

Understanding and fostering soil carbon sequestration

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E-CHAPTER FROM THIS BOOK



Understanding the value of and reasoning behind farmer adoption of carbon centric practices

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1 Introduction

Recognition of the need to reduce atmospheric greenhouse gas concentrations and appreciation of the role that agricultural soils can immediately play in climate change mitigation have created a demand for policies and programmes that promote C sequestration in soil. Public and private support for efforts to increase soil organic carbon (SOC) stocks are justified by the fact that we possess both the knowledge and technologies needed to make rapid progress towards sequestration goals to mitigate climate change while enhancing soil's provisioning, buffering, and regulating services (Amelung et al., 2020; Stockmann et al., 2013). While this is nothing new (Wander and Nissen, 2004), interest has grown rapidly due to governmental and private willingness to invest in mechanisms to promote C sequestration in arable soils (Honeycutt et al., 2020; Rumpel et al., 2020; Keenor et al., 2021). Twenty-eight countries currently include SOC in their Nationally Determined Contributions to meet pledges to the Paris Agreement (Wiese et al., 2021). The positive correlation between SOC and ecosystem services has made soil organic matter and related indicators of soil quality proxies for soil stewardship that are valued separately or in addition to climate offsetting (Paustian et al., 2019; Rumpel et al., 2020). The association between SOC and other ecosystem services beyond C storage (Amelung et al., 2020; Weil and Magdoff, 2004) explains why soil organic matter features

prominently in the battle for public perceptions. Different farming sectors are vying for legitimacy even as farmers' standing as moral actors has been eroded due to perceptions of agriculture's environmental and social harms (Williams and Martin, 2011).

Adoption of land stewardship practices tied to C sequestration by farmers depends on a variety of factors including the agroecological region, scale of production, incentives from public or private institutions, and cultural and the economic context (Piñeiro et al., 2020). Recognition of these variables is important as organizations acting at different levels of society develop outreach programmes and work with stakeholders to shape policy and implement practices for C stewardship. Typologies should not only consider individual but also the household and community services in addition to access to infrastructure (Ng'ang'a et al., 2019). This chapter explores factors including perceptions of risk or gaps in knowledge, technology, and resources, along with economic or social inducements that influence farmers' commitments to SOC stewardship. To learn about both the voluntary and regulatory government programmes as well as business-backed efforts influencing farmers' decision-making, we engaged farmers using conservation, conventional, or organic grain-producing practices in the US Midwest. We considered socio-economic factors determining farmers' willingness or ability to adopt conservation behaviours associated with soil building through C sequestration to understand how to adapt knowledge systems to promote the use of C-centric practices. We also explore how efficacy of information or inducements vary among groups.

2 Farmers' rationale, mechanisms and tactics

2.1 Farmers' eye view: between a rock and a hard place

Many mechanisms or/and strategies have been used to promote soil stewardship of arable lands by influencing individual behaviours or societal norms and actions through economic costs or opportunities. To improve these tactics it is crucial to understand what factors most determine farmers' behaviours assuming that they, and private land owners, determine land-use practices based on agronomic, economic, and social factors where lands are privately held. Even though collective land ownership remains important to subsistence agriculture, collective rights give way to individual decision-making when there is competition for land and opportunity for profit (Debolini et al., 2015; Wily, 2018). Through history, colonial lands and collectivized farming operations have been converted to private enterprises due to the belief that group rights hinder the adoption of farm improvements and, that private property rights provide the best way to reduce poverty because they allow individual operators to invest in, and profit from, improved productivity

(Debolini et al., 2015). The farmers' actions are predicated by a tangle of issues and constraints that influence their interest and ability to act as stewards of the land. Tauger (2010) argues that this farmers' eye view must be seen as one that incurs a dual subordination to nature, with climate and land hazards, and to society, including its markets, taxes, rents, and institutions. Farmers are asked to be stewards of the land even as they face these pressures. Societal trust is placed because agrarian ideals commonly cast farmers as morally superior to industry agents (Dixon and Hapke, 2003; Freyfogle, 2007). This perspective is commonly challenged where agriculture is perceived to have harmed public health and the environment and failed to reduce but rather increased rural poverty (de Janvry and Sadoulet, 2000; Williams and Martin, 2011; Kannuri and Jadhav, 2018).

2.2 Extensive production systems

Historically SOC in agricultural systems has been equated with soil fertility and thus sought through the use of practices that increase organic matter return to the soil and/or prevent loss of C through soil erosion or depletion. Awareness of the value of SOC is reflected by early agricultural traditions manifested across the globe through the use of practices like terracing, intercropping, and manure management to build soil and maintain productivity (Mafongoya et al., 2006). Techniques commonly used by extensive systems vary depending upon the factor (typically nutrients, water, or pests) that is limiting productivity. In pre-industrialized societies and currently where limited-resource farmers do not rely upon intensive use of external inputs to maintain fertility, producers must avoid land overuse that results in land degradation (see references in Aref and Wander (1997) and King (2004)) by implementing a variety of practices. Low input or extensive production systems that rely on rest or rotation, strategic stocking or grazing, slash and burn, fallowing, green manuring or diversification become unsustainable if the area required to support farmers is inadequate, or when economic conditions prevent the purchase of supplements needed to overcome limits (Demir et al., 2015; Tauger, 2010). While these traditional systems are often seen as static, some of the earliest producer organizations were created to protect their rights and help them gain access to new ideas and practices. Conservative motives and commitment to self-reliance are commonly associated with grower groups and social movements pursuing sustainability (Monk, 2011). This is because practices used to improve and sustain productivity within extensive or low input production systems that include methods to conserve, concentrate, and recycle resources also tend to promote C sequestration. Current examples of commercially viable farming systems engaged with stewardship that explicitly identify C sequestration as an aspirational goal include organic, biodynamic, conservation and regenerative

agriculture, and permaculture (Balfour, 1976; Brouder and Gomez-Macpherson, 2014; Conford, 2001; Heckman, 2006; Kirchmann et al., 2008).

The mechanisms and inducements that support and encourage the success of C-centric farming systems often differ from commodity-focused production in that they decommodify crops through certifications or product claims. Organic certification is an example of a voluntary market-based programme in which farmers may engage if there is enough knowledge of the opportunity costs to compensate for costs of practice implementation (Piñeiro et al., 2020). Farmers opting for organic certification must adopt practices that enhance soil biological processes through soil organic matter management. These standards have been effective due to their offer of clearly articulated guidelines and independent auditing and verification (Monk, 2011). The National Organic Standards (USDA-AMS, 2002) and The International Federation of Organic Agriculture Movements (IFOAM, 2005) emphasize that organic production fosters the natural cycling of nutrients by using practices that 'promote ecological balance and conserve biodiversity.' To maintain certification, farmers must comply with a generalized set of practices and restrictions. There is no verification of indicators of soil functioning. Expansion of certified organic production, or other similar systems, will depend upon consumer demand. The burden of record keeping, system complexity, and costs of certification may limit adoption by some (Piñeiro et al., 2020). Critiques of conventionalization associated with organic commodities have fostered interest in local food movements (Guthman, 2004; Fonte, 2008).

2.3 Intensive production systems

A shift from traditional farming systems to industrial production reliant on the use of modern technologies occurred following the green revolution. Increased reliance on inorganic fertilizers and pesticides decoupled the link farmers previously made between soil organic matter and productivity (Aref and Wander, 1997; Tauger, 2010). Industrial or commodity based agriculture has expanded due to the support of national-scale agricultural practices developed countries designed to promote commodities and trade (Lapola et al., 2014). Despite societal recognition of soils' importance to national economic well-being (Robinson et al., 2012), the national policies that have promoted the use of modern agricultural practices including mechanization, intensification of production, shortened rotations, and use of inorganic fertilizers and synthetic pest control measures, have frequently reduced SOC levels and associated services (Al-Kaisi and Kwaw-Mensah, 2020; Guo and Gifford, 2002; Lal et al., 2003; Lapola et al., 2014). Pressure to compete globally

has prompted agricultural intensification and has compromised industrial-scale agriculture's social license to operate. In an attempt to reverse this trend, food-security-focused agricultural policies in both the US and EU were reformed in the 1980s and 1990s to require participants in governmental programmes to adopt conservation measures. Conservation compliance provisions in the US that included protections of highly erodible lands and wetlands or riparian habitat required minimal measures to participate in direct payments (Doering and Smith, 2012). Questions about the efficacy of conservation compliance and the underlying perception that these programmes were not truly voluntary undermined their support (Claassen et al., 2008; Cox, 2007). In the US, fixed-price support approaches have been replaced by crop revenue insurance coverage based on expected market prices (Glauber, 2013), and working lands provisions that reward the use of conservation practices are assumed to provide ecosystem services (Coppess, 2018). Both cost-share and technical service programmes encourage farmer adoption of C-centric practices to improve soil health (Bowman and Lynch, 2019). However, the practice-based enrolment or ranking tools that the government relies on do not measure actual delivery of services including C sequestration (Ugarte et al., 2014, 2018; Zilberman and Segerson, 2012).

Similar reforms to the EU Common Agricultural Policy (CAP) were made to reduce large surpluses of agricultural commodities, high transaction costs, distortion of markets, and concerns from consumers and taxpayers over environmental harms caused by intensive agriculture practices (Pe'er et al., 2019; Williams and Martin, 2011). In the most recent version (2023–2027), the CAP requires farmers to provide environmental services through compulsory cross-compliance of practice implementation (Buitenhuis et al., 2020). Cross-compliance provides a basis for payments when farmers undertake environmental commitments that exceed mandatory requirements. The CAP seeks compliance with environmental rules, including new requirements on public, animal and plant health, animal welfare, and the maintenance of all productive land in good agricultural and environmental conditions. These practices are implemented based on the standards of Good Agricultural and Environmental Conditions (GAEC) (Borrelli et al., 2016; FAO, 2021). The GAEC includes standards for protection against soil erosion, maintenance of soil organic matter and structure, avoidance of the deterioration of habitats, and water management (MARS, 2014). Programmatic approaches that are heavily focused on productivity have challenged the goals outlined in the CAP (Moschitz and Home, 2014; Pe'er et al., 2019, 2020). To address this, participatory efforts and systems approaches have been recommended to improve policy success (Moschitz and Home, 2014).

2.4 Markets and valorization

Efforts like the Global Business Compact, undertaken by multilateral organizations to spawn public-private partnerships and, calls for sustainable intensification have dramatically increased interest and support for market-backed trading schemes. The EU efforts built upon the Thematic Strategy for Soil Protection, which recognized farmers' central role in protecting soils, and focused on market mechanisms as a primary tactic for encouraging the use of sequestration and other conservation measures (European Commission, COM (2006)231). The '4 per mille' initiative launched by the French government embraced the SOC sequestration goals realized in different countries with the aspirational target for sequestration of 0.4% of existing SOC stocks per year (le Foll, 2015; Rumpel et al., 2020). Parallel efforts in the US and Australia have leveraged public-private partnerships to promote SOC sequestration in association with soil health and established C trading markets. These efforts have spurred innovation and captured large amounts of speculative conservation investment that is being marketed to mainstream agricultural sectors (Honeycutt et al., 2020; Sullivan, 2013; Chapters 26 and 27 of this book).

At present government-backed conservation programmes fill a market gap to secure environmental benefits to society that would otherwise go unrealized (Zilberman and Segerson, 2012). To replace or supplant the government's role, commercial markets must verify services rendered. Individualized outputs, however, may be difficult to verify. Association between best practices and outcomes like no-tillage, which is widely promoted as a conservation practice and important deterrent of erosion, do not consistently result in increased C sequestration. In the US Midwest there is little to no difference in the SOC contents of soils in conventional row crop systems under conventional or conservation management (Al-Kaisi and Kwaw-Mensah, 2020; Ugarte et al., 2018). In other regions, however, the combined implementation of reduced or no-tillage with cover crops commonly promotes SOC accumulation (Snapp et al., 2022), particularly in drylands (Thapa et al., 2019).

In the US, voluntary initiatives like the Climate Action Reserve aim to register projects in agricultural lands seeking C credits that would be assessed using protocols devised by a commercial entity (Oldfield et al., 2021). Importantly, sampling requirements for verification purposes are left up to the verifier (Climate Action Reserve, 2020; Jackson Hammond et al., 2021). Given the fluidity and hype in this arena, farmers are rightly asking about transaction costs and the veracity of claims as they wonder how to engage with markets and weigh in on policy. The resulting partnerships between corporations and civic organizations are undergoing 'paradigm struggle' as they negotiate assumptive worldviews, vocabularies, goals, and loyalties as they struggle to capture and hopefully deserve credibility (Botan, 1993). Whether these market-based

approaches can deliver their promise is a source of concern (Baveye et al., 2016; Bracking and Leffel, 2021; Ghosh and Wolf, 2021). Many fear markets will compound problems of industrial agriculture and have detrimental outcomes (Ainscough et al., 2019; Clapp and Isakson, 2018).

3 Sequestration strategies and motivations of Midwest grain farmers

To understand why and how farmers in the US undertake stewardship behaviours, we first sought to identify practices that perform well enough to compete for C trading and conservation programmes in Illinois. This is located in the Midwest, where grain cropping systems vary in rotation length, quantity and quality of inputs, and frequency and intensity of tillage. We engaged farmers classified as conventional or conservation that typically manage 2-year rotations in this region and include a corn phase that is followed by soybean. Nitrogen and other fertilizers are applied in the years when corn is grown. The conservation group uses a mixture of 'best tillage practices' that include reduced or strip tillage frequently made in spring to maintain soil surface coverage and habitat for wildlife during the winter months. In this group, they frequently use split N applications and different formulations of N that typically have nitrification inhibitors. We also engaged organic farmers certified by the USDA National Organic Standard who use longer rotations that typically include the 2-year corn and soybean sequence followed by a year of small grains and use organic amendments and green manures to satisfy crop nutrient requirements. Soil sampling was carried out in spring to explore how information could be used at the individual level (e.g. conservation compliance, verification of C credits), or at the group level, with pooled data being used to assess differences at the practice-based level. Samples were collected from 21 groups (blocks) containing the comparisons of the above-described management systems and geographically distributed to account for differences in soil inherent characteristics as detailed in Ugarte et al. (2018). Within each field, 16 samples (0–30 cm divided into 15 cm increments) were collected using a hydraulic probe (4.06 cm of internal diameter) in a grid sampling pattern to account for field variability. In the field, sampling points were defined within a 4-ha area and based on the dominant soil series in a given group of fields and separated at least 30 m apart. Samples were collected in the spring before the start of field operations from 2011 to 2013. Each farm operator also provided detailed information on management practices leading to field preparation, nutrient management, and average yields. Samples were processed to determine SOC concentrations and stocks as well as other fractions of soil organic matter known to respond to management.

3.1 Farmers' individual and collective use of data

Field specific data were shared with individual farmers in a format that was similar to a soil testing report in that it included targets and threshold values (Fig. 1). While farmers knew how to use information resulting from standard soil tests, results describing stocks of SOC or labile fractions of SOC that are useful indicators of soil quality needed to be supplemented with other inputs to be useful or informative. Fortunately, recent improvements in scoring curves for SOC that draw on large national datasets can provide regional curves that allow farmers to compare their SOC stock values with a reference to determine where their soil ranks on a logit regression curve (Nunes et al., 2021).

We used the data to explore whether it was possible for farmers to use their individual data to assess change over time and to qualify for C credits. To detect changes at the plot or field scale, farmers need to sample using a sampling density that overcomes spatial variability. Based on our sampling from the 4-ha area within a field, we found it may not be logistically feasible to sample fields to detect small changes in C that are in line with C trading protocols (Table 1). Using the aspirational goal of 0.4% C per year as an example, we note that over a 10-year period, sampling needs are reduced fourfold but are still quite demanding. Sampling demands would pose a challenge for verification as institutions and practitioners rely on limited or no budgets for this purpose (Amelung et al., 2020). We considered change within the 30 cm of soil profile as protocols for C sequestration verification require taking samples to at least 30 cm where the greatest proportional change occurs (VandenBygaart et al., 2011). While the 4 per mille recommends sampling at 30 cm, many protocols

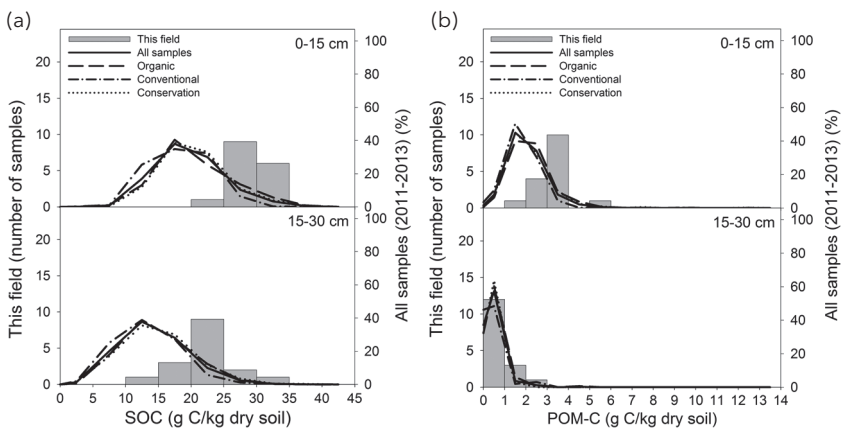


Figure 1 Example of data shared with farmers comparing specific fields with the project-wide results for SOC (a) and particulate organic C (b).

recommend sampling to 1 m (FAO, 2020; The Earth Partners, 2012). This may be fiscally impossible or at least unreasonable as sampling to deeper depths would greatly increase sampling density due to increased variability and reduced statistical power (<80%) (Kravchenko and Robertson, 2011; Necpálová et al., 2014).

One might have expected sampling demands to be lower and statistical power to be higher for the evaluation of changes in labile fractions of organic matter like particulate organic C (POM-C), which is known to reflect changes due to management in a shorter time frame than total soil organic matter stocks (Magdoff and Weil, 2004; Wander, 2004); but, we did not find this to be the case. Only by pooling data, from 21 locations could we successfully separate management treatments with a minimum detectable difference of 10% (Table 1). It must be noted that 10% is an extremely unrealistic rate of change unless dramatic changes in land use occurred.

Sampling efforts and costs might be lowered if the information gained from samples and site history is augmented through the use of process-based models or indirect ranking tools. For example, the Soil Carbon Protocol (Climate Action Reserve, 2020) relies on a combination of soil measures and biogeochemical modelling in the delineation of a baseline and projection of C gains. Aside from costs related to sampling, the costs associated with laboratory analysis should also be considered. In this region, only a few commercial laboratories are equipped to conduct SOC testing using combustion analysis, and typical costs per sample remain around US\$10. Current verification of C sequestration is assumed based on surveys of practice adoption. While physical documentation of C sequestration at the field level is currently not required, its costs could limit enrolment in C sequestration programmes.

Table 1 Plot requirement and within plot sample density needed to account for differences in soil organic carbon (SOC) and particulate organic carbon (POM-C) with a Power=0.8 and $\alpha=0.05$

	Plots (fields) needed to detect differences of 10% change*	Samples needed to detect differences at the 4-ha plot scale		
		0.4% change per year	0.4% change per year in a 10-year period	10% change
Mg C ha ⁻¹ in ESM 0-30 cm	21	15 226	153	25
Mg POM-C ha ⁻¹ in ESM 0-30 cm	78	81 744	818	131

*Considering regional variability, these represent the number of fields that would need to be sampled using the 16 samples per 4-ha area used in this study.

Data analysis using concentrations and soil equivalent mass basis (ESM) better accounts for differences in bulk density that can contribute to inaccurate comparisons of SOC and POM-C stocks (Ellert and Bettany, 1995). Comparisons of surface layers (0–30 cm) showed that conservation and organic systems had significantly higher SOC than their conventional counterparts (Table 2, $P < 0.05$). A similar trend was observed for concentrations of POM-C with stocks in the conservation category being intermediate ($P < 0.05$). Even with data-pooling a tremendous amount of research support is needed to account for regional variability and supply sufficient experimental power (>80%) Table 2.

Farm interviews allowed us to score stewardship using the Conservation Measurement Tool (CMT), which was previously used to determine enrolment in the Conservation Stewardship Program (CSP). Practice-based tools like this that are low cost compared to sampling are used to prioritize applications for government programs that reward the use of practices that increase C sequestration and soil health (Bowman and Lynch, 2019; Wallander et al., 2021). Based on actual field samples we were able to pool results to compare farm practices and farm sectors. This analysis determined that the CMT scores overestimated the benefits of reduced tillage and use of manure on SOC (Ugarte et al., 2018). Improvements in the Conservation Assessment Ranking Tool (CART), which replaces CMT and inventories management and conservation practices to compute baseline levels of soil stewardship at the farm operation scale (NRCS, 2021) are more regionalized. Pooled data from on-farm studies like this have tremendous potential to validate and refine tools like CART that assess soil quality and erosion, air quality and water quality and quantity. This kind of participatory work is a valuable tool for policy and programme design. However, we

Table 2 Mean separation for the effect of management practices on SOC and particulate organic C (POM-C) expressed in concentration and equivalent soil mass (ESM)

	SOC (g C Kg ⁻¹ soil 0–30 cm)	SOC (Mg C ha ⁻¹ in ESM 0–30 cm)	POM-C (g POM-C kg ⁻¹ soil 0–30 cm)	POM-C (Mg POM-C ha ⁻¹ in ESM 0–30 cm)
Conservation	20.28 ± 0.89 a	86.25 ± 4.64 a	1.62 ± 0.08 ab	10.34 ± 0.64 ab
Conventional	18.45 ± 0.85 b	78.77 ± 4.50 b	1.47 ± 0.07 b	9.21 ± 0.58 b
Organic	20.29 ± 0.85 a	86.67 ± 4.48 a	1.73 ± 0.07 a	10.71 ± 0.57 a
Power	0.94	0.84	0.94	0.91

Note: Means within columns not followed by the same letter differ at the 0.05 percent probability level.

must remember that researcher-driven explorations like ours that carry out between-group comparisons for farm-sector and treatment-based analyses are unfortunately not immediately useful to farmers as decision support tools for on-farm management.

3.2 Farmer behaviours

3.2.1 Attitudes, norms, and constraints

To understand factors influencing their use of practices likely to sequester C, we used mixed methods, surveys, and interviews by exploring the theory of planned behaviour (Ajzen, 1991). This was implemented in three stages (Fig. 2) that included generative, evaluative and, verification phases. The generative phase started with the framework as modified by Morrison et al. (2012), who replaced perceived constraints (time and capital constraints) to include business orientation, access to information, and prior action. Participants (>200 farmers and farm industry professionals) at a grower field day were surveyed with electronic clickers to identify attitudes and norms influencing their use of practices thought to increase or conserve SOC. This was followed by three focus groups with farmer cohorts representing conservation, conventional, and organic farmer categories in which we trialled questions for individual interviews. The generative phase included farmer interviews carried out in association with the 21 general locations we sampled (Fig. 2). Farmers were asked open-ended questions about attitudes and norms (Table 3; evaluative phase) before being asked about (1) threats to sustainability where they lived (i.e. weather, economic trends, pressure to produce, farm-size expansion, lack of knowledge about best practices, and others); (2) specific issues (i.e. changing weather, drought, flooding, loss of wildlife habitat, water pollution, spray drift, community health, jobs, poverty, and others); next, they were asked what (3) practices they associated with good stewardship; (4) attitudes about technology and innovation; and (5) where or how they marketed their crops (e.g. the local elevator with no on-farm storage, on a contract basis with on-farm storage, with a contract based on certification or an identity-preserved trait). Finally, they were then asked to identify any added value tactics (i.e. certifications or eco-labels including USDA Organic, animal welfare, American Grassfed Beef, Global Good Ag Practices, GMO free, Fair Trade) and to list any government programmes promoting soil conservation in which they participated. In the verification phase, summary information was refined through engagement with conservation experts at a workshop, reviewed by participating farmers in small group webinars and at a 'Soil and Water Conservation Society' meeting.

3.2.2 Realized actions as individuals or groups

Measured results, interviews, and surveys suggest business orientation and social connectedness most influence farmers' practice choices and propensity to participate in voluntary stewardship efforts. This information can be used to segment producers into groups with distinct information and programmatic needs.

Farmers' individual choices are mostly levied through purchasing, participation, and actions that extend beyond practice or land use choices that are the typical focus of most research on practice adoption. Commercial interventions that target information use by individual operators attempt to relate information or product use to economic gain achieved principally through increasing productivity (yield) and/or crop quality or by reducing risk. This explains why the use of standard soil test information and crop insurance are far more common than participation in C trading markets (Table 4). As an individual operator engaging in a C trading market, a farmer might be expected to verify changes in organic matter stocks using approaches similar to soil testing performed to inform soil fertilization routines. Based on our analysis, the expected rates of SOC change needed to secure payments (US\$10-15 per C ton) (Keenor et al., 2021) are not practical for grain cropping systems in this region. Additionally, little is known about costs associated with the adoption of C-centric practices. Further, fine-scale indicators of change in SOC that are measured on-farm may not adequately reflect change over time or predict benefits provided at the watershed or regional climatological scale. This creates scale mismatch wherein individual farmer decision-making about tillage or fertilization practices with stewardship and climate abatement inadequately address or overcome differences in the spatial or temporal scale over which decision-making and ecological processes occur (Guerrero et al., 2013). Farmers did not express concern over the lack of evidence directly relating stewardship to ecosystem services and provided

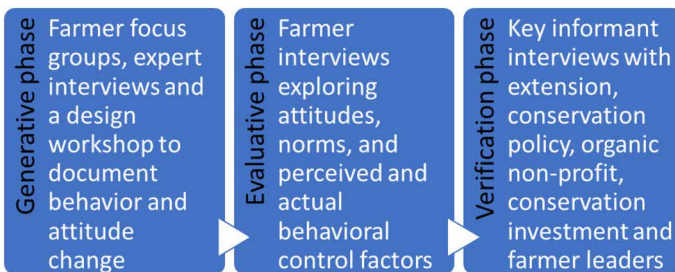


Figure 2 Phases of engagement with stakeholders are various levels to identify barriers preventing farmers from implementing stewardship practices using the theory of planned behaviour.

Table 3 Evolution of the theory of planned behaviour during the three stages of the study

	Generative phase	Evaluative phase
Attitudes towards behaviour	Economic motivations	Economic
	Trust	Trust
	Innovativeness	Goodness
	Satisfaction	Success
Subjective norms	Environmental responsibility	Innovation
		Privacy (information)
		Environmental responsibility
		Family responsibility
Perceived behavioural control	Business orientation	Group responsibility
	Information seeking behaviour	Time constraints
	Past environmental behaviour	Capitol constraints
	Connectedness	Competition
		Government regulations/programmes

Source: A generative list of attitudes, norms, and constraints was taken from Morrison et al. (2012). Items in bold during the evaluative phase were identified during the generative phase.

no indication that lack of knowledge influenced their decision-making about farming practices.

Voluntary participation by individuals in public or market mechanisms helped to distinguish farm sectors. While farmers selling into conventional markets consistently took advantage of crop insurance and precision technologies, farmers in the other two categories varied much more in their attitudes about independence from government and new technologies. Individuals within the organic and conservation groups represented the most and least intensive users of government programmes and precision tillage, guidance, and vision systems. In general, the farmers in the region were receptive to technologies with smaller operations being more judicious in their use. Larger scale operations may have benefited more from tax incentives that encourage purchase of new equipment. Lease agreements and access to land were points of concern for all but large operators more frequently complained about outsiders renting ground 'out from under them'. Key factors influencing conventional farmers were pressure to produce and expand the size of farm operations. Organic price premiums being received at the time allowed organic farmers to secure and retain leases. Even though farmers complained about transaction costs associated with paperwork needed for government programmes and certification, these opportunities enabled conservation behaviours. Farmers engaged in alternative markets relied more heavily upon social networks (Table 4). Cooperative coping strategies offer risk avoidance tactics that are not necessarily economically rationale but are socially wise where social capitol can be traded (Mustafa et al., 2019; Okonya et al., 2013;

Table 4 Summary of results from the implementation of the theory of planned behaviour to identify barriers preventing farmers from implementing stewardship practices or using information to direct management practices

Programmes and mechanisms promoting conservation	Organic	Conservation	Conventional
Soil testing	Many	All	All
Certification (USDA National Organic Program)	All	None	None
USDA Conservation Reserve	Many	Many	Some
USDA Conservation Stewardship or Environmental Quality Incentives Programs	Some	Many	Some
Crop insurance	Many	Many	All
Attitudes and interests in approaches	Organic	Conservation	Conventional
Independent (anti-governmental programs)	Several	Few	None
Interest in C sequestration contracts	Some	Many	Some
Interest in sustainability certification	Some	Many	Some
Concerns	Organic	Conservation	Conventional
Agricultural sustainability	Many	Some	Some
Changing weather (drought and flooding)	Many	Many	Many
Loss of wildlife habitat	Many	Many	Few
Water pollution	Many	Many	Few
Spray drift	Many	Many	Few
Input costs	Some	Few	Many
Land rental by community outsiders	Few	Some	Many
Land price	Some	Many	Few
Important values	Organic	Conservation	Conventional
Profitability	Many	Many	All
Environment	Many	All	Some
Social/religious network	All	Many	Few
Family	Many	Many	All
Goodness	Many	Many	Some

All = 100%, Many > 75%, Some > 25%, Few < 10%.

Sima et al., 2015). Conventional farmers' responses suggested they value economic success and family quite highly, often farming at a larger scale and selling into commodity markets through their local elevators. Because farmers live where they work, there is a natural tension between competitive business and communal motives. A dominant concern for all was depopulation and loss of jobs within their communities. Despite this, larger operators reported benefiting financially from lower input prices sourced in bulk outside their communities. Farmers in all groups expressed interest in reversal of the trend in farm-size expansion and increased reliance on crop insurance that promote resource degradation and discourage conservation.

Results showed resources and policies that align with the different attitudes, norms, and behavioural controls determine farmers' conservation behaviours. Farming styles, which include norms and practices used by more or less connected groups of farmers, evolve over time (Vanclay et al., 2006). Differences among these groups provide a useful way to target efforts and assess outcomes. Government-backed conservation programmes that reflect cultural and social goals, and not just economics, achieve community goals (Lago et al., 2019). Evolving private markets that aim to market ecosystem services associated with C sequestration will need to verify services in an affordable way. Pooling of on-farm data has already been used to demonstrate how remote sensing can be used to document the use of C-centric practices (Xia et al., 2021) and how rapid hand-held sensors can successfully and cheaply quantify C based on colour (Ewing et al., 2021).

We found that a focus only on mechanisms influencing the use of in-field farm practices would limit our understanding of farmers' decision-making by blinding us to important social and economic factors. Farmers not only influence C sequestration directly by practice adoption but also through engagement with farm or community organizations, service providers, the research community, governmental agencies and, consumers to influence whether or how they are rewarded for their efforts (Ledingham and Bruning, 1998). Again, we show that pooling farmer data and farmer networks can empower cross-scale efforts to effectively address individual and institutional concerns about management as was suggested by Cash et al. (2006).

4 Conclusion

- 1 Field-based verification by direct soil sampling may be unrealistic for producers wanting to be compensated during the years immediately following the adoption of practices that sequester C.
- 2 Existing tools and datasets are not adequate to support site- and system-based assessments of ecosystem services derived by implementing C-centric practices. Scale mismatch and improper allocation of

responsibility to individual operators charged with delivering services through market mechanisms exacerbate this problem.

- 3 Blended approaches that leverage reference datasets that verify benefits for site-specific farming systems and use models or rapid soil testing methods (e.g. apps that sample colour and remote sensing that documents residue cover, presence of cover crops) will reduce costs and make this more practical.
- 4 Farmers' engagement in groups increases both the development and use of effective sequestration practices by embracing social norms, spurring innovation, orienting research, and justifying policy, premiums, or product claims that promote the use of C-centric practices.
- 5 Use of C sequestration as a proxy for ecosystem services likely undervalues the use of conservation practices and will not help farmers overcome trends in farm size that are generally seen as threats to sustainability.
- 6 Clear differences in farming styles, values, and norms argue strongly for targeting efforts to promote C sequestration among different farm sectors.

5 Acknowledgements

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6 Where to look for further information

- The Food and Agriculture Organization is a primary source for world agriculture that considers all types of farmers and farming systems: <https://www.fao.org/home/en>.
- The Food and Agriculture Organization's Global Soil Organic Carbon Map is a key resource: <https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/global-soil-organic-carbon-map-gsocmap/en/>.
- The Food and Agriculture Organization's Map of Soil Carbon Sequestration is also of interest: <https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/global-soil-organic-carbon-sequestration-potential-map-gsocseq/en/>.

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