently engaged in those practices. You can see from the histogram of survey respondents below (Figure 10) that engaging in cover cropping was the most popular regenerative practice amongst the survey respondents, both for practices adopted in the past four years, as well as intentions to implement in the next five years, while reduced tillage was the second most popular.

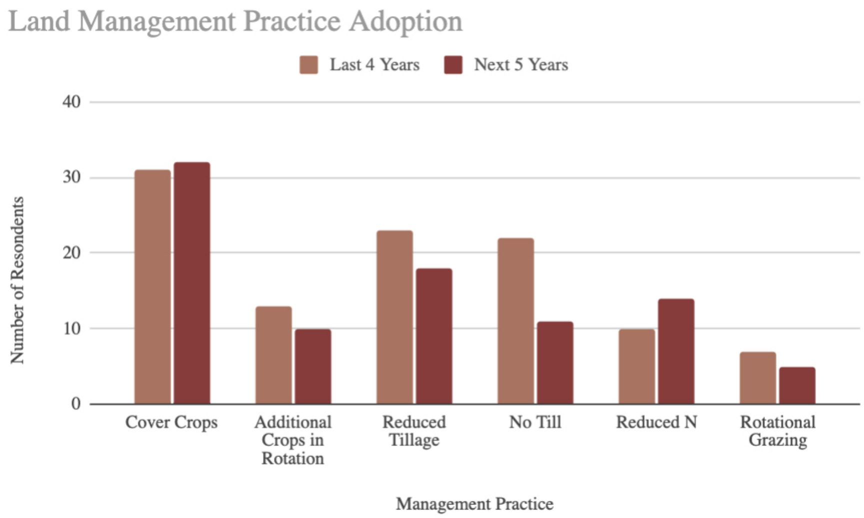


Figure 10. Distribution of land management practice adoption amongst survey respondents.

Those farmers with a higher percentage of their acreage already engaged in reduced tillage had the strongest tendency, with a r = 0.36 correlation value, to be interested in learning more about carbon markets. A pre-existing commitment to all of the other practices did not show any noteworthy correlation with an interest in learning more about carbon credits. This may suggest that engagement with cover crops is something of a first step, but that reduced tillage is when farmers begin to see value in carbon markets and are willing to seek out information.

Pre-existing knowledge of carbon markets was not noticeably correlated to any other variable. However, interest in learning more and interest in participating in carbon markets were both somewhat correlated, at r = 0.41 and r = 0.35, respectively, with participation in other ecosystem service payment programs. The more programs a respondent was enrolled in, the more interested they were in learning about and participating in carbon markets. The most common program respondents were already enrolled in was the Environmental Quality Incentives Program (EQIP), administered by the Natural Resource Conservation Service (NRCS) within the United States Department of Agriculture (USDA). Participation in EQIP specifically had an even stronger correlation with interest in learning more about carbon markets (r = 0.44) or interest in participating in carbon markets (r = 0.49) than the number of programs a farmer was enrolled in. Attempting to identify further details around which farmers tend to participate in these programs is difficult from the broad survey data itself since there are no noteworthy demographic correlations with these variables.

Beyond predicting interest in participating in carbon credit programs, the broad qualitative survey also helped expand our understanding of which priorities farmers might have that drive them to commit more of their land to greater soil-sequestering practices, such as no-till. For example, if the primary motivation for farming was profitability, farmers were noticeably more likely to report more acres already committed to no-till practices, with a correlation of r = 0.48. On the other hand, if the primary motivation was continuing a family legacy, there was a negative correlation, albeit not a very strong one, with acreage already committed to no-till, at an r = -0.28 value. Unfortunately, these two motivation groups did not correlate strongly with any other variables, and so again, it is difficult to further identify the potential customer for marketing purposes. However, this does suggest that farmers focusing on profitability may see real value in pursuing no-till more so than those farmers focused on maintaining a family legacy. This may be because a commitment to family legacy disincentivizes innovation, especially as a first-mover on something perceived as high risk, to prioritize the long-term viability of the farm, while also keeping a strong connection with the past.

In summary, the first two of the three most important insights from the broad survey results, when it comes to better understanding potential farmer clients for Carbon Yield and Nori, are that participation in other ecosystem service programs, especially EQIP, and a greater pre-existing commitment of acres in reduced tillage, are potentially key indicators for farmers being interested in participation in carbon markets. The final insight is that those farmers with a greater pre-existing commitment of acres in no-till, which can effectively be considered an extension of reduced tillage, tend to be those farmers prioritizing profitability over family legacy. The next challenge will be to figure out how to better identify individual profitability-motivated farmers participating in ecosystem service programs already engaged in practices like reduced tillage.

8.3.2 Marketing Recommendations

According to the USDA's most recent Census of Agriculture, there are approximately 2 million farms in the United States. As shown in Figure 11, over 40% of the nearly $200 billion in 2020's cash crop receipts were attributed to corn and soybeans (USDA). Of these, only a small portion is operating organically. According to the USDA's 2019 Organic Survey, only 17,000 of all farms were certified organic (USDA 2019).

Carbon markets are a relatively new concept, with the first trading starting in 1997 with the Kyoto Protocol. Over the last several decades, voluntary carbon markets have moved through three phases: (1) Early Market Formation and Innovation, (2) Consolidation and Strengthening, and (3) Mainstream (where we are today).

In recent years, carbon removal markets have become a hot topic within the agricultural world. Major industry titans, such as Bayer and Land O'Lakes, as well as newcomers such as Granular and IndigoAg, have started various carbon removal credit schemes.

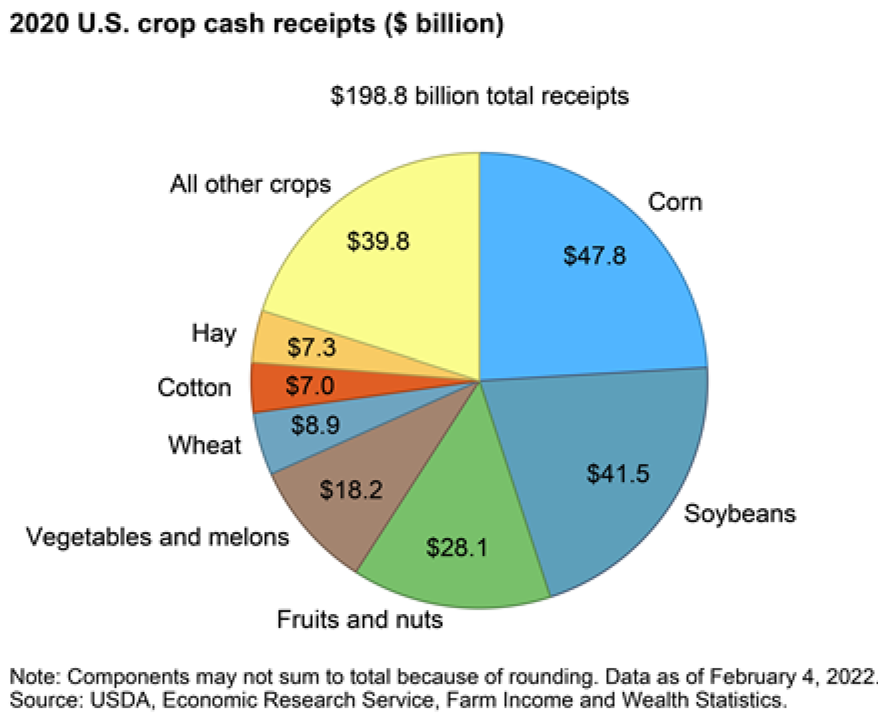


Figure 11. Corn and soybeans are the dominant crops grown in the US by cash receipts. (USDA)

Grower Recruitment

Through our research, we found that carbon market awareness was quite low, but that there was an appetite to learn more. One carbon market industry professional estimated that only 1% of farms were enrolled in carbon credit projects in 2021, while about one-third were actively assessing options and the rest were unaware. On a scale of 1 - 5, where 1 was low, we asked survey respondents to rank their personal knowledge of carbon credit registry programs as well as their interest in both participating in them and their enthusiasm to learn more. Figure 12 shows the results. Self-reported proficiency was low, averaging 2.0. However, the means of interest in participating in these markets or learning more about them saw a jump to 2.6 and 2.5, respectively.

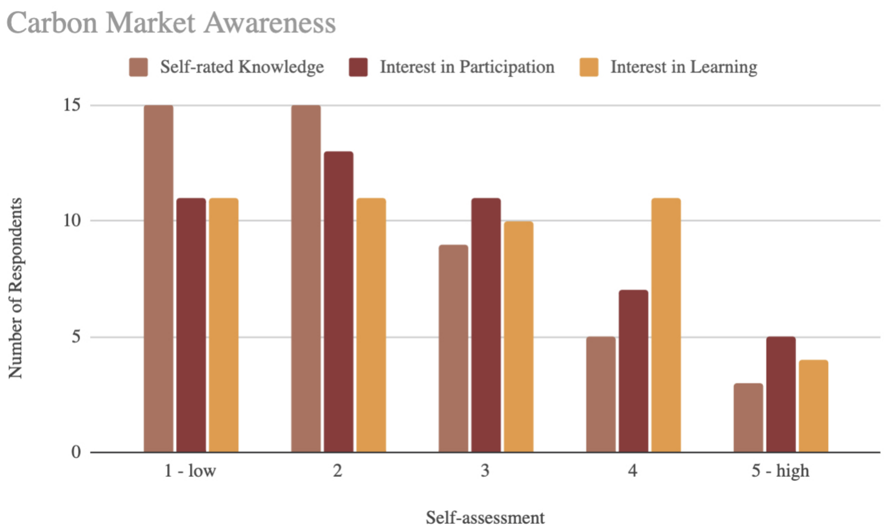


Figure 12. Knowledge of carbon markets and interest in participation.

While completing the data management process, student researchers logged that the farmers seemed to have a lot of follow up questions during the initial call. Our data management exit interview analysis highlighted a lack of knowledge as well. Nearly all those interviewed indicated that, while they were generally aware of carbon market programs before embarking on the feasibility study, they had very little knowledge of these inner workings of them. About half mentioned other programs they had heard from or were considering. Several either indicated or showed that they did not understand the drivers behind the markets, such as what the incentive was for the buyers of the credits.

The Post-Data Management Interview also highlighted a disconnect between the grower's understanding of the market and the realities of the drivers at play.

Farmer Concerns

Fairness - Trust was a theme that came up often throughout the research, primarily through both formal and informal conversatiofollow-uprs needed trust that the process was going to be fair. An organic dairy farmer in Michigan told us that "farmers are skeptical of the government. There's this pervasive feeling that stuff is pushed down the chain from the government, the public, and the processors." We saw some of this ourselves at the Great Lakes Crop Summit when an attendee asked a speaker on carbon markets a question about the cut that farmers take compared to everyone else. There is a sense of wanting to get a fair deal.

The same dairy farmer highlighted influencers in the industry: "peer networks are the way to do this. Farmer-to-farmer, a handful of agronomists and agribusiness". She also highlighted that agricultural extension offices are perceived as helping especially the smaller businesses. This statement is supported by some of the data from the qualitative survey. When asked "Which type of organization would you most likely turn to for more information about carbon credit programs at this time?", approximately half mentioned either an input supplier, such as their "seed guy" or the agricultural office, while the remainder would defer to an organization with more expertise in the industry (Figure 13).

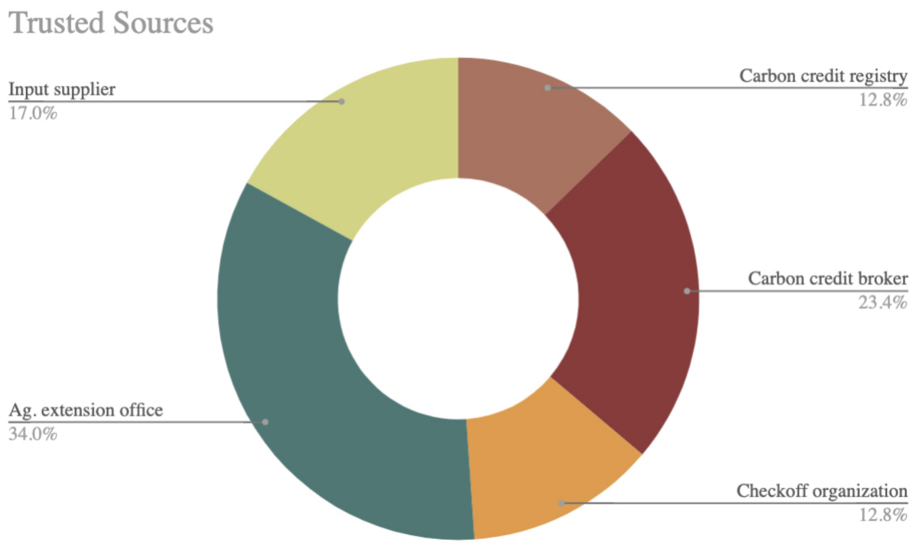


Figure 13. Most trusted sources for carbon credit market information.

Recommendations to mitigate concerns about fairness:

- Continue to be fully transparent and frank throughout the process. Farmers responded positively to this. One option would be to highlight the firm's independence from a corporate option that may have ulterior motives.
- Identify involved stakeholders and their cut. Share who is involved in this ecosystem and where the farmer financially sits.
- Word-of-mouth recommendations from clients will be particularly helpful in this industry. Any artifacts, such as quotes, videos, or relationships with agricultural offices, will be beneficial in building credibility.
- The majority of data management work can only be completed seasonally at times when the farmer is not seeding or harvesting. Hire tech-savvy farmers in the off-season to do data management as an additional way to build trust and equity.

Flexibility - Carbon removal tokens come in all sorts of formats. Through our research, we saw contracts of varying lengths and acreage requirements. The most common contracts were 1-year, 5-year, and 10-year. Given the seasonality of the industry, farmers tend to think yearly. The longer the contract means less flexibility to manage the land as things change. One farmer, who chose not to proceed with a project, stated "I mean 10 years of cover crops might be a long time to commit yourself, that's what I'm afraid of".

Farmers plan on a seasonal basis. Innovators and early adopters are especially prone to being experimental, so a 10-year contract might be daunting. While there may be limited opportunity to adjust contracts, we recommend:

- Identifying for the farmer which attributes, such as length or number of plots that are adjustable, are negotiable and how various registries compare.
- Share advantages to registering now over later.

Security - On several occasions, we heard the refrain from farmers that carbon markets are "the wild wild west". This attitude that carbon markets are nascent was further seen in our data management exit interviews. Both the regenerative agricultural movement and agricultural offset programs are only a few years old. As farmers switch from the practices they are familiar with, reducing nitrogen application or going no-till, they risk a bad season and poor yields. There is an inherent risk in switching to a new practice. There is also a factor of timing. Due to the current variability in the price for credits, some farmers may wait to sign up for a registry. Given that these markets are so new and the awareness is still quite low, there is an opportunity to educate farmers on the process and players involved in this market.

Another aspect of security is the belief that data will be kept private. Through the grower recruitment process, we did note a few growers who were resistant to sharing their data. For example, in an initial call with a dairy and row crop farmer, the questions were centered on ensuring the farmer's name and information would not be published.

Recommendation on mitigating concerns about security:

- Showcase studies of how various adding specific practices have changed payout on similar land.
- Lock in farmer prices over the length of the contract and provide financing options to de-risk income variability.
- Guarantee that data will be used only for model assessment.

Ease - The final primary concern we heard from farmers was about the ease of the process. While the majority of our data management cohort stated they had records for all the years of data management, collecting it all often took many hours and was a bit convoluted. A key here will be to highlight the added value that the data management process provides. Our recommendations for making the process easier are:

- Show that the data management process is valuable as it provides an opportunity to review historical practices and plan for the future
- Make carbon markets easy to comprehend. Namely, peak the same language to ease comprehension, i.e. $ / acre per practice

8.3.3 Ideal Carbon Credit Price Recommendation

The goal of our pricing analysis is to recommend an ideal target price in $/ton that Carbon Yield should negotiate with offset buyers. To arrive at this recommendation, we used both a cost-based and competitive-based pricing strategy. The sources compiled for this analysis are referenced by number within the tables in this section. Appendix 4 provides a key to the numbered sources. This section first presents our recommended price target and then provides evidence to support this conclusion. Specifically, we provide a summary of available case studies on the net income impacts of shifting to practices that sequester carbon, including cover crops and reduced tillage/no-tillage, as well as a summary of currently available cost-share programs and carbon offset payments. In aggregate, these sources demonstrate the current costs and revenues a farmer might consider when deciding whether or not to pursue a soil carbon offset opportunity. To conclude our analysis, we compare these benchmarks to data from our data management cohort and broad survey participants about the profit that would effectively incentivize them to move forward with a soil carbon offset project and then discuss these findings concerning the pricing currently offered by Carbon Yield. A key goal of our analysis is to represent the farmer perspective when considering the ideal price. We believe meeting the needs of farmers is the most effective way to catalyze greater soil carbon sequestration and thereby maximize climate mitigation impact.

Recommendation

Based on the information to follow, we recommend that Carbon Yield continue to seek the highest prices possible for high-quality credits, but use $50/acre desired farmer profit as a guideline for determining pricing and profit margins for projects with varying carbon sequestration rates and sizes. We find that $100/ton is a very justifiable price to charge to compensate farmers for the true value of their practices changes while providing Carbon Yield a viable revenue stream to continue developing projects.

Scope of the Analysis

A full study of the costs and revenues for corn, soybean, and wheat farmers is beyond the scope of this report. We focus on the incremental costs and returns associated with changes in management practices that a farmer might undertake to qualify for soil carbon credit payments. However, we provide a few benchmarks for total net income, costs, and revenues for typical row crops in Tables D and E. This is not meant to be a comprehensive review, and there may be other sources with more representative “typical” costs. Nonetheless, we include this information to ground our analysis with a general scale of reference for the financial metrics a farmer may be compared to when making carbon market decisions.

Most numbers in this analysis are in $/acre, which is the unit we found to be overwhelmingly preferred by farmers. We present our final recommendation in both $/acre and $/ton units.

Typical Corn and Soybean Financial Benchmarks

Table D provides a list of example net incomes, or equivalently, net returns. These represent total revenue less total costs to grow the specified crop. Table E provides a list of example total revenues and total costs. Net incomes for conventional corn and soybeans are in the range of -$1 to $124/acre for farms in Michigan, based on samples of 25 to 26 farms. A study by the Soil Health Partnership reported net returns of $267 to $363/acre for corn and $123 to $251/acre for soybeans. These numbers are significantly higher than the first reference point, which could be due to the low sample size of the second study or to differences in methodology. In an example, crop budgeting tool for farmers, Iowa State Extension and Outreach lists $954/acre net income at $9.80/bushel for organic corn and $373/acre net income at $19.90/bushel for cleaned organic soybeans. Overall, these net income numbers, along with the total revenue and total cost numbers, are an order of magnitude higher than the carbon prices and change in net income associated with shifting to more regenerative practices.

Table D.

Example Total Net Income (Net Return) Data Points, for Reference

Description of Benchmark	$/Acre	Sample Size	Type of Benchmark
Corn			
Net return per acre, corn, Michigan (MI)	-$1.00	26 farms	University of Minnesota Farm Financial Database (17)
Net return per acre, with govt payments, corn, MI	$77.41	26 farms	University of Minnesota Farm Financial Database (17)
Net returns for corn for experienced cover crop adopters (more than 5 years of experience)	$362.60	1-7 farms	Soil Health Partnership Study (10)
Net returns for corn for cover crop adopters with five or fewer years of experience	$266.72	1-7 farms	Soil Health Partnership Study (10)
Net returns for conventional tillage corn with no cover crops	$324.48	1-7 farms	Soil Health Partnership Study (10)
Organic Corn			
Net returns, Iowa organic corn @$9.80/bushel	$954.30	1 farm	Iowa State University Extension and Outreach Publication (24)
Soybeans			
Net return per acre, soy MI	$44.66	25 farms	University of Minnesota Farm Financial Database (17)
Net return per acre, soy MI, with govt payments	$124.33	25 farms	University of Minnesota Farm Financial Database (17)
Net returns soybeans experienced cover crop adopters	$250.61	1-7 farms	Soil Health Partnership Study (10)
Net returns soybeans inexperienced cover crop adopters	$123.29	1-7 farms	Soil Health Partnership Study (10)
Net returns conventional tillage soybean no cover crops	$215.70	1-7 farms	Soil Health Partnership Study (10)
Organic Soybeans			
Net returns, Iowa organic soy @$19.90/bushel, cleaned	$372.92	1 farm	Iowa State University Extension and Outreach Publication (24)

Table E.

Description of Benchmark	$/Acre	Sample Size	Type of Benchmark
Revenue, Corn			
Corn revenues range across all farms	$728-781	1-7 farms	Soil Health Partnership Study (10)
Revenue, Soybeans			
Soybean revenues range across all farms	$456-527	1-7 farms	Soil Health Partnership Study (10)
Cost, Corn			
Total direct expenses, corn, Michigan (MI)	-$538.51	26 farms	University of Minnesota Farm Financial Database (17)
Total direct and overhead expenses, corn, MI	-$653.79	26 farms	University of Minnesota Farm Financial Database (17)
Cost, Soybeans			
Total direct expenses, soy, MI	-$371.89	25 farms	University of Minnesota Farm Financial Database (17)
Total direct and overhead expenses, soy, MI	-$455.09	25 farms	University of Minnesota Farm Financial Database (17)

Throughout this analysis, net income is influenced by the $/bushel price of each crop. For reference, Table F below shows the 2021 average conventional grain prices for Michigan, as reported by the National Agricultural Statistics Service.

Table F.

National Agricultural Statistics Service - 2021 Average Conventional Grain Prices for Michigan	
Wheat per Bushel	$6.20
Corn per Bushel	$5.35
Soybeans per Bushel	$13.40

Summary of Financials of Regenerative Practice Changes

We focused our research for this section on two of the regenerative practice changes that occurred most frequently amongst our data management cohort: cover crop adoption and shifts to reduced tillage or no-till management practices. A future extension of this research might be to include financial considerations related to rotational grazing or more diverse crop rotations, which were also strategies amongst our growers.

Cover Crop Net Income Benchmarks

The tables below summarize both positive (Table G) and negative (Table H) net incomes associated with adopting cover crops, as reported by case studies in the peer-reviewed literature and from industry sources. Later tables will focus on changes to tillage. There was a large amount of variation in reported net incomes. Positive net income data points ranged from just over $0 to $58/acre, while negative reported numbers ranged from -$15 to -$64/acre.

One of the sources may be a useful tool to share with farmers. The Iowa Soybean Association Cover Crop Economic Simulator, developed by a Conservation Innovation Grant from the USDA Natural Resources Conservation Service, and available online for farmer use, is an interactive tool that allows farmers to choose their cover crop variety and various potential revenue and cost factors. The tool then reports a range of incremental net income projections by $/bushel cash crop price and cash crop yield.

Table G.

Examples of Impacts to Net Income due to Cover Crop Adoption, Positive Impact

Description of Benchmark	$/Acre (-) = cost; (+) = revenue or reduced expense)	Sample Size	Type of Benchmark
Net income impact to add cover crops, not including $25 cost share, 2019-2020	$16.78	1 farm	Case Study: Cover Crop Grazing (2)[1]
Net income impact, cover crops alone (experienced cover cropper= 6 years of cereal rye), 2018	$28.66	1 farm	American Farmland Trust Case Study: Ifft Yorkshires Farm, IL (4)
Net income per acre from cover crops (includes benefit in drought years, SOC, erosion reduction, fertilizer reduction), 2017	$57.76	1 farm	Case Study: Successful Farming Magazine, Rulon Enterprises (13)[2]
Net return, normal weather, corn, for 3 years cover cropping, 2012-2016	$1.42	2000 farmers, extension data sources	USDA Sustainable Agriculture Research and Education (SARE) (21)
Net return, normal weather, corn, for 5 years cover cropping, 2012-2016	$17.90	2000 farmers, extension data sources	USDA Sustainable Agriculture Research and Education (SARE) (21)
Net return, normal weather, soy, for 3 years cover cropping, 2012-2016	$0.42	2000 farmers, extension data sources	USDA Sustainable Agriculture Research and Education (SARE) (21)
Net return, normal weather, soy, for 5 years cover cropping, 2012-2016	$10.18	2000 farmers, extension data sources	USDA Sustainable Agriculture Research and Education (SARE) (21)
Net income from cover crops followed by corn, terminated with herbicide, including grazing revenue/savings and cost share, 2015	$8.59	440 respondents	Peer-Reviewed Study (16)[3]
Net income from cover crops followed by soy, terminated with herbicide, including grazing revenue/savings and cost share, 2015	$14.25	440 respondents	Peer-Reviewed Study (16)[3]

Assumptions:

1 This is from a case study of cover crop grazing. This estimate ignores the grazing costs and reports only the costs independent of grazing. The cover crop establishment costs were split between the grazing farmer and the cover crop farmer, so this estimate doubles them.

2 Farmer has 14 years of cover crop experience. Corn price was $4/bushel. Soy prices was $10/bushel.

3 Half of respondents had less than 5 years of cover crop experience and half had more than five years experience.

Table H.

Examples of Impacts to Net Income due to Cover Crop Adoption, Negative Impact

Description of Benchmark	$/Acre (-) = cost; (+) = revenue or reduced expense)	Sample Size	Type of Benchmark
Net income from cover crops followed by soy, terminated with herbicide, no grazing but with cost share, 2015	-$18.29	440 respondents	Peer-Reviewed Study (16)[1]
Net income from cover crops followed by corn, terminated with herbicide, no grazing but with cost share	-$26.41	440 respondents	Peer-Reviewed Study (16)[2]
Net income from cover crops followed by corn, terminated with herbicide, no grazing or cost share	-$48.82	440 respondents	Peer-Reviewed Study (16)[3]
Net income from cover crops followed by soy, terminated with herbicide, no grazing or cost share	-$38.42	440 respondents	Peer-Reviewed Study (16)[4]
Cost to shift to cover crops if already no-till, 2016	-$25.60	n/a; based on state extension service data	University of Illinois Farm Economics Article (14)
Cost to shift to cover crops if minimum till, 2016	-$15.10	n/a; based on state extension service data	University of Illinois Farm Economics Article (14)
Median net change in profits, cover crops, with cost share, 2015	-$64.06	15 farmers	Peer-Reviewed Study (15)[2]
Net return, normal weather, corn, for 1 year cover cropping, 2012-2016	-$31.36	2000 farmers, extension data sources	USDA Sustainable Agriculture Research and Education (SARE) (21)
Net return, normal weather, soy, for 1 year cover cropping, 2012-2016	-$23.55	2000 farmers, extension data sources	USDA Sustainable Agriculture Research and Education (SARE) (21)
Cereal rye cost to establish (includes seed $10, planting $15, labor .125 hrs * $14.75/hr, termination cost $18, herbicide savings $5, tillage savings $16.7)	-$39.84	n/a	Iowa Soybean Association Cover Crop Economic Simulator (27)
Net income impact, corn after cereal rye cover crop, including reduced expenses	-$25.97	n/a	Iowa Soybean Association Cover Crop Economic Simulator (27)

Assumptions:
1 Half of respondents had less than 5 years of cover crop experience and half had more than five years experience.
2 The 15 farmers had 4-30 years of cover crop experience and planted mostly cereal rye with herbicide termination. The study did not consider equipment costs. Range -$164 to +$163. Cost share payments were on average $29.

Cover Crop Revenue Benchmarks

Tables I, J, and K below report specific impacts to revenue associated with cover crops. Grazing contributes significantly to cover crop revenue ($32-$83/acre) through offset cost of feed, but not all farms have access to livestock or to the infrastructure (fencing, water sources) required to incorporate grazing. An area for further research would also be how grazing cover crops affects their carbon sequestration function.

Multiple sources reported positive impacts to yield as a result of cover crops, ranging from $13-$44/acre, though these numbers depend on annual $/bushel cash crop prices. The Sustainable Agriculture Research and Education (SARE) Cover Crop Economics study reported yield impacts in percentages, which can easily be translated to revenue for a given $/bushel price. This study was unique in that it compared cover crop yield impacts for one, three, and five years of consecutive cover crop usage. The report finds that positive yield impacts increase as years of consecutive cover crop usage increase, with yield increases rising from 0.5% to 3% for corn and from 2% to 5% for soybeans between one and five years of consecutive usage (SARE, 2019). This finding emphasizes the importance of working with farmers to present and discuss the long-term net income considerations for carbon credit payments.

The SARE report also emphasizes situations in which farmers may see increased profitability for cover crops. The subset of this list most relevant to soil carbon markets includes situations where farmers: (1) face severe herbicide-resistant weeds, (2) have access to grazing income, (3) have soil compaction challenges, (4) are also transitioning to no-till, or (5) are likely to face drought conditions. For example, in a drought year (2012), cover crops improved yields by 10% for corn and 12% for soybeans compared to non-cover cropped acres (SARE, 2019). Cover crops may therefore be particularly attractive to farmers in drought-prone areas, or in other areas of high cover crop profit potential. One way to identify candidate growers for soil carbon offset opportunities might be to find locations where farmers face the above challenges more than in other areas, and to target recruitment efforts accordingly.

Table I.

Examples of Cover Crop Revenues and Decreased Expenses, Grazing

Description of Benchmark	$/Acre (-) = cost; (+) = revenue or reduced expense)	Sample Size	Type of Benchmark
Animal feed savings from grazing cover crops, followed by corn, 2015	$35.00	440 respondents	Peer-Reviewed Study (16)[1]
Animal feed savings from grazing cover crops, followed by soy, 2015	$32.54	440 respondents	Peer-Reviewed Study (16)[1]
Cover crop grazing income, fall	$32.41	n/a	Iowa Soybean Association Cover Crop Economic Simulator (27)
Cover crop grazing income, spring	$83.33	n/a	Iowa Soybean Association Cover Crop Economic Simulator (27)

Assumptions:
1 Half of respondents had less than 5 years of cover crop experience and half had more than five years experience.

Table J.

Examples of Cover Crop Revenues and Decreased Expenses, Yield Impacts

Description of Benchmark	$/Acre or Percentage Impact (-) = cost; (+) = revenue or reduced expense)	Sample Size	Type of Benchmark
Increased soybean yield due to cover crops (5 bu/ac) @ $8.60/bu, 2018	$43.86	1 farm	American Farmland Trust Case Study: Ifft Yorkshires Farm, IL (4)
Yield increase due to cover crops ($16/acre soybeans, $10/acre corn, avg at right), 2018	$12.95	1 farm	American Farmland Trust Case Study: Thordyke Farms, IL (7)
Median revenue increase, cover crops, 2015	$37.07	15 farmers	Peer-Reviewed Study (15)[1]
Yield increase in corn due to cover crops 2013-2016	1.3% to 3.1%	500 farmers	USDA Sustainable Agriculture Research and Education (SARE) (21)
Yield increase in soy due to cover crops 2013-2016	2.8% to 4.3%	500 farmers	USDA Sustainable Agriculture Research and Education (SARE) (21)
Yield difference over non-cover cropped in 2012 drought year, corn	9.60%	500 farmers	USDA Sustainable Agriculture Research and Education (SARE) (21)
Yield difference over non-cover cropped in 2012 drought year, soy	11.60%	500 farmers	USDA Sustainable Agriculture Research and Education (SARE) (21)
Percent increase in corn yield after 5 years consecutive cover crop use	3%	500 farmers	USDA Sustainable Agriculture Research and Education (SARE) (21)
Percent increase in soy yield after 5 years consecutive cover crop use	4.96%	500 farmers	USDA Sustainable Agriculture Research and Education (SARE) (21)
Percent increase in corn yield after 3 years consecutive cover crop use	1.76%	500 farmers	USDA Sustainable Agriculture Research and Education (SARE) (21)
Percent increase in soy yield after 3 years consecutive cover crop use	3.54%	500 farmers	USDA Sustainable Agriculture Research and Education (SARE) (21)
Percent increase in corn yield after 1 year cover crop use	0.52%	500 farmers	USDA Sustainable Agriculture Research and Education (SARE) (21)
Percent increase in soy yield after 1 year cover crop use	2.12%	500 farmers	USDA Sustainable Agriculture Research and Education (SARE) (21)

Assumptions:
1 The 15 farmers had 4-30 years cover crop experience and mostly planted cereal rye with herbicide termination. No equipment costs included.

Additional small revenue benefits (in the form of reduced expenses) occur due to insurance, herbicide, or fertilizer cost reductions.

Table K.

Examples of Cover Crop Revenues and Decreased Expenses, Other

Description of Benchmark	$/Acre (-) = cost; (+) = revenue or reduced expense)	Sample Size	Type of Benchmark
Crop insurance premium discount due to cover crops, 2019-2020	$5.00	1 farm	Case Study: Cover Crop Grazing (2)
Reduced herbicide expense due to cover crops, 2019-2020	$20.57	1 farm	Case Study: Cover Crop Grazing (2)
Herbicide savings due to cover crop weed control, 2018	$14.80	1 farm	American Farmland Trust Case Study: Ifft Yorkshires Farm, IL (4)
Nutrient reduction (20% P&K) due to cover crops, 2018	$19.83	1 farm	American Farmland Trust Case Study: Ifft Yorkshires Farm, IL (4)

A larger, but more difficult to quantify potential revenue and/or reduced expense source is on-farm benefits to ecosystem services or operating costs. Table L reports an itemized list of these benefits, as incorporated into the Iowa Soybean Association's Cover Crop Economic Simulator. According to this tool, a farmer could achieve a total benefit of $52.92/acre for the combination of reduced erosion (by 0.1 to 1.7 tons of soil/acre), improved soil health/organic matter, improved water retention, improved early-season trafficability of the field in a wet year, reduced insurance requirements, and reduced commercial fertilizer need (ISA, 2022).

Table L.

Examples of Cover Crop Revenues and Decreased Expenses, Ecosystem Services and Other On-Farm Benefits

Description of Benchmark	$/Acre (-) = cost; (+) = revenue or reduced expense)	Sample Size	Type of Benchmark
Reduced erosion .1 to 1.7 tons/acre	$3.87	n/a	Iowa Soybean Association Cover Crop Economic Simulator (27)
Improved soil health/organic matter	$5.00	n/a	Iowa Soybean Association Cover Crop Economic Simulator (27)
Improved water retention	$5.00	n/a	Iowa Soybean Association Cover Crop Economic Simulator (27)
Early season trafficability in a wet year	$5.00	n/a	Iowa Soybean Association Cover Crop Economic Simulator (27)
Reduced insurance requirement	$10.50	n/a	Iowa Soybean Association Cover Crop Economic Simulator (27)
Reduced commercial fertilizer need	$23.55	n/a	Iowa Soybean Association Cover Crop Economic Simulator (27)

Cover Crop Cost Benchmarks

Numerous case studies reported benchmarks for cover crop costs. We sorted the data in Tables M, N, O, P, and Q into establishment costs (benchmarks that included seed, seeding, and any other establishment costs in one number) and itemized costs for seed, seeding, and other costs. Total establishment cost benchmarks ranged from $15 to $78/acre, depending on the seed variety and planting method. Total costs including termination ranged from $17 to $101. As stand-alone items, seed cost benchmarks ranged from $5 to $50/acre, seeding ranged from $10 to $49/acre, and other costs (termination and time spent learning about cover crops) ranged from $2 to $6/acre. To provide an additional data point, one grower in our data management cohort stated that they would expect to pay $30-40/acre for cover crops if drilling was the planting method. This aligns with the ranges reported above.

Table M.

Examples of Cover Crop Establishment Costs

Description of Benchmark	$/Acre (-) = cost; (+) = revenue or reduced expense)	Sample Size	Type of Benchmark (Source Number)
Cover crop establishment (oats (38 lb/ac), cereal rye (56 lb/ac) and radish (2 lb/ac) in 2019 and 2020)	-$37.85	1 farm	Case Study: Cover Crop Grazing (2)[1]
Cover crop establishment costs (cereal rye after corn, ahead of soy, 6 years of the practice), 2018	-$30.00	1 farm	American Farmland Trust Case Study: Ifft Yorkshires Farm, IL (4)
Cover crop costs for corn and soy (barley and hairy vetch mix with twin row planter), 2018	-$27.00	1 farm	American Farmland Trust Case Study: Homewood Farms, OH (5)
Cover crop costs (multi-species mixes specific to corn and soy - roller crimper to terminate and planted green), 2018	-$49.50	1 farm	American Farmland Trust Case Study: MadMax Farms, OH (6)
Cover crop costs for corn and soy rotation (cereal rye, Hagie sprayer), 2018	-$39.00	1 farm	American Farmland Trust Case Study: Thordyke Farms, IL (7)
Median cover crop seed and seeding cost, 2012-2016	-$37.00	2000 farmers	USDA Sustainable Agriculture Research and Education (SARE) (21)
Variation in cover crop seed, seeding, and termination cost, depending on seed variety, seeding and termination methods, 2012-2016	-$15 to -$78	unknown	USDA Sustainable Agriculture Research and Education (SARE) (21)
Cereal rye/oats cost to establish	-$41.84	n/a	Iowa Soybean Association Cover Crop Economic Simulator (27)
Winter wheat cost to establish	-$38.84	n/a	Iowa Soybean Association Cover Crop Economic Simulator (27)
Cereal rye/root vegetable cost to establish	-$42.84	n/a	Iowa Soybean Association Cover Crop Economic Simulator (27)

Assumptions:
1 This is from a case study of cover crop grazing. This estimate ignores the grazing costs and reports only the costs independent of grazing. The cover crop establishment costs were split between the grazing farmer and the cover crop farmer, so this estimate doubles them.

Table N.

Examples of Cover Crop Costs, Total

Description of Benchmark	$/Acre (-) = cost; (+) = revenue or reduced expense)	Sample Size	Type of Benchmark
Median total cost increase, cover crops, 2015	-$101.13	15 farmers	Peer-Reviewed Study (15)[1]
Ohio, legume cover crop seed+planting+termination, 2011	-$31 to -$99	unknown	Ohio State University Extension Presentation (23)
Ohio, grass cover crop seed+planting+termination, 2011	-$17 to -$49	unknown	Ohio State University Extension Presentation (23)

Assumptions:
1 The 15 farmers had 4-30 years cover crop experience and mostly planted cereal rye with herbicide termination. No equipment costs included.

Table O.

Examples of Cover Crop Seed Costs

Description of Benchmark	$/Acre (-) = cost; (+) = revenue or reduced expense)	Sample Size	Type of Benchmark
Range of cover crop seed costs amongst 7 farms with 3-10 years of cover crop experience	-$7 to -$25.07	7 farms	Soil Health Partnership Study (10)
Median seed cost, 2019	-$15.00	82 respondents	Soil Health Partnership Survey (11)[1]
Median seed cost, cover crops, 2015	-$44.48	15 farmers	Peer-Reviewed Study (15)[2]
Median cover crop seed cost, 2012	-$25.00	759 farmers	USDA Sustainable Agriculture Research and Education (SARE) (21)
Cover crop seeds, large conventional farms using single species, low cost, 2012-2016	-$5 to -$10	unknown	USDA Sustainable Agriculture Research and Education (SARE) (21)
Cover crop seeds, organic or veggie growers using mixes, 2012-2016	up to -$50	unknown	USDA Sustainable Agriculture Research and Education (SARE) (21)

Assumptions:
1 Respondents from IA, IL, IN, KS, MN, MO, NE, OH, SD, WI, MI; Note: $14 for single species; $16.66 for two, $22.50 for 3+ spp mixes
2 The 15 farmers had 4-30 years cover crop experience and mostly planted cereal rye with herbicide termination. No equipment costs included.

Table P.

Examples of Cover Crop Seeding Costs

Description of Benchmark	$/Acre (-) = cost; (+) = revenue or reduced expense)	Sample Size	Type of Benchmark
Range of cover crop seeding costs amongst same farms (aerial, drilled, or broadcast)	-$10 to -$20	7 farms	Soil Health Partnership Study (10)
Median planting cost, 2019	-$12.00	82 respondents	Soil Health Partnership Survey (11)[1]
Median planting cost, cover crops, 2015	-$49.42	15 farmers	Peer-Reviewed Study (15)[2]

Assumptions:
1 Respondents from IA, IL, IN, KS, MN, MO, NE, OH, SD, WI, MI; Note: $14 for single species; $16.66 for two, $22.50 for 3+ spp mixes
2 The 15 farmers had 4-30 years cover crop experience and mostly planted cereal rye with herbicide termination. No equipment costs included.

Table Q.

Examples of Cover Crop Costs (Other)

Description of Benchmark	$/Acre (-) = cost; (+) = revenue or reduced expense)	Sample Size	Type of Benchmark
Cover crop termination, 2019-2020	-$4.50	1 farm	Case Study: Cover Crop Grazing (2)[1]
Cover crop learning activities, corn and soy rotation, 2018	-$5.86	1 farm	American Farmland Trust Case Study: MadMax Farms, OH (6)
Cover crop learning activities, corn and soy rotation, 2018	-$1.74	1 farm	American Farmland Trust Case Study: Thordyke Farms, IL (7)

Assumptions:
1 This is from a case study of cover crop grazing. This estimate ignores the grazing costs and reports only the costs independent of grazing. The cover crop establishment costs were split between the grazing farmer and the cover crop farmer, so this estimate doubles them.

Reduced Tillage Net Income, Revenue, and Cost Benchmarks

Table R summarizes our research on the net income, revenue, and cost benchmarks associated with shifts to reduced tillage. Apart from one instance of $5/acre for increased pesticide costs, our research identified reduced expenses for tillage equipment and fuel to be the main net income impacts. Reduced tillage is expected to reduce costs by $16 to $95/acre, depending on the type of practice change. We note that the sample size for each of these benchmarks is small, so this may be an area for additional research. Nonetheless, these numbers give a sense of the possible net income impacts associated with tillage reduction.

Table R.

Examples of Cost and Revenue/Reduced Expense Impacts of Changing to Reduced or No-Till Practices

Description of Benchmark	$/Acre (-) = cost; (+) = revenue or reduced expense)	Sample Size	Type of Benchmark
Increased pesticide cost due to reduced tillage, 2018	-$5.00	1 farm	American Farmland Trust Case Study: Thordyke Farms, IL (7)
Machinery cost savings due to strip till (avoided conventional tillage machinery purchases), 2018	$24.25	1 farm	American Farmland Trust Case Study: Homewood Farms, OH (5)
Reduced machinery cost due to reduced tillage, 2018	$17.68	1 farm	American Farmland Trust Case Study: Thordyke Farms, IL (7)
Cost savings per acre conservation tillage over conventional tillage, corn	$43.53	2-7 farms	Soil Health Partnership Study (12)
Cost savings per acre conservation tillage over conventional tillage, soy	$94.40	2-7 farms	Soil Health Partnership Study (12)
No-till saves more than 4 gallons diesel per acre per year compared to continuous conventional till	$16.00	n/a	USDA NRCS Blog (19)[1]

Assumptions:
1 Assumes a $4/gallon price for diesel.

Multiple Soil Health Practices Net Income, Revenue, and Cost Benchmarks

A few of the sources in our review reported net income impacts for a suite of soil health practices combined. The exact combination of practices varies by source, but usually includes tillage reduction and cover crops, with some studies also including nutrient management adjustments. Only one benchmark was a negative net income (-$7/acre for corn for one year of cover cropping while transitioning to no-till). Otherwise, net income impacts from multiple soil health management practices ranged from $0 to $74/acre in benefits. A subset of the benchmarks from a research partnership between the Soil Health Institute and Cargill reported wider ranges of net incomes, with some negative examples, but on average these studies still reported positive net incomes and only one to two farms in each sample had negative outcomes. Tables S and T summarize the results.

Table S.

Examples of Net Income Impacts from Adopting Multiple Soil Health Practices

Description of Benchmark	$/Acre (-) = cost; (+) = revenue or reduced expense)	Sample Size	Type of Benchmark
Net income impact of cover crops and nutrient management, 2018	$45.62	1 farm	American Farmland Trust Case Study: Ifft Yorkshires Farm, IL (4)
Net income impact from strip till, nutrient management, cover crops, 2018	$73.51	1 farm	American Farmland Trust Case Study: Homewood Farms, OH (5)
Net income impact from no-till, cover crops, variable rate nutrient management, 2018	$43.56	1 farm	American Farmland Trust Case Study: MadMax Farms, OH (6)
Net income impact from soil health practices (cover crops, strip till and no-till, nutrient mgmt), 2018	$52.75	1 farm	American Farmland Trust Case Study: Thordyke Farms, IL (7)
Net income, corn, for 1 year cover cropping while transitioning to no-till, 2012-2016	-$7.40	2000 farmers, extension data sources	USDA Sustainable Agriculture Research and Education (SARE) (21)
Net income, corn, for 3 years cover cropping while transitioning to no-till, 2012-2016	$25.38	2000 farmers, extension data sources	
Net income, corn, for 5 years cover cropping while transitioning to no-till, 2012-2016	$41.86	2000 farmers, extension data sources	
Net income, soy, for 1 year cover cropping while transitioning to no-till, 2012-2016	$0.41	2000 farmers, extension data sources	
Net income, soy, for 3 years cover cropping while transitioning to no-till, 2012-2016	$24.38	2000 farmers, extension data sources	
Net income, soy, for 5 years cover cropping while transitioning to no-till, 2012-2016	$34.14	2000 farmers, extension data sources	

Table T.

Examples of Net Income Impacts from Adopting Multiple Soil Health Practices, Continued

Description of Benchmark	$/Acre (-) = cost; (+) = revenue or reduced expense)	Sample Size	Type of Benchmark
Michigan corn soil health management system (no-till, cover crops), change in net farm income	$24.74 (-$38 to $94 range)	10 farms	Cargill/Soil Health Institute Study (25)[1]
Michigan soy soil health management system (no-till, cover crops), change in net farm income	$38.38 (-$39 to $123 range)	10 farms	
Michigan winter wheat soil health management system (no-till, cover crops), change in net farm income	$7.37	10 farms	
Michigan dry edible beans soil health management system (no-till, cover crops), change in net farm income	$54.28	10 farms	
Michigan sugar beets soil health management system (no-till, cover crops), change in net farm income	$47.35	10 farms	
Illinois corn soil health management system (no-till, cover crops), change in net farm income	$39.12; (-$43 to $135 range amongst the farms)	11 farms	
Illinois soy soil health management system (no-till, cover crops), change in net farm income	$37.56 (-$31 to $113 range amongst the farms)	11 farms	

Assumptions:
1 89% of the MI farmers' acres used no-till and 83% cover crops. Only 25% of MI farmers use no-till currently and 11% use cover crops; 37% and 5% nationally, respectively.Michigan corn benchmark: $4.20/bushel, accounts for equipment ownership; 8/10 farms had positive net income impact. Michigan soy benchmark: $10/bushel, accounts for equipment ownership; 9/10 farms had positive net income impact. IL farmers had no till on 74% of acres and cover crops on 71% of acres. Current adoption for no-till in IL is 29% and cover crops 3%. IL corn benchmark: 7/11 farms had positive net income impact. IL soy benchmark: 9/11 farms had positive net income impact.

We found limited examples of revenue and no cost examples for combined sets of soil health practices. Table U shows the revenue impact benchmarks, which include two instances of major yield increases that generated $69 and $142/acre in additional revenue, and two instances of reduced expenses for changing from conventional to conservation tillage with cover crops.

Table U.

Examples of Revenue or Decreased Expense from Adopting Multiple Soil Health Practices

Description of Benchmark	$/Acre (-) = cost; (+) = revenue or reduced expense)	Sample Size	Type of Benchmark
40 bu/ac more corn yield @ $3.55/bu, 2018	$142.00	1 farm	American Farmland Trust Case Study: Homewood Farms, OH (5)
Yield impact due to soil health practices overall (corn up 165 to 195, soybeans up 45 to 65 bu/ac, corn @ $3.55/bu, soy @ $8.60/bu, 2014-2018	$69.00	1 farm	American Farmland Trust Case Study: MadMax Farms, OH (6)
Reduced expense per acre for conservation tillage with cover crops over conventional tillag, corn	$12.72	7 farms	Soil Health Partnership Study (12)[1]
Reduced expense per acre for conservation tillage with cover crops over conventional tillage, soy	$0.77	7 farms	Soil Health Partnership Study (12)[1]

Assumptions:
1 Budget items compared included burndown, fuel, repairs, machine hire/application, and equipment (does not include the cover crop specific costs for seed and seed planting).

Cost Share and Payment for Ecosystem Services

Cost share programs have the potential to impact farmer decision-making about soil carbon programs because they can greatly offset the costs associated with transitioning to carbon-sequestering practices, especially cover crops. Table V below summarizes the cost share programs we located, grouped by state, federal, and private corporate/NGO programs. The private partnerships are often limited geography programs to pay for practices implemented in certain locations or marketed to certain supply chains. We included Environmental Quality Incentives Program (EQIP) cost share rates for three representative Midwestern states. For additional rates, please see the SARE Cover Crop Economics Report, Table 6. The limited geography programs offered payments between $10 to $40/acre, with acreage limits and higher payments for newer cover crop adopters. The state and federal EQIP program payments ranged from $15 to $76/acre, depending on the program and whether a single- or multi-species cover crop mix was used. Some programs limit the length of time over which a grower can receive payments. In the case of the EQIP program, payments are meant to support a three-year period of transition to cover crops, and in the case of the Iowa State program, cover crop payments decline from $25 to $15/acre beginning in year two.

Table V.

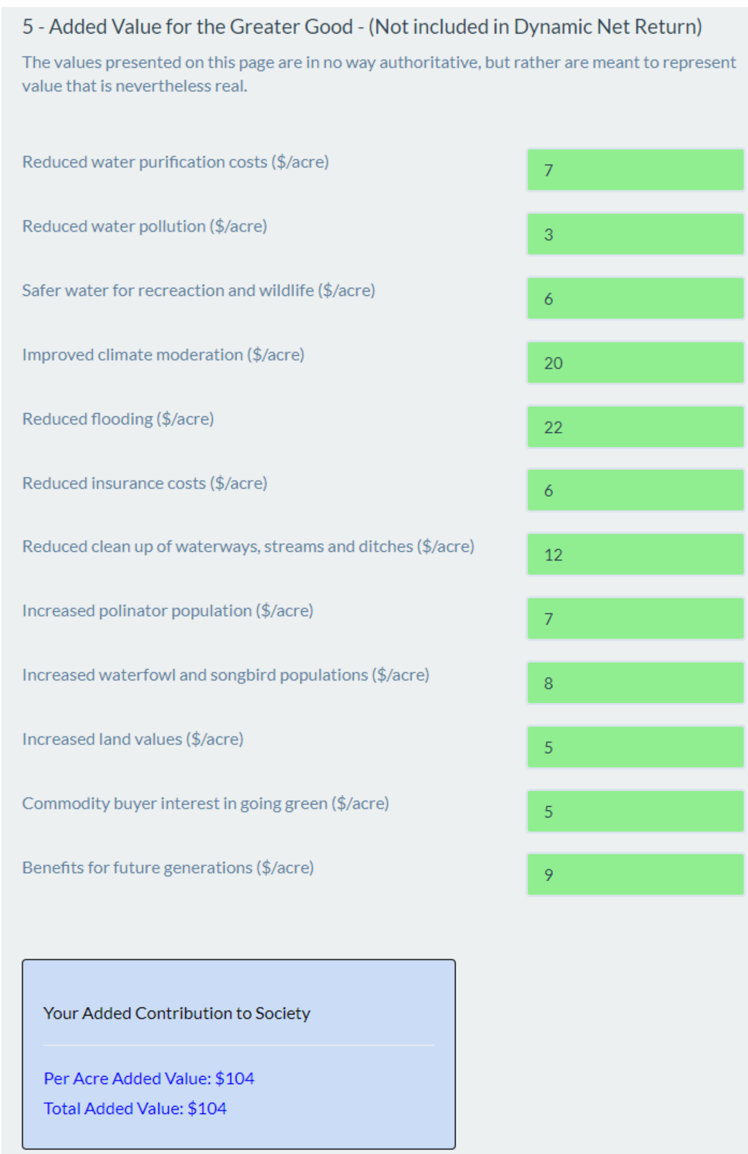
Example Cost Share Programs and Rates, Cover Crops

Description of Benchmark	$ Amount	Type of Benchmark
Nebraska Cargill, Bayer, Pepsico with Practical Farmers of Iowa	$10 per acre of fall cover crops planted for up to 200 acres	Corporate/NGO, Limited Geography Program (1)
Nebraska Cargill, Bayer, Pepsico with Practical Farmers of Iowa	$15 per acre of summer cover crops planted for up to 100 acres	Corporate/NGO, Limited Geography Program (1)
Nebraska Cargill, Bayer, Pepsico with Practical Farmers of Iowa	An option to receive an additional $10 per acre if nitrogen use was reduced by 40 pounds per acre	Corporate/NGO, Limited Geography Program (1)
Practical Farmers of Iowa and ADM/Keurig Dr Pepper/Pepsico and Bunge/Pepsico in NE and Cargill/Pepsico/Bayer in NE and IA and Pepsico/Lifeline in MO in 2021	$10/acre on up to 200 acres for cover crops (can't overlap with other carbon programs)	Corporate/NGO, Limited Geography Program (1)
Additional Unspecified Practical Farmers of Iowa Partnership Program	$40 per acre on up to 40 acres for new cover crop adopters; $10 per acre on 160 acres, or 10% of acres farmed, whichever is larger, for experienced cover crop users	Corporate/NGO, Limited Geography Program (1)
Ag Soil and Water Outcomes Program, Iowa	$33.46	Corporate/NGO, Limited Geography Program (1)
Program in Iowa	$25 in year 1, $15 thereafter	State Program (2)
Illinois NRCS EQIP cost share incentive rate, 2019, basic cover crops	$51.32	Federal Program (21)
Illinois NRCS EQIP cost share incentive rate, 2019, multi-species cover crops	$57.39	Federal Program (21)
Illinois NRCS EQIP cost share incentive rate, 2019, highest cover crop rate	$75.80	Federal Program (21)
Michigan NRCS EQIP cost share incentive rate, 2019, basic cover crops	$51.35	Federal Program (21)
Michigan NRCS EQIP cost share incentive rate, 2019, highest cover crop rate	$61.62	Federal Program (21)
Iowa NRCS EQIP cost share incentive rate, 2019, basic cover crops	$33.83	Federal Program (21)
Iowa NRCS EQIP cost share incentive rate, 2019, multi-species cover crops	$37.88	Federal Program (21)
Iowa NRCS EQIP cost share incentive rate, 2019, highest cover crop rate	$56.81	Federal Program (21)
Conservation Stewardship Program Contract	$30.00	Federal Program (27)

Value of Ecosystem Services Benchmarks

Though few programs currently exist to compensate farmers more broadly for the ecosystem services their practices provide, this is a possibility in the future. The Iowa Soybean Association's Cover Crop Economic Simulator lists the potential benefits of cover crops to society at $110/acre, as shown below in Figure 14. A next step for future research would be to contact the developers of this tool (Peter Kyvergya pkyveryga@iasoybeans.com; Suzanne Fey sfey@iasoybeans.com) to see how they generated their estimates for the value of each ecosystem service. The tool allows users to estimate an amount for each item. If payments could be received for all of these benefits, the net income for farmers would be significant.

Figure 14. A screenshot of the Iowa Soybean Association's Cover Crop Economic Simulator page that helps users estimate the value of less tangible ecosystem service benefits to society at large.



5 - Added Value for the Greater Good - (Not included in Dynamic Net Return)

The values presented on this page are in no way authoritative, but rather are meant to represent value that is nevertheless real.

Reduced water purification costs ($/acre)	7
Reduced water pollution ($/acre)	3
Safer water for recreaction and wildlife ($/acre)	6
Improved climate moderation ($/acre)	20
Reduced flooding ($/acre)	22
Reduced insurance costs ($/acre)	6
Reduced clean up of waterways, streams and ditches ($/acre)	12
Increased polinator population ($/acre)	7
Increased waterfowl and songbird populations ($/acre)	8
Increased land values ($/acre)	5
Commodity buyer interest in going green ($/acre)	5
Benefits for future generations ($/acre)	9

Your Added Contribution to Society

Per Acre Added Value: $104

Total Added Value: $104

Financial Decision-Making without Carbon Markets

Figure 15 summarizes the net income, revenues, costs, and cost share payments discussed so far. If a farm adopts cover crops without cost share, incremental net income from the change is likely to be between -$64 and $58/acre, and similarly, for adopting multiple soil health practices that include cover cropping and no-till, the incremental net income is likely to be between -$7 and $74/acre. Adding cost share payments shifts the ranges to -$54 to $134/acre for cover crops and $3 to $150/acre for multiple soil health practices. Adding idealistic compensation for non-monetized ecosystem services would shift the ranges up significantly to $46 to $168/acre and $103 to $184/acre, respectively, but this form of compensation does not yet exist. The key question that arises from this analysis is whether these net income figures are relevant to farmers, and how much they would be additionally impacted by carbon credit payments.

Figure 15. Summary of net income, revenue, and cost ranges for shifting to practices likely to sequester carbon and build soil health. Bolded rows are net income rows, whereas non-bolded rows are either revenues or costs. The two columns at right show how the range of possible net incomes would differ if the farmer received cost share or payments for traditionally non-monetized ecosystem services.

Benchmark	Range ($/acre)	Range with Cost Share ($/acre)	Range with Value of Non-Monetized Ecosystem Services ($/acre)
Cover Crop Net Income	**-$64 to $58**	**-$54 to $134**	**$46 to $168**
Cover Crop Revenue - Grazing	$32 to $83		
Cover Crop Revenue - Non-Grazing	$13 to $44		
Cover Crop Reduced On-Farm Expenses	$53		
Cover Crop Cost - Establishment	$15 to $78		
Cover Crop Cost - Total	$17 to $101		
Cover Crop Cost - Seed	$5 to $50		
Cover Crop Cost - Seeding	$10 to $49		
Cover Crop Cost - Other	$2 to $6		
Sum of the Above 3 Lines (Similar to Establishment)	$17 to $105		
Tillage Reduced Expense	$16 to $95		
Tillage Cost	$5		
Multiple Soil Health Practices Net Income	**-$7 to $74**	**$3 to $150**	**$103 to $184**
Multiple Soil Health Practices Revenue - Yield Increase	$69 to $142		
Multiple Soil Health Practices Revenue - Reduced Tillage	$1 to $13		
Cost Share	$10 to $76		
Value of Non-Monetized Ecosystem Services	$110		

Financial Decision-Making with Carbon Markets

In both our data management exit interviews and our broad survey of farmers, we asked questions about the ideal price farmers would like to be paid to change practices such as adopting cover crops or reducing tillage. Our key finding was that farmers would like to be paid significantly more than current agricultural carbon credit prices. One farmer stated, "on a good crop year we'll gross about say $1000 an acre…so $2.35 an acre [for $15/ton carbon price] on that is such a drop in the bucket". Another commented, "for the $10 an acre, $8 an acre if you're asking me to change my entire life to do that no…$8 I could lose on the margins on a bad marketing call."

Six of the eight farmers in our data management cohort said they would ideally like to be paid $50/acre for their carbon credits, with one elaborating, "past $30, definitely $50, you got my attention". One grower said they would like to receive $20/acre, and the remaining grower preferred $35/acre.

In our survey of 48 farmers (39 at the Great Lakes Crop Summit in Michigan, plus our data management cohort), respondents estimated that they would need to receive an average of $28 to $45 of additional profit per acre to change to various regenerative farming practices. Figure 16 summarizes these results. The average profit desired to switch to cover crops was $38/acre, to switch to reduced tillage was $31/acre, and to switch to no-till was $45/acre, all of which are slightly lower than the carbon payment desired by a majority of our data management cohort.

Figure 16: The rows below show the $/acre profit that farmers would like to receive to change to the regenerative practices indicated, as reported in our survey of 48 farmers. The sample size varies because some respondents to the survey skipped the question. Most farmers were Michigan residents.

Survey Question (Questions are of the format: "What is the minimum dollar amount of additional per acre profit you would need in order to _________? (Assume all costs have been covered and this is purely profit.)") The phrase below fills in the blank.	Mean	Range	Standard Deviation	Variance	Sample Size
Decide to adopt cover crops	$38	[0,100]	26.32	692.73	41
Shift to reduced tillage (30% or more of residue left on the surface after tillage)	$31	[0,100]	24.48	599.48	31
Shift to no till (75% or more of residue left on the surface after tillage)	$45	[0,100]	34.71	1204.83	24
Reduce N lbs/acre applied	$38	[0,100]	28.52	813.22	29
Reduce the application of a non-N fertilizer	$33	[0,100]	28.55	814.97	27
Add crops to your rotation	$39	[0,100]	27.03	730.75	26
Adopt rotational grazing	$28	[0,50]	16.55	274.01	10

Though we include these numbers in our report, we also caution that there is uncertainty in the data. The range and standard deviation for each mean are very high (the survey only allowed responses between $0 and $100/acre). It is also possible that respondents missed the instructions to consider profit, rather than revenue per acre. Furthermore, in conversation with growers while administering the survey, we heard that profit desired would depend on the starting conditions. For example, a farmer reducing N from overapplication would save money whereas a farmer who already had a nutrient management plan and further reduced N could have a reduced yield and lose money. This amount would also be dependent on the quantity of N reduced, which we did not specify. A next step for further research would be to rephrase the questions for more specificity. For now, we use this as an indication that farmers definitely require a non-zero profit from shifting practices.

In comparison to the ranges for possible net income mentioned earlier in this section and summarized in Figure 15 (-$64 to $58/acre for cover crop adoption without cost-share, -$7 to $74/acre for adopting multiple soil health practices without cost-share, -$54 to $134/acre for cover crops with cost-share, and $3 to $150/acre for multiple soil health practices with cost-share), it is clear that some farmers would not receive their desired profit amount without a carbon credit or other payment for ecosystem services, even with cost-share. To move the low end of each range above $50/acre would require an additional profit of $47 to $114/acre.

Farmers on the high end of the net income ranges would require no additional profit (perhaps reflecting why many farmers are already making changes), but for a subset of farmers, carbon payments could be a significant incentive to make the practice changes. $47 to $114/acre, therefore, is a conservative estimate of the minimum carbon credit price that would incentivize the largest number of growers to make practice changes and thereby maximize carbon mitigation impact. Further study is needed to identify how farmers are distributed across these ranges.

<u>Current Carbon Prices</u>

Table X lists the prices offered by Carbon Yield's competitors in the carbon market space, as of April 2022. None of the programs currently offer a price high enough to compensate farmers the amount they desire, demonstrating that Carbon Yield can offer significant value to farmers by negotiating a price that others cannot offer. This higher price would more fairly reward farmers for their contributions to climate change mitigation and other environmental co-benefits.

Table X.

Program	Type of Payments for Ecosystem Services	Current Price of Carbon	Portion of Price that Farmers Receive	Date of Price and Information	Notes
Land O'Lakes Truterra (TruCarbon)	C and other envtl	$20/ton	$20/ton	2/4/2021	Microsoft is first buyer, at $20/ton; Truterra pays for soil sampling
Farmers Business Network (Gradable Carbon)	C and insets	$20/credit	$12/credit	2019, 2020 growing seasons	60% of credit price goes to grower, 15% to fees, 25% to buffer; farmers can also bank credits to sell later at future market price; lists typical sequestration from cover crops, no till, or reduced nutrient appliction at 0.25-1.5 C/ac/yr but did not specify units for the credits.
Corteva (Granular Ag Carbon)	C	$20/ton, projecting $30/ton soon	$20/ton	4/9/2022	Corteva and partner Indigo Ag pay for soil sampling and verification. "1 carbon credit = 1 metric ton CO2e sequestered or abated"; Payments vest over five years, so farmers receive 50% of the credit in year 1, 20% in year 2, and 10% each in years 3-5.
Bayer Carbon Program	Pays for practices, not carbon directly	$3-9/acre/yr	$3-9/acre/yr	4/9/2022	$3/acre/yr for strip till or no till; $6/acre/yr for cover crops, $9/acre/yr for both; up to 5 years back payments for practices completed since 1/1/2012
Cargill RegenAg (RegenConnect regenerative ag program)	C	$20/ton	$20/ton	9/16/2021	Goal to advance regenerative ag on 10 M acres by 2030; 1 year contracts
Indigo Ag	C	$20/credit	$15/credit	4/9/2022	Farmers are guaranteed 75% of selling price of credit; Website advertises that farmers could get up to $30/acre/year and that in the first year, farmers usually store 0.2-0.5 credits/acre.
Nori	C	$15/credit	$15/credit, less verification costs	4/9/2022	Price to buyer is $15 plus 15% transaction fee to keep the market going; Grower pays verification costs; one credit is 1 tonne CO2e C stored for 10 years; In 2022, price will be dynamically set by the market. Credits are currently sold out, according to the website on 4/9/2022.
Ecosystem Services Market Consortium	C	PILOT PHASE	PILOT PHASE	4/9/2022	Non-profit; promote ecosystem services, water quality, emissions reductions; no Michigan pilots, but plenty of bordering midwest states

Carbon Yield Pricing

Carbon Yield is working to offer a much more attractive price to farmers than the competitors listed above. To discuss the ideal price, it is important to reconcile the $/acre units most important to farmers with the $/ton prices often quoted by carbon offset developers. Our data management exit interviews clearly indicated that farmers think in cost per acre, with seven out of eight of our interviewees preferring cost per acre to cost per ton of carbon as the meaningful unit for decision-making. Table Y shows how various NRT amounts and $/ton credit prices convert to $/acre. Only three combinations in the matrix (in bold) exceed the desired per acre price from our data management cohort, and only four exceed the minimum $47 to $114/acre carbon payment calculated earlier in this section that would adequately compensate farmers on the low end of the incremental net income range for shifting to practices that store more carbon.

Table Y. Numbers in bold indicate $/acre/year payments that would exceed the $50/acre/year profit desired by a majority of the participants in our data management cohort.

$/acre Grower Profit Examples, Not Including Verification Costs or Developer Margin

	NRT/acre/year	$65/NRT Carbon Yield Price	$100/NRT Carbon Yield Price
Example Grower 1	0.28	$18	$28
Example Grower 2	0.48	$31	$48
Nori Average	0.60	$39	**$60**
Nori Low End	0.20	$13	$20
Nori High End	1.00	**$65**	**$100**

Note: $/acre/year = [$/NRT from Carbon Yield] * [NRT/acre/year]

Per acre prices are highly dependent on the carbon sequestration rates achieved on a given farm. For comparison purposes, Table Z shows the $/ton price that would be needed to compensate growers their desired amount in $/acre, for various carbon sequestration rates. This data suggests that Carbon Yield's $65/ton carbon price goal is in alignment with our assessment of farmer needs for high NRT/acre/year projects. For example, a project that sequesters 0.77 NRTs/acre/year would receive $50/acre/year at a $65/ton price ($50/acre/year / $65/ton = 0.77 tons/acre/year). However, for lower sequestration rates, a price as high as $167/ton might be necessary to meet farmer goals. One of our growers, for example, had just under 0.3 NRTs/acre/year, which would require $167/ton to equate to a $50/acre/year payment.

Table Z. This table starts with the $/acre/year profit desired by the growers in our data management cohort and converts it to $/NRT at various example NRT/acre/year rates.

Desired Grower $/acre Profit, Converted to $/NRT

$/acre Desired	$/NRT Equivalent at 0.3 NRT/acre/year	$/NRT Equivalent at 0.4 NRT/acre/year	$/NRT Equivalent at 0.6 NRT/acre/year	$/NRT Equivalent at 1.0 NRT/acre/year
$50	$167	$125	$83	$50
$35	$117	$88	$58	$35
$20	$67	$50	$33	$20

Note: $/NRT = [$/acre/year] / [NRT/acre/year]

It is important to note that this analysis does not yet include verification costs or profit margin for Carbon Yield. Depending on the assumptions Carbon Yield makes for these costs, all farmer profits would need to be adjusted down accordingly. The profit margin would simply reduce the $/acre amount by the percentage of the margin, but verification costs would scale with the total acreage of the project. As an example, for a project with 0.6 NRT/acre/year (the Nori average rate) that requires an $83/ton price to equate to $50/acre and a 25% profit margin, Carbon Yield would need to sell the credits for $111/ton to continue giving the farmer $50/acre ($83/ton / 0.75 = $111/ton). Assuming $1000/year for verification of 1000 acres, this would equate to only $1/acre, so we ignore this cost for large projects.

Given that this price might be hard to justify to buyers, Carbon Yield might consider taking a lower margin for $100/ton credits, assuming marketing costs are similar to go from the market rate of $20/ton to either $65 or $100/ton. For example, a 25% profit margin at $65/ton is equivalent to a 16.25% profit margin at $100/ton, so the $100/ton price at 16.25% profit margin would still provide a farmer with 0.6 NRTs/acre/year with a $50/acre profit.

Carbon Yield's pricing goals, though higher than competitors, may be in line with the future of carbon markets overall (including agricultural and non-agricultural offsets). An analysis by Bloomberg New Energy Finance found that if markets remain open to all carbon offset types (and continue to allow lower-quality avoided emissions credits), prices would stay below about $25/ton until 2045 and reach $50/ton by 2050, but that if markets were limited to removal credits only (such as soil carbon sequestration credits), the price of carbon offsets could reach $50/ton by 2027, peak at $200/ton around 2030, and finally fall back to $100/ton by 2050 (Bullard, 2022).

In this context, Carbon Yield's pricing of $65/ton or greater anticipates future trajectories. Even if market prices do not reach these numbers, however, Carbon Yield's higher pricing goals are still the best strategy to achieve outcomes that properly compensate farmer suppliers. We recommend continuing to seek the highest prices possible for high-quality credits, but to use $50/acre desired farmer profit as a guideline for determining pricing and profit margins for projects with varying carbon sequestration rates and sizes.

8.4 Justice Recommendations

As a small start-up, we recognize that Carbon Yield cannot be expected to address every aspect of hundreds of years of injustice within U.S. agriculture. We also recognize that while markets tend to efficiently allocate resources, they often fail to offer perfectly just solutions. This is true when considering carbon markets as well. For voluntary agricultural carbon markets to proceed there is, at least to some extent, a tradeoff between removing carbon from the atmosphere by financially incentivizing farmers to adopt regenerative practices and ensuring that the financial incentives do not continue to perpetuate a system of patriarchal White supremacy. Through our research, we have identified three areas for recommendations from a justice perspective. First, enabling BIPOC farmers to best access agricultural carbon markets by marketing their credits with a price premium. Secondly, enabling small farmers to best access carbon markets by spreading the verification fee. And lastly, alternative financial incentives for farmers who do not meet the criteria for additionality in carbon credits.

8.4.1 Greater Price Premiums for BIPOC Farmers

Few farmers in the United States identify as non-White, and approximately 94% of farmland is operated by White people (Horst and Marion 2019). People of Color have been driven out of farming for a variety of reasons (see Racial Inequity in Agriculture above) but now as awareness of systemic racism and the desire to take meaningful action rises, there is a growing market opportunity for Carbon Yield. As the carbon market currently functions, large likely White-owned farms are positioned for the greatest benefit. But because Carbon Yield's position is already in the premium end of carbon credits, there is likely to be an opportunity to further find more premium prices for non-White farmers. In selling the premium carbon credits, Carbon Yield de-commodifies them by telling the story of the farmer, sharing photos, and making the intangible nature of carbon credits more resonant and emotional to their customers.

We expect that being able to include a racial justice component to these premium carbon credits would drive the price higher still. This in turn will benefit the BIPOC farmer and Carbon Yield. Carbon credits that also offer the buyer a sense of racial justice will be rare (see the above statistics on farm operators) which should also serve to drive the price upward. In fact, through Carbon Yield's model of premium carbon credits, BIPOC and other minority-generated credits would rationally avoid commodification through a program like Bayer or Indigo Ag and instead opt for a firm like Carbon Yield. Carbon Yield could be the broker of choice to earn the highest possible price for BIPOC farmers. As the agricultural carbon market stabilizes, Carbon Yield does not expect to compete on scale but could conceivably carve out a niche for minority farmers in particular. To achieve this, Carbon Yield would need to build on its positioning as independent, farmer-oriented, transparent, and trustworthy brokers to include ideas of racial justice consciousness with an understanding of the unique lived experience of BIPOC farmers. The end result would be a market niche that larger carbon markets are likely to be unable to compete in and higher carbon prices to the benefit of BIPOC farmers.

8.4.2 Spreading Verification Fees for Small Farms

The second justice related barrier is at the expense of small farms. Agriculture as an industry has seen large scale consolidation and the size of farms has grown. Smaller operations struggle to compete with the larger farms that take advantage of economies of scale, economies of learning, and cheaper access to the capital necessary for industrialized farming. Carbon markets as they currently exist are poised to perpetuate this uneven playing field. In the case of agricultural carbon credits we have observed that the verification cost (typically $1,000-3,000) is the largest barrier for small farms to participate in carbon markets. For the most part, the verification fee can be considered a fixed cost allowing large operations to spread the cost more thinly over their acreage which in turn is more likely to be offset by the carbon credit revenue per acre. Said another way, the marginal cost for a verifier to verify another field is likely to be lower than the farmer's marginal revenue so it's mutually beneficial for both sides to bundle large quantities of acres and divide up the surplus value.

Agricultural cooperatives have long been used to pool the resources of small farmers, and it remains a viable option to the verification fee problem as well. When smaller farmers band together their fields can all be entered as the same project in a registry like Nori and the verification cost, as well as the gains, can be split fairly among the opted-in farmers. While this option is viable it clearly takes on additional complexity. For example, farmers will have different forms of data to be entered into the model and there may be internal disagreements on how gains and costs are shared among farmers. Regardless, Carbon Yield could seek to partner with existing farmer cooperatives to make their inclusion more economically viable. Where Carbon Yield may run into trouble given their premium strategy is that it will be more difficult to tell the story of these specific carbon credits because it will not always be clear which small farmer it came from. Carbon Yield runs the risk of re-commodifying the credits when the transaction is not perfectly clear. However, the market attractiveness of buying from small farmers may be enough to overcome this risk.

8.4.3 Turning Early Adopters of Regenerative Practices into Ambassadors

Lastly, through our research we encountered many growers that were very interested in carbon markets and who also tended to be early adopters of regenerative farming. These farmers were also interested in being early adopters of carbon markets but due to their history of regenerative practices do not generate significant amounts of additional credits when their operation is modeled. In short, they cannot be paid for carbon sequestration practices they have already been doing. To do so would violate the principle of additionality and undermine the essential trust in the whole carbon market. This means that farmers that have been most destructive to their SOC stand to financially gain the most from changing practices and sequestering carbon. There is a common perception that this is unjust and unfair, but for the market to function, additionality must not be a justice-related effort to still reward early adopters of regenerative practices, Carbon Yield could offer financial incentives for them to be an “ambassador” to other farmers.

This ambassadorship could take two possible forms depending on how active the ambassador is in the new farmer’s subsequent practice shift. The first, and simplest is to offer a referral bonus to one farmer that brings in a new farmer that ultimately sells carbon credits. This could be a flat amount or a percentage of the final sale value. This type of system could be offered to all farmers in Carbon Yield’s network. To reward early adopters of regenerative farming, ambassadors could earn an additional commission for offering technical assistance and support to new farmers unsure of adopting certain practices. This not only brings in new farmers to Carbon Yield, but any credits generated are likely to qualify as additional while still rewarding the early adopter.

8.5 The Future of the Carbon Industry and Policy Context

Since his inauguration in January 2021, President Biden has pursued multiple climate mitigation pathways focusing on the 10% of US carbon emissions that come from the agricultural sector (Davies, 2022). One popular idea for the first year of his administration was the establishment of a federally administered Carbon Bank, housed in the USDA, which would serve as an exchange for carbon credits. This approach was highly anticipated by actors in private carbon markets; there were high hopes this approach might provide the confidence needed to generate demand in the private markets as well. There were, however, also some fears. Many feared the administration of this Carbon Bank would cost too much in tax money and ultimately might not truly succeed in mitigating climate change because the science behind soil-based carbon sequestration was not clear enough.

Meanwhile, it seems the Carbon Bank idea has been reduced to a more recent iteration of the Biden administration's attempts at addressing agricultural carbon emissions. In February 2022, the USDA launched its Climate-Smart Commodity initiative. This $1 billion program will essentially establish the resources within the USDA to provide information and financial support to those farmers who want to adopt more carbon-sequestering farm management practices, while also developing a certification label for consumers to see which products were grown using climate-smart practices (Newburger, 2022). The hope is that this will help drive confidence and participation amongst farmers regarding these practices, and also consolidate efforts to reach greater certainty on the science behind soil-based carbon sequestration methods (Braun, Stabenow, Graham & Whitehouse, 2020).

There is some speculation that this infrastructure will eventually lead to the establishment of something more like a Carbon Bank, using the network of farmers and learnings from those partnerships to then launch into a real carbon credit exchange within the USDA. Whether this happens or not, this current Climate-Smart Commodity program will play a key role in building confidence and standardization within the private carbon markets continuing to develop alongside these federal government policy initiatives.

9 Conclusions

As the effects of climate change become increasingly apparent, carbon markets will have an important role to play in averting the worst human and ecological consequences. An agricultural carbon market has attractive features for both buyers and suppliers, but with the novelty and uncertainty of this type of market, large numbers of would-be participants are currently reluctant. Our research confirmed many of our initial hypotheses about barriers to farmer participation, including low compensation, the difficulty of modeling carbon sequestration, and the time spent conducting a feasibility study to assess profit potential. As Carbon Yield seeks to build its presence as a soil carbon credit developer, the findings from our project will be a useful guide for strategic planning, though we note that further research is needed to confirm our findings for a broader set of farmers in regions beyond Michigan and with management practices not represented in our study cohort, such as highly diversified or perennial rotations.

Carbon Yield's strategy of premium, personal carbon credits will allow them to compete with larger providers by securing higher prices. These higher prices are key to recruiting farmers in the first place and convincing them to make farm management practice changes that can be considered additional. $100 per ton is the key benchmark that provides fair compensation for the cost and risk of transitioning practices When communicating with growers, however, we found that price per acre is the more meaningful metric. Though variable based on the carbon sequestration rates on a given field and the target profit margin of the project developer, we found that $100 per ton equates to approximately $50 per acre, which is the minimum profit desired by our interviewees.

There are also opportunities for Carbon Yield to revise the grower engagement process to account for some of the themes in our study. First, screening growers for project viability early on would more efficiently use resources, both from a farmer and Carbon Yield perspective, so that farmers who ultimately have low carbon sequestration potential are not left feeling empty-handed after a long engagement process. Second, many farmers throughout our research reported that one of the primary benefits of working with us was gaining knowledge of how the market is intended to function. Broadly speaking, this is still a new and unfamiliar space for both farmers and potential buyers, so continued education and willingness to engage in dialogue will also be crucial in the growth of this market. Lastly, agriculture is not exempt from being tainted by the centuries of systemic racism, dispossession, and disenfranchisement woven into the land's history. Carbon Yield should look for ways to amplify BIPOC voices and achieve larger price premiums for these farmers.

As a participant in a nascent market, Carbon Yield must remain agile and remain open to how the market shifts. One such potential is the widespread adoption of cheaper soil sampling to reduce the reliance on carbon sequestration models. The integration of other regenerative agricultural practices into the market, such as rotational grazing, could also have unpredictable ripple effects. Ultimately, Carbon Yield's primary currency is trust: trust that intangible carbon offsets are real and permanent, trust that farmers are not going to be once again exploited by the broader food industry, and trust that by working together, farmers, carbon offset developers, and carbon credit buyers can have a real impact on averting the climate crisis before it is too late.

10 Appendix

10.1 Grower Recruitment Flier

Carbon Curious?

Description

Carbon Yield is partnering with graduate student researchers at the University of Michigan School for Environment and Sustainability to quantify the potential value of carbon credits for growers who have adopted regenerative growing practices and to better understand barriers to growers accessing carbon credit markets. By the end of this project, participating growers will know the quantity and the projected value of carbon credits if assessed with the USDA COMET Model. Participating growers may proceed with registering and selling any credits generated, however there is absolutely no obligation to do so.

Purpose

The objective of this research is to understand benefits and barriers to grower participation in agricultural carbon credit markets, so that barriers can be reduced and benefits can be realized.

Grower Participant Benefits

- Receive an assessment of the farm's carbon credit potential
- Contribute to the development of carbon credit markets to benefit future growers
- Growers will receive compensation ($200 gift card) at the end of the project

Grower Role

- Be available for roughly 5 hours of interview/data gathering over a period of a few months and roughly 1 hour for a follow-up interview about the process
- Share historical data about growing practices and be willing to make estimates for missing data

We're looking for growers with:

- Interest in exploring how carbon and/or ecosystem services markets function, how to access them, and whether there is an opportunity for good ROI
- Farms with roughly 400-1000 acres of land in Michigan and ownership of at least 50%
- Able to meet time commitment
- Grows grain/field crops (with or without integrated livestock)
- Able and willing to provide robust data documenting farm practices and inputs on enrolled land
- Intentional soil regenerative practices implemented over the past 2-5 years

Contact us at: [REDACTED]@umich.edu
Sean Cannady: [REDACTED], Katharine Chute: [REDACTED], Wes Davis: [REDACTED], Colleen Sain: [REDACTED]

10.2 Data Management Exit Interview

10.2.1 Interview Questions

The following questions were asked to exit interview participants and recorded using Zoom's video call recording. Automated speech-to-text transcripts and audio reviews were used to codify themes.

1. Before the project, what did you already know about carbon markets?
2. What were your questions about the process before you had the initial call?
3. What could be improved about how the program is presented?
4. How much time did it take you to collect the data necessary for the Nori model? What were the more time-demanding parts of that process?
5. Given what you now know about the data upload process, how comfortable would you be embarking on this without a data management partner, such as one of us?
6. Of the following parts of the project process, which do you see as the greatest areas for improvement, and do you have any suggestions on how to improve them?
    a. Initial connection/introduction call
    b. Interview about historical and future land management processes
    c. Data Sharing
    d. Confirming accurate model entry
    e. Landowner Conversations
    f. Model results discussion
7. Do you expect to register these credits with Nori? Why or why not?
    a. If yes, what is the minimum price you would sell the credits for?
8. What costs do you consider when evaluating a transition to greater carbon sequestering practices?
9. How has your understanding of carbon markets changed after participating in this project?
10. One a 1-10 scale, how likely are you to recommend this process, i.e. Carbon Yield managing data upload to the Nori system, to family, friends, or neighbors?
11. Did you explore other carbon credit registries?
    a. If yes, when and how did they compare?

10.2.2 Coding Themes

The table below summarizes the parent and child (sub) themes we identified from our data management exit interviews. The count column lists the number of growers expressing each theme out of the eight total interviewees.

Parent Theme	Child Theme	Count
Prior Knowledge	Basic knowledge of whether/not they'd qualify	3
	Negative impression	2
	Knowledge of drivers behind carbon markets	2
	Very little knowledge, generally aware	6
	Corporate payment for practices program	4
General barriers to participate	Hard to get information about carbon markets	3
Motivation to participate	Opportunity to learn more	3
	Early adopter/open-minded	4
	Contacted by trusted advisor (extension agent and friend)	2
	Opportunity for income	5
	Nori seemed the most customizable for unique farm	2
Skepticism of carbon markets	Corporate greenwashing	1
	Dislike for concept of offsets	2
	Corporations are too big with too much control	1
	Lack of real impact	2
	Farmers do all the work and take on the risk	1
	Already doing the desired practices with no room to improve more	2
	Farmers are forming strong opinions with little real knowledge	1
	Government should be the one making the carbon payments	1
	System isn't founded enough on soil science	2
	Farmers who are increasing acreage aren't using regenerative practices because not profitable	1

	Carbon markets may take advantage of farmers struggling economically	1
	Farmers are not asking for this	1
	Perception that contracts are too restrictive/long	3
	Verification worries	2
	Unclear motivations for buyers	2
	Concern its just a fad	1
Process of working with us	Zoom/virtual is new	1
	Already had good records accessible	7
	Low time commitment to gather data (one or 2 hours)	5
	Winter was the perfect time to do it	2
	Enjoyed the process	3
	Good incentive to learn in depth about carbon markets	4
	Would not pay someone prior to learning credit amount	1
	Too much time invested prior to learning farmer isn't a candidate	4
	Clear expectations set at the start	1
	Yields should be more important	1
	Unclear on what final benefit would be	5
	Too slow	1
	Would like a physical form to fill out with required data prior to data collection call	1
	Still confused about carbon markets	3
	Difficult explaining tillage practices to non-farmer	1
	Should use simple, clear, concise language	3
	Should make carbon sequestration tangible	1
	Should use FSA data to plug into Nori	1

	Found Nori through Google searches on carbon markets	1
Barriers to farmer independent use of Nori tool	Much of data seems irrelevant/impractical	1
	Takes too long	3
	Does not have detailed crop records	1
	Not technologically inclined	3
	Difficult to learn the tool for one-time use	4
Financial considerations	Cost per acre is the meaningful metric	7
	Concern that the middleman or non-farmers make the money	3
	Profits are too low	3
	C price variability	1
	Customization of Nori can lead to better carbon price	1
Ideal carbon credit profit	$50/acre	6
	$20/acre/year	1
	$35/acre/year	1
Costs involved in changing to regenerative	Cost of seed	6
	Time spent coordinating the change	4
	Equipment wear and tear	1
	Already own no-till equipment	1
	Weather complications	3
	No-till drill would be $80,000-$100,000	1
	Cover crops could be $30-40/acre if drilled, including seed	1

	FSA state and EQIP cost-share covered 75-80%	1
	Negative effect on yields	3
Level of interest in competing carbon registries	Did not look at any others	3
	Briefly explored others	4
	Contacted by Bayer, LoL, Granular, or other private registries	3
Likelihood of recommending the process to friends/family/neighbors	10	1
	depends	2
	6 or 7	2
	5 to 7	2
	9	2

10.3 Broad Qualitative Survey Questions

1. How many acres did you plant in field crops?
2. If you planted more than 2000 acres in field crops last season, check an option below.
3. Which crops (choose up to 3) are your main sources of income?
4. What percent of your farmed acres are certified organic?* What crops do you grow organically?*
5. Which of the farm practices listed below did you adopt in the last four years and still continue to implement, and on what acreage did you implement those practices this past year?
6. Are you currently considering implementing any of the below practices in the next five years?
7. What is the minimum dollar amount of additional per acre profit you would need in order to decide to adopt cover crops? (Assume all costs have been covered and this is purely profit.)
8. To shift to reduced tillage? (Assume reduced tillage means 30% or more of residue left on surface after tillage.)
9. To shift to no-till? (Assume no-till means 75% or more of residue left on surface after tillage.)
10. To reduce Nitrogen lbs/acre applied?
11. What is the minimum dollar amount of additional per acre profit you would need in order to decide to reduce the application rate of a non-Nitrogen fertilizer? (As above, assume all costs have been covered and this is purely profit.)
12. To add crops to your rotation?
13. To adopt rotational grazing?
14. How easy would it be for you to summarize planting dates, harvest dates, tillage practices, and nutrient management applications for the past five years based on your farm records from your data management system? (1 easy - 5 difficult)
15. Which of the following options best describes your farm records?
16. Are you currently enrolled in any cost-share or payment for ecosystem services programs, such as carbon or water quality credits?
17. Please rate your level of knowledge of carbon credit opportunities. (1 low - 5 high)
18. Please rate your interest in participating in carbon credit programs at this time (1 low - 5 high)
19. Are you interested in learning more about carbon credit programs at this time? (1 low - 5 high)
20. Which type of organization would you most likely turn to for more information about carbon credit programs at this time?
21. Do you believe climate change is directly affecting your farming operations (changing weather patterns, more extreme conditions, higher temperatures, etc.) ?
22. Do you believe climate change poses a tangible threat to long term global wellbeing?(1 Strongly Disagree -5 Strongly Agree)
23. In what county is your operation primarily located?
24. What is the age group of your farm operation's primary decision maker?

25. How many years of farm management experience does your farm operation’s primary decision maker have?
26. What is your primary reason for farming?
27. What is your main source of news?
28. What ethnicity is your farm operation’s primary decision maker?
29. What gender is your farm operation’s primary decision maker?
30. Anything else you’d like to share?

10.4 Numbered Source List for Pricing Analysis and Recommendations

The references below are all included in our full References section, but they also correspond to specific numbered citations in our Pricing Analysis and Recommendations Section. For sources numbered in the net income, revenue, and cost data tables of the Pricing Analysis and Recommendations Section, please see the key below.

Source 1: Nicholson, C.M. (2021, November 5). Farmers in Eastern Nebraska adopt regenerative practices through project led by PepsiCo, Cargill, and Bayer. *Midwest Row Crop Collaborative*. Accessed April 9, 2022. Available at: https://midwestrowcrop.org/news-press/farmers-in-eastern-nebraska-adopt-regenerative-practices-through-project-led-by-pepsico-cargill-and-bayer/.

Source 2: Filbert, M. (2022, January 19). Economic and Soil Health Impact of Contract Grazing Cover Crops. *Practical Farmers of Iowa*. Accessed April 9, 2022. Available at: https://practicalfarmers.org/research/economic-and-soil-health-impact-of-contract-grazing-cover-crops/.

Source 3: Jones, T. (2021, August 27). Cover crop cost-share funds available for farmers in Iowa, Missouri, and Nebraska. *Practical Farmers of Iowa*. Accessed April 9, 2022. Available at: https://practicalfarmers.org/2021/08/cover-crop-cost-share-funds-available-for-farmers-in-iowa-missouri-and-nebraska/.

Source 4: Bruner, E. (2020). Soil Health Case Study: Jim, Julie, and Josh Ifft, Ifft Yorkshires, IL. *Accelerating Soil Health Adoption by Quantifying Economic and Environmental Outcomes & Overcoming Barriers on Rented Lands*. American Farmland Trust, USDA NRCS. Available at: https://farmlandinfo.org/publications/soil-health-case-studies/.

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Source 6: Brandt, B. (2019). Soil Health Case Study: Eric Niemeyer, MadMax Farms, OH. *Accelerating Soil Health Adoption by Quantifying Economic and Environmental Outcomes & Overcoming Barriers on Rented Lands*. American Farmland Trust, USDA NRCS. Available at: https://farmlandinfo.org/publications/soil-health-case-studies/.

Source 7: Bruner, E. (2019). Soil Health Case Study: Larry, Adam, and Beth Thorndyke, Thorndyke Farms, IL. *Accelerating Soil Health Adoption by Quantifying Economic and Environmental Outcomes & Overcoming Barriers on Rented Lands*. American Farmland Trust, USDA NRCS. Available at: https://farmlandinfo.org/publications/soil-health-case-studies/.

Source 8: Gilchrist, J. (2021). The Promise of Regenerative Agriculture: The Science-Backed Business Case and Mechanisms to Drive Adoption. *E2 and Natural Capitalism Solutions*. Available at:

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Source 10: —. (2021). Cover Crops Can be Part of a Profitable System, Especially as Experience Grows. *Soil Health Partnership*. Accessed April 9, 2022. Available at: https://www.soilhealthpartnership.org/farmfinance/cover-crops-profitable-system/.

Source 11: —. (2019) Cover Crop Planting Report. *Soil Health Partnership*. Accessed April 9, 2022. Available at: https://www.soilhealthpartnership.org/staging/wp-content/uploads/2020/08/SHP-cover-crop-survey-results-2020.pdf.

Source 12: —. (2021). Conservation Tillage Reduces Operating Costs. *Soil Health Partnership*. Accessed April 9, 2022. Available at: https://www.soilhealthpartnership.org/farmfinance/conservation-tillage-reduces-operating-costs/.

Source 13: Looker, D. (2018, October 29). The Economics of Cover Crops. *Successful Farming*. Accessed April 9, 2022. Available at: https://www.agriculture.com/crops/cover-crops/the-economics-of-cover-crops.

Source 14: Schnitkey, G., Coppess, J., and Paulson, N. (2019, July 6). Costs and Benefits of Cover Crops: An Example with Cereal Rye. *farmdoc daily* (6):126, Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign. Accessed April 9, 2022. Available at: https://farmdocdaily.illinois.edu/2016/07/costs-and-benefits-of-cover-crops-example.html.

Source 15: Plastina A, Liu F, Miguez F, Carlson S (2020). Cover crops use in Midwestern US agriculture: perceived benefits and net returns. *Renewable Agriculture and Food Systems* 35, 38–48. https://doi.org/10.1017/S1742170518000194

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Source 19: Creech, E. (2021, August 3). Saving Money, Time and Soil: The Economics of No-Till Farming. *United States Department of Agriculture*. Accessed April 9, 2022. Available at: https://www.usda.gov/media/blog/2017/11/30/saving-money-time-and-soil-economics-no-till-farming.

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Source 24: Chase, C., Delate, K., Hanlon, O. (2019). Organic Crop Production Enterprise Budgets. Iowa State University Extension and Outreach. Available at: https://store.extension.iastate.edu/product/12267.

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Source 27: Kyvergya, P., Fey, S., Hare, E., McDanel, J. (2022). Cover Crop Economic Simulator. *Iowa Soybean Association*. Available at: https://analytics.iasoybeans.com/cool-apps/CoverCropEconSimulator/.

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