Table S3: The examples of enablers and barriers affecting the adoption of sustainable agricultural practices, as identified by U.S. agricultural producers.

Examples of the enablers	Examples of the barriers
Domain 1: The Psychosociological Context	
(i) Awareness and knowledge	
Awareness of the negative impact of agriculture on the environment (Li et al., 2023; M. Smith, Lal, & Vedwan, 2023). History of past practices adoption (Johnson et al., 2023). Formal education is positively associated with the adoption of sustainable agricultural practices (Golden et al., 2024; Li et al., 2023). There is increasing evidence base supporting the positive effects of conservation practices on both the environment and the economy. Numerous organizations are integrating sustainability into agricultural education by incorporating it into their teaching, research, and extension programs. Access to private consultants enhance the adoption of sustainable agricultural practices (Luther et al., 2020). Access to quality information and extension training has a positive impact on the adoption of sustainable agricultural practices (Mishra et al., 2018). Crop advisers are among the most trusted sources for farmers seeking advice and information for their farm management decisions (Eanes et al., 2017; Linda Stalker Prokopy et al., 2015).	There is a lack of standardized terminology in the field of sustainable agriculture (Frankel-Goldwater et al., 2024; Lemke, Smith, Thiim, & Stump, 2024; Matthew M. Smith et al., 2022; T. Wang, Jin, Kreuter, & Teague, 2022). Agricultural producers' unfamiliarity with terminology e.g., agroforestry, no-till (Malone & McClintock, 2023; Matthew M Smith et al., 2022) A lack of one-on-one support (Schattman et al., 2023). A lack of adequate knowledge about the variety of sustainable agricultural practices (Mishra et al., 2018). An increased need for locally relevant and specific information on sustainable agricultural practices e.g., crop-specific information (Ikendi et al., 2024). Public sector institutions (extension educators, soil and water conservation districts, and USDA agencies have been identified as providing information that is outdated, irrelevant, or too general (Beethem et al., 2023). Low levels of awareness among farmers regarding voluntary carbon market opportunities (N. M. Thompson et al., 2022). Private industry often lacks technical expertise in more innovative agronomic or conservation practices. The lack of experience with

Examples of the enablers	Examples of the barriers
	management-intensive conservation practices (e.g., cover crops) leads to a lack of confidence among these private-sector advisors in promoting sustainable agricultural practices (A. Reimer et al., 2023). Uneven access to the information and support networks on the adoption of sustainable agricultural practices (Eanes et al., 2019). Information on conservation practices often overlooks non-operating landowners (NOLs), particularly those who live out of state or do not fit the typical farmer profile, such as women or investors (Petrzelka, Buman, & Ridgely, 2009; Ranjan, Wardropper, et al., 2019). A lack of data and models to predict potential biological response to conservation practices. Difficult to track the cumulative footprint and estimate the ecological benefits of conservation practices at multiple scales (Fales et al., 2016).
(ii) Social factors	
Strong networks and engagement in peer-to-peer farming groups (e.g., U.S. Farmers & Ranchers in Action) influence on-farm decisions regarding the adoption of sustainable practices (Asprooth et al., 2023; Day & Cramer, 2022). A sense of social responsibility in farmers is a potential way to improve the efficiency and effectiveness of conservation programs and increase the long-term durability of practice adoption (Vaske et al., 2020). Availability of social learning opportunities (Day & Cramer, 2022). Increased societal pressure to reduce agricultural externalities and public demand for	Differences in values, beliefs, and perceptions of ecosystems and environmental conditions between the public and scientists or other experts in the field can potentially hinder the implementation of effective policies and conservation practices (Bergtold et al., 2022). Connections with public institutions (USDA-NRCS, conservation districts, extension services) are often weakened due to a lack of agency capacity, mismatched perspectives, and a perceived lack of innovation by agencies (A. Reimer et al., 2023).

Examples of the enablers	Examples of the barriers
sustainable agriculture (Dingkuhn et al., 2024; Suraj Upadhaya et al., 2023). Evolving consumer preferences, with a growing emphasis on health, the environment, climate, and ethical factors when making food choices (A. Reimer et al., 2023). Women farmers tend to lead farming projects that provide direct nutritional, environmental, educational, and social services to their communities, aligning with elements of agroecology (Gomori-Ruben & Reid, 2023). Trust in government and conservation organizations leads to increased participation in conservation programs (Levers et al., 2021; L. S. Prokopy et al., 2019). The adoption of sustainable agricultural practices can be encouraged by offering reputational benefits, such as publicizing best management practices. Land managers show a willingness to participate in conservation efforts when group achievements are acknowledged and rewarded (Byerly et al., 2021). Monetary and non-monetary incentives can increase response rates among U.S. agricultural producers, but monetary pre-incentives are the most effective (Avemegah et al., 2021). Surveys conducted by universities or public institutions tend to receive higher response rates compared to those sponsored by private entities (Avemegah et al., 2021).	There is widespread distrust between farmers and public agricultural advisors (Guynn et al., 2024; Petersen-Rockney, 2022). Social risk perception can slow the pace and scale of climate action, including sustainable agricultural practices. In some contexts, efforts focused on educating or convincing farmers of climate science may actually increase, rather than decrease, the perceived social risks of climate action (Petersen-Rockney, 2022). There is a sense of disconnection between farmers and the public, with the latter seeing the need for change in agricultural practices but having different experiences and perspectives (Schneider, 2017). Commodity markets largely ignore product qualities associated with socially positive attributes, such as sustainable practices or nutrient density, instead focusing on qualities that mee the needs of the food processing industry (A. Reimer et al., 2023). A slight adverse impact of education on the adoption of cover crops were identified. Higher levels of education were linked to a lower perception of feasibility, thereby reducing the likelihood of adopting cover crops (Walpole & Wilson, 2022). Survey fatigue is contributing to declining response rates from agricultural producers regarding their attitudes, values, and behaviors (Avemegah et al., 2021; L. S. Prokopy et al., 2019; Raynor et al., 2019). Insufficient engagement of farmers in the decision-making process (Deguine et al., 2021).

Examples of the enablers	Examples of the barriers
	The aging population of agricultural producers (Raynor et al., 2019). Lack of place attachment and generational difference (Ranjan, Wardropper, et al., 2019). Local networking capacity is often limited (Fales et al., 2016).
(iii) Psychological factors	
Farmers' self-efficacy and response efficacy (or the perceived ability of an individual or practice to achieve goals) have been positively associated with adoption behavior (Han & Niles, 2023; Wardropper et al., 2024). Farmers are more likely to adopt practices if they perceive that they have the knowledge and financial resources required to use conservation practices (Pradhananga & Davenport, 2019). The adoption of sustainable agricultural practices is positively linked to relational values such as place attachment, moral responsibility to steward the land, and a "good farmer identity" (Frankel-Goldwater et al., 2024; Houser et al., 2024; Ranjan et al., 2022; Vaske et al., 2020; Wardropper et al., 2024). Farmers who are systems thinkers are more likely to adopt multiple conservation practices (Lu et al., 2024). Associated beneficial functions (e.g., aesthetics, hunting opportunities) positively influence willingness to adopt sustainable farming practices (Soldo et al., 2022). The decision of certain farmers to adopt conservation practices and allow access to private land is linked to their empathy towards others (Byerly et al., 2021).	A lack of confidence appears to reduce the likelihood of adopting sustainable agricultural practices, such as cover crops (Lee et al., 2018; S. Upadhaya et al., 2023). There is a perceived limited applicability and efficiency of sustainable agricultural practices in real-world scenarios. Resistance to changing existing farming practices (Malone & McClintock, 2023; Petrzelka et al., 2009; Ranjan, Wardropper, et al., 2019). The decoy effect and choice overload. The USDA often uses traditional logic in promoting conservation efforts by offering a wide range of choices, assuming that offering more options will encourage greater involvement. However, research has shown that this approach can have unintended consequences. Psychological phenomena like the decoy effect and choice overload demonstrate that adding more options may actually result in more producers choosing to do nothing (Ferraro et al., 2021). Potential risks linked to trade-offs between initial investments, environmental benefits, and overall profit margins significantly influence decision-making regarding adoption

Examples of the enablers	Examples of the barriers
Perceptions of environmental issues impact producer beliefs and attitudes, driving the adoption of sustainable agricultural practices and interest in participating in conservation programs (Raynor et al., 2019). Farmers are more inclined to adopt sustainable agricultural practices when they feel a moral obligation to protect natural resources (Pradhananga & Davenport, 2019).	(Dong & Mitchell, 2023; Ranjan, Wardropper, et al., 2019; H. Wang et al., 2020). Farmers' perceptions about the availability of resources (e.g., knowledge, skills, and financial resources) to implement sustainable agricultural practices can act as barriers to norm activation and the adoption of conservation practices (Pradhananga & Davenport, 2019). Aesthetics. Some stakeholders believe that a well-managed farm should have neat rows and be free of weeds, which implies it should also be free of cover crops and residue (Ranjan, Wardropper, et al., 2019). A productivist mindset, which aligns with prevailing farming norms, prioritizes maximizing crop yields, increasing profitability, and achieving short-terms financial benefits (Hayden et al., 2018; Ranjan, Wardropper, et al., 2019).
Domain 2: The Economic and Practical Capacity	
(iv) Technologies and Tools	
Advances in agricultural technologies and the ongoing digitalization of U.S. agriculture include innovations such as agrivoltaics, precision irrigation, weed detection, livestock monitoring and welfare assessment, smart greenhouses, AI, robots, blockchain, etc. These technologies have emerged to enhance sustainability and support smarter, more efficient, and environmentally responsible agricultural production (Javaid et al., 2022). New technologies have the potential to more closely link environmental and conservation benefits with agricultural production benefits,	Farmers and scholars have long acknowledged that various technologies - whether mechanical, biological, chemical, genetic, or digital - can both free farmers from traditional limitations and burdens while also imposing new dependencies and vulnerabilities (Snorek et al., 2024). Mechanization and modern climate-smart technologies, which often come with significant initial expenses, are more financially viable for large-scale operations (Khanna et al., 2022).

Examples of the enablers	Examples of the barriers
while also rewarding innovation and management skills (A. Reimer et al., 2023). Technological compatibility with existing farm systems is crucial (Luther et al., 2020).	Access to training for young farmers and farm laborers is a potential barrier to the further adoption of new technologies (A. Reimer et al., 2023). Due to the unfamiliarity of new technologies, farmers naturally gravitate towards those that can be tested (i.e., are "trialable"), to learn more about the technology and its potential benefits (Luther et al., 2020). A variety of tools are available to forecast the outcomes of conservation practices, but they either suffer from a lack of accuracy due to limited monitoring data, or are model-based and too complex for use by conservation planners (White et al., 2019).
(v) Economic factors (land, labor, capital, market access)	
Nascent state funds that invest in beneficial practices have the potential to be layered with federal and private initiatives to address financial and implementation challenges. This approach allows for leveraging the unique institutional and social knowledge within each state to effectively identify and bridge these gaps (Tallis et al., 2019). Farmers are adopting regenerative practices as a means to reduce their dependence on agrochemical inputs and private companies expertise, while achieving technological sovereignty (Snorek et al., 2024). Operation scale (e.g., the size of cattle operations, land parcels) plays a role in adoption, with larger farm/ranch sizes that have access to greater capital being more likely to adopt sustainable agricultural practices (Dyer et al., 2021; Johnson et al., 2023; O'Hara et al., 2023; Ruzzante et al., 2021). However, some studies found no relationship between farm size and	Uncertainty in short-run and long-run economic benefits. Dynamically changing economic factors influence farmers' decisions regarding the disadoption of sustainable agricultural practice by affecting the costs and benefits of using them (Gedikoglu, 2020; Maas et al., 2023; Park et al., 2023). Typically, implementing sustainable agricultural practice e.g., cover crops for a short duration (1-2 years) does not yield immediate profits for farmers. This means that the initial costs outweigh the private benefits in the short run. Positive net returns are more likely with the medium to long-term adoption of this practice, specifically after 3 years or more (Park et al., 2023). Sustainable agricultural practices, such as no-till, may lead to negative socio-economic consequences, such as job losses that have

Examples of the enablers	Examples of the barriers
these practices, or inconclusive results. One study found large farms were less likely to adopt conservational grazing than small farms (Lambert et al., 2020). Land access and tenure security encourage the adoption of sustainable agricultural practices (A. Reimer et al., 2023; Ruzzante et al., 2021; S. Upadhaya et al., 2023). Diversification of farm income and potential to generate short- and long-term cash flow play a positive role in the adoption of sustainable agricultural practices (Poudel, Pent, & Fike, 2024). Availability and accessibility of financial incentives programs (Surdoval et al., 2024; Vaske et al., 2020). Higher agri-food products premiums are a great mechanism to deliver conservation incentives (Houser et al., 2024). There is an increase in the number of organic farms, the area of farmland dedicated to organic practices, and sales of organic products. This grows holds potential for the production of food using sustainable agricultural practices (Mpanga et al., 2021). Access to non-farm income (Doran et al., 2020). Better quality of resources, such as fertile soil or the availability of clean water, encourage the adoption of sustainable agricultural practices, especially those that enhance productivity (Luther et al., 2020). Consumers are motivated to empower farmers to play an active role in sustainable agriculture	accompanied increased herbicide use (Malone & McClintock, 2023). Low incentive payments may act as a barrier to participation in soil carbon markets (Canales, Bergtold, & Williams, 2020). Capital constraints prevent initial investments (Gelardi, Rath, & Kruger, 2023; Maas et al., 2023). Sustainable agricultural practices, such as rotational grazing, can be associated with no increases in animal and plant production (O'Hara et al., 2023). Sustainable agricultural practices can negatively affect enterprise returns (Maher et al., 2023). Long-term commitments are required from farmers (Houser et al., 2024; Lambert et al., 2020). Consolidated markets: Consolidation in key input and commodity markets narrow farmer choices in crops, livestock varieties, and management systems, locks producers into constrained markets, and reduces returns to good management (A. Reimer et al., 2023; Surdoval et al., 2024). Externalizing the environmental costs of production and tailoring farm safety net programs toward major commodity crops have resulted in a lack of incentives for farmers to adopt more sustainable practices (Carlisle et al., 2019). Market access: Organic production has lower marketable yield and requires more labor and

Examples of the enablers	Examples of the barriers
programs and are willing to pay a premium for such program practices (Yue et al., 2020). Consumers also emphasize the promotion of scientific principles in sustainability, the establishment of tangible metrics for measuring sustainability, and the effective communication of sustainable practices to consumers and downstream industries (Yue et al., 2020). The profitability aspect can have a significant impact on the continuous use of sustainable agricultural practices without disadoption (Gedikoglu, 2020). Crop insurance: A sliding scale for crop insurance, with lower insurance rate provided to farmers who adopt practices that improve the nutrient, water, and soil characteristics of their production system. This sliding scale mechanism would not only incentivize beneficial practices but also disincentivize practices that increase farmers' risk (Tallis et al., 2019). Transition from a sales-based to a pay-for-service-business model in private services. The service-based model motivates crop advisers to provide farmers with knowledge and tools that assist them in adopting beneficial sustainable agricultural practices. This model is tailored to specific locations, enabling private providers to offer targeted advice relevant to local contexts and markets. This approach maximizes the economic and environmental benefits for both individual farmers and their communities (Tallis et al., 2019). Initial venture capital support from private companies or investors could support early adopters and help prove the viability of the business model, driving potential long-term investment by food companies willing to pay price premiums for verifiable beneficial practices	equipment (Mpanga et al., 2021; A. Reimer et al., 2023). High input costs and the rising costs of farm equipment pose challenges to sustainable transitions (Hayden et al., 2018; Koundinya et al., 2023). There is a labor shortage in the agricultural sector in the U.S. Declining number of farm operations and acres operated, alongside increasing value of agricultural production (Munch, 2024). Farmers and ranchers are currently experiencing the highest production expenses on record. There is a growing competition from lower-cost foreign markets. The lack of diversity in agricultural landscape (monocrop-based system) in certain states, such as the Midwestern states (A. Reimer et al., 2023). A lack of supportive infrastructure and self-funding correlates with higher rates of practice abandonment (Yoder et al., 2021). Rental arrangements on U.S. farmlands can disincentivize the adoption of sustainable agricultural practices (Ranjan, Wardropper, et al., 2019). Lease terms, including lease length, type, and rental market competitiveness, have been identified as barriers (Ranjan, Wardropper, et al., 2019). One of the biggest challenges faced by would-be sustainable farmers is acquiring or gaining access to land, particularly land with adequate access to water (Carlisle et al., 2019).

Examples of the enablers	Examples of the barriers
that make their sourcing networks more sustainable (Tallis et al., 2019). Novel and expanding markets, such as pastured goat and lamb meat, renting goats for invasive species control, 100% grass-fed dairy, and organic grains for local distilleries and bakers, are regarded as key opportunities encouraging farmers to transition to organic integrated crop–livestock systems (Hayden et al., 2018). The availability of, and connections to, markets for the commodities produced by farmers plays a significant role in sustainable transitions (Mishra et al., 2018).	Markets and policies often prioritize commodity production and other aspects of food production, such as food safety, over sustainable land management (A. P. Reimer et al., 2018). It is unclear whether the cost-share program leads to the displacement of other practices, promotes additional practices, or has no notable indirect effects. In programs such as conservation cost sharing, indirect effects can have a significant impact. (Fleming, 2017).
(vi) Implementation capacity	
Availability of pre-existing infrastructure: For example, farmers with irrigation facilities are more likely to adopt soil conservation practices like cover crops (Mishra et al., 2018). The conservation planning service and technical assistance provided by National Resources Conservation Service (NRCS) to farmers are free of charge, and participation in NRCS conservation planning is voluntary (Lu et al., 2024). Farmers with a conservation plan are more likely to adopt conservation practices, including multiple practices (Lu et al., 2024). There is increased access to trusted private sector intermediaries e.g., crop advisers as sources of information for farmers (Eanes et al., 2019; Houser et al., 2024; Tallis et al., 2019). Conservation programs may not directly persuade farmers to adopt a particular practice. However, once farmers decide to implement conservation practices, the presence of these programs significantly influences their choice of	The issue of time constraints, such as the limited time available to plant and establish cover crops after the fall harvest (Yoder et al., 2021). It is a major challenge for farmers to simultaneously optimize the profitability, productivity, and sustainability of their operations (C. D. Thompson et al., 2022) Technical service providers (TSPs) from agencies, extension services, private crop consulting, and other boundary-spanning organizations often lack locally relevant adaptation and mitigation resources to help farmers make and implement decisions (Ikendi et al., 2024). Complexity in implementation, whether real or perceived (Maas et al., 2023; Mishra et al., 2018). Farmers may hesitate to adopt sustainable agricultural practices when the process and

Examples of the enablers	Examples of the barriers
practices (Quintana-Ashwell et al., 2022; A. Reimer et al., 2023). Complementarities between conservation practices may enhance the benefits from adoption, allowing farmers to adopt bundles of conservation practices more rapidly. Agricultural producers who had previously adopted soil conservation practices are more likely to adopt additional complementary practices (Canales et al., 2020). Certain practices are better targets for increased implementation than others. Sustainable practices with a high degree of willingness to implement, such as trap crops, have the potential to yield significant improvements while requiring relatively fewer resources (C. D. Thompson et al., 2022). The communities of practice are emerging, supporting the shift towards sustainable agriculture (Hayden et al., 2018). Demonstration sites and field days have a positive impact on the adoption of conservation practices (A. Singh et al., 2018).	outcomes are not straightforward (Byerly et al., 2021). Adopting sustainable practices can make production more sensitive to environmental conditions, such as fluctuations in weather patterns and pest pressures (Dong & Mitchell, 2023). The adoption of certain practices has the potential to reduce yield variance and/or increase yield skewness (Dong & Mitchell, 2023). Excessive paperwork and the overuse of acronyms (Surdoval et al., 2024). High labor demands associated with implementation (Carlisle et al., 2019). Farmers' willingness to adopt sustainable agricultural practices is influenced by local-level limiting factors such as low access to water or temperature impacts, highlighting the importance of geographic context and climate impacts on farmer adoption (Koundinya et al., 2023; Niles, Lubell, & Brown, 2015; Schattman, Hurley, Greenleaf, Niles, & Caswell, 2020). Sustainable practices they can introduce greater variability in input availability and effectiveness (Dong & Mitchell, 2023). Sustainable agricultural practices, such as no-till may, lead to an increased use of herbicides. Conservation practices should not simply trade one environmental problem for another (Malone & McClintock, 2023). There is increasing evidence indicating that public organizations such as the Cooperative Extension Service and Soil and Water

Examples of the enablers	Examples of the barriers
	Conservation Districts have a decrease in their capacity to offer conservation programs related services due to the decrease in funding support they receive (Eanes et al., 2019). In certain commodity markets farmers increasingly operate under contracts with companies, such as corn seed companies, that impose restrictions on various aspects of their operations, including fertilizer management (A. P. Reimer et al., 2018; Stuart & Houser, 2018). Evidence regarding the substitution and complementarities of conservation practices is scarce (Fleming, 2017).
Domain 3: The Governance System	
(vii) Policies and Regulations	
The current Farm Bill already includes the Clean Water Act, Clean Air Act, and Growing Climate Solutions Act. The forthcoming Farm Bill should include provision to reward farmers for ecosystem services through a proposed "Soil Health Act" to further promote conservation agriculture as a solution to climate change and other environmental issues (Reicosky, Brandt, Reeder, Lal, & Montgomery, 2023). Increased policy support, along with a growing number of private sector carbon programs operated by food manufacturers, agribusinesses, and ag-tech startups (Snorek et al., 2024). Policy interest and support for cover crops have increased at the national, regional, and state levels (Guo, Marquart-Pyatt, Beethem, Denny, & Lai, 2023).	Local, state, and federal regulations are becoming increasingly complex (Koundinya et al., 2023; Surdoval et al., 2024). Regulatory and management challenges arise, as they require expertise either within the operation or through third-party consultants to manage documentation of certification (Mpanga, Tronstad, Guo, LeBauer, & Idowu, 2021). Organic agriculture, as defined by the USDA, is largely a process-based certification program rather than an outcome-based one (Lemke et al., 2024). The current crop insurance policy discourages farmers from adopting sustainable agricultural practices (Beetstra et al., 2022; Reicosky et al., 2023).

Examples of the enablers	Examples of the barriers
Cost-share programs and incentives are positively associated with higher adoption rates (Beetstra et al., 2022; Canales et al., 2024). The Environmental Quality Incentives Program (EQIP) payments have a statistically significant positive effect on cover crop adoption at the county level (Park et al., 2023). Conservation easement positively affects the intention to adopt sustainable agricultural practices, such as nutrient management (Doran et al., 2020). Increased flexibility (e.g., ability to leave a conservation program without penalty), certainty, and higher incentive payments boost farmers' willingness to adopt sustainable agricultural practices (Golden et al., 2024; Maas, Fuller, Hatzenbuehler, & McIntosh, 2023). Agricultural conservation programs and policies that are better aligned with farmers' goals and values advance the transition toward sustainable agriculture (Perry & Davenport, 2020). Recent flexibility in federal conservation policy has allowed programs to test unconventional partnerships in conservation and explore the effectiveness of relying on nontraditional intermediaries, such as crop advisers, to encourage program enrollment and decreasing barriers to adoption (Eanes et al., 2019; Adam Reimer, 2015). In recent years, there has been a growing use of conservation compliance policies that require agricultural companies to meet environmental standards to be eligible for payments and subsidies provided through federal agricultural support programs, including subsidized crop insurance (Palm-Forster et al., 2019).	Conservation programs enrollment complexity is a barrier (Houser et al., 2024; Wallander et al., 2023). Statistical evidence has shown that Conservation Stewardship Program (CSP) payments reduce the county-level proportion of acres planted to cover crops (Park et al., 2023). Difficulties in collaboration and communication between private and government agencies present a significant barrier to the promotion of conservation policies and programs by crop advisers (Eanes et al., 2019). The agricultural conservation policy has given little attention to the role of non-operating landowners and rental agreements (Ranjan, Wardropper, et al., 2019). In the policy context, private agricultural lands have been perceived and managed as a patchwork consisting of distinct production and nonproduction lands (Duff et al., 2017).

Examples of the enablers	Examples of the barriers
Government policy at the federal level encourage the adoption of conservation practices on actively farmed land, especially through working lands programs that offer both technical and financial incentives (A. P. Reimer et al., 2018).	