# Enhancing Biodiversity and Resilience in Intensive Farming Systems

By ETH-Zurich and IFPRI, October 2022

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# Executive Summary

The IPBES report named land use change, fragmentation, and degradation as the number one root cause of terrestrial biodiversity decline and agriculture is one of the major drivers behind. On the other hand, agriculture benefits from biodiversity and the ecosystem services it provides such as pollination, natural pest control or healthy soils which ensure food and feed supply, groundwater replenishment, erosion protection and many other ecosystem services. Based on this, ETH and IFPRI engaged in a collaboration to enhance the understanding of factors positively and negatively influencing farmers decisions to apply and implement measures to preserve or restore biodiversity and with that resilience of their farming systems with a focus on intensive row cropping systems (corn, soy, or wheat). The collaboration worked on 5 different work packages starting with farmer interviews in Brazil, Germany, France, and the United States to better understand farmers' knowledge, perceptions, and experience with biodiversity. In the second work package the collaboration looked at suitable parameters and indicators to assess the impact of those measures in a holistic way i.e., covering all 3 dimensions of sustainability (environmental, economic & social). The third work package was a comprehensive literature review (meta-analysis) with the objective to identify measures and management options which not only benefit biodiversity but also generate a value for farmers. A special focus was set on cover crops. The fourth work package was a deeper dive into farmers behavior by identifying and evaluating the factors relating to farmer willingness to participate in subsidy schemes or market mechanisms related to biodiversity. The last work package explored the spatial extent of the intensive corn, soy, or wheat production systems in the four selected countries. The collaboration leveraged a scientific and farmers network and tapped into comprehensive research, insights, and experiences in the field of biodiversity and agriculture.

The farmer interviews revealed that reduced chemical inputs, cover crops, crop rotation, reduced or no tillage as well as the preservation or restoration of habitats such as forests, permanent grassland, flower- or buffer strips are currently the most widely implemented measures. Farmers recognize that those measures and practices can have beneficial effects on input costs, soil health, soil erosion, water quality and beneficial insects such as pollinators. This was also confirmed by some of the available scientific meta-analysis which looked at the effects of measures such as cover crops or crop diversification. However, not all studies confirm a positive correlation between measures such as cover cropping and yield or profitability. In the light of these findings, it would be helpful for farmers to have more information and support available to be able to decide whether a certain measure makes sense to implement. The holistic assessment framework could bring more transparency on the benefits, synergies, and trade-offs of particular measures. In addition, it could not only advice farmers but also policy makers who seek to incentivize farmers for sustainability outcomes.

The main limitations for a wider adoption of biodiversity enhancing measures – particularly those related to habitat preservation or restoration are financial risks due to possible negative effects on crop yield and extra costs and efforts of implementation and maintenance. Policies which are supposed to increase adoption rates of biodiversity measures are very often considered as too strict and inflexible – particularly in France and Germany – and mostly do not cover the varying opportunity costs farmers face when adopting those measures. Also, current market conditions do not support a more wide-spread adoption of measures and practices, but carbon markets and food-chain company commitments around regenerative agriculture can have a positive impact here. Overall, farmers' willingness to adopt

biodiversity enhancing practices could be increased by providing support that makes the practices more financially appealing and by shifting from action-based payment schemes to result-based schemes which provide more flexibility.

We also did a spatial analysis to find out where the intensive farming systems are located. We had a focus on systems which have narrow crop rotations based on corn, soy (US, BR) or wheat (DE, FR). There is strong spatial heterogeneity of the distribution of cropland area, and individual crops. Each country shows unique spatial patterns, and the “hotspots” or clustering patterns are clearly demonstrated. We believe such assessment could help identifying the potential for connecting existing “habitats”, and pinpointing areas where “habitats” adoptions make more sense in terms of both biodiversity and agronomy.

# WP1. Analysis of interviews with farmers on biodiversity and resilience interventions


## Authors

Adina Kuncz, Wei Zhang, Nastasia Boul Lefeuvre, Pedro Brancalion, Michael Castellano, Anne Dray, Ana Paula Cervi Ferez, Fatima Lehnhardt, Peter Zander[1]



## Summary

In attempt to understand farmers' knowledge, perceptions, and experience with biodiversity enhancing practices, we conducted interviews with selected farmers in the United States, France, Germany, and Brazil. The interviews were split into four different sections: perceptions and attitude, experience, policies and programs, and aspirations and challenges. The intention of these interviews and the qualitative analysis detailed in this report is to help the project gain insight into the motivations that influence farmers' adoption of practices that improve biodiversity and the existing barriers that may limit their ability to embrace such practices. This report provides a summary of the key findings from each of the four countries we conducted interviews in. The information gained from these interviews can help improve our understanding about the kinds of strategies needed to help encourage farmers to use biodiversity enhancing practices, support farmers' implementation of practices, and mitigate any limitations they may be challenged with, or which cause discouragement. The generalization of the results, however, is limited by the non-representativeness of the farmer respondents.


## Methods

### Data Collection

The interviews were conducted in-person, over the phone, or through Zoom during late 2021-early 2022, depending on the country context (including the COVID-19 situation) and preference. Table 1 provides details on the interviews, recruitment, compensation, and data recording and analysis for the four countries we researched. Respondents were identified through various sources and channels, including country teams' own networks of farmers, which tended to represent relatively progressive farmers. The transcripts from interviews conducted with farmers in France and Germany and notes from interviews in Brazil were all translated to English. We conducted 16 interviews in the United States, 17 in France, 18 in Germany, and 16 in Brazil. Figure 1 shows the locations of the farmers who participated in the interviews. While the farmers were not randomly selected or representative, insights from these scoping interviews help ground our findings from the literature review, improve our first-hand understanding of farmers' perspective and experience with biodiversity enhancing practices, and can inform the design of future rigorous research.

### Analysis

The qualitative data analysis software, NVivo, was used to analyse the United States, France, and Germany transcripts. Excel was used to analyse the Brazil interview notes because transcripts were not available. Interviews were not recorded due to hesitations of some Brazilian producers who agreed to take part in

[1] AK and WZ corresponding authors, and remaining authors listed in alphabetical order.

the interview. Codes in NVivo and colour coding in Excel were used to identify and categorize themes across responses within each country. The NVivo and Excel analyses were documented into individual analysis summary documents, which provided an extensive overview of the main findings and themes from the interviews and highlighted supporting excerpts. This report was created based on the findings from the analysis summary documents (see Supplemental Information).

# Results

## Brazil

*Knowledge & Experience*

Some farmers defined biodiversity as a variation in plant, animals, and insects and a variation of fauna, flora, and microorganisms in soil, while other farmers described biodiversity as the maintenance of preservation areas. Nearly half of farmers indicated that they supported biodiversity through practicing no-tillage on their farms. Farmers believed that they could improve biodiversity on their farms by reducing their use of chemical inputs, using organic and natural products, crop rotation, and maintenance of preservation areas. Many farmers recognized that a benefit of biodiversity enhancing practices was cost savings that were gained from a reduced use of chemical inputs. Farmers also discussed the positive impact that biodiversity could have on soil, such as improved conservation, reduced erosion, and a stronger existence of microorganisms.

*Limitations & Adoption Considerations*

Farmers shared the risks that they believed were associated with implementing biodiversity enhancing practices and mixed responses were received. Over half of farmers said that they believed there were no risks involved with biodiversity enhancing practices. Conversely, a few farmers expressed that there was a risk in the unpredictable nature of biodiversity enhancing practices. Farmers were concerned it could negatively impact crop production or would be an investment that would not result in positive returns. Many farmers, however, recognized that although there were costs associated with implementing biodiversity enchaining practices, they were minimal and reasonable. The specific costs that were noted by some interviewees were alternatives to chemical inputs, poultry waste, rock dust, and hiring of a professional to assist with fauna protection.

Farmers also discussed the factors that motivated them to adopt practices that benefit biodiversity which included wanting to maintain or preserve water resources, a desire to improve soil quality, and environmental considerations. Some farmers also said their adoption decision were motivated by economic factors such as profitability, cost reduction, financial returns, and market trends. Over half of farmers expressed that a criterion they considered in their decision to adopt biodiversity enhancing practices were the financial impacts such as implementation costs, ability to lead to cost savings, and economic viability. Some farmers also said their decision-making criteria was based on practices' impact on the environment, ability to improve and maintain farm productivity, and ability to increase efficiency.

*Neighbouring Farmers*

All interviewed farmers said that they share their experiences with neighbouring farmers. Several farmers indicated that their experience sharing is well received, and several other farmers said they receive both positive and negative responses. Only a couple of farmers noted that sometimes neighbours were not receptive toward learning about their experiences. Farmers also provided several ideas on ways to increase regional support for biodiversity. One suggestion was to share best practices or positive results of biodiversity enhancing practices. Other suggestions were to increase research on biodiversity enhancing practices or incorporate local and farmer input on public efforts that are designed to support

biodiversity. Farmers also emphasized that financial support and incentives should be offered to those who adopt biodiversity enhancing practices.

*Policies & Programs*

Over half of interviewed farmers indicated that they have experience with biodiversity enhancing policies and programs, such as the Round Table on Responsible Soy (RTRS), Soja Plus, Brazil's Low Carbon in Agriculture Plan (ABC), the ABC plus plan, financing for irrigation, and Rabobank financing. Farmers held varying views on the freedom they believed they had within the policies and programs they participated in. Over half of farmers stated that they did not feel like they had freedom in deciding which preservation practices to adopt and how to implement them. However, nearly half of farmers expressed an opposing view and said that they felt like they did have freedom in choosing the practices they adopted. Farmers criticized policies and programs and stated that the benefits received are marginal, payments for environmental services are not yet a reality, and that resources from programs often arrive late. Several farmers noted that their decisions to adopt policies and programs are influenced by initial investment costs, financing assistance, reduced interest rates and costs, grace period, and risks.

Farmers suggested several changes to biodiversity enhancing policies and programs. Many said that more financial incentives, such as additional lines of credit, attractive interest rates, and market rewards, should be offered to farmers who participate in policies and programs. Farmers would also like to see greater disclosure, articulation, and publicizing of policies and programs. Farmers expressed that they would like to see changes in governance and said there was a misunderstanding between programs, a need to understand specific location rather than making a regional generalization, and a lack of in-depth explanations and monitoring of programs.

*Aspirations*

Farmers also shared their ideal property template, obstacles that they believed could limit their ability to achieve their desired farm in the future, and measurements of success. Many farmers said their ideal farm would be one that is more profitable, incurs lower costs, or better meets market demands. Some farmers also expressed that their ideal property template would incorporate new technology or include a biological factory. One of the main obstacles that farmers said could limit their ability to achieve their ideal farms were financial factors such as maintenance costs, price of inputs, inflation, difficulty accessing a line of credit, and challenges within the market for smaller production farms. Some farmers also felt that governance could be a challenge due to laws that dissuade agriculture technology development, bureaucratic issues, lack of government incentives, unclear laws, and political uncertainty and insecurity. Most farmers also said they would use financial factors to measure the future success of their farms, which could include a reduction in production costs, greater profitability, market visibility, more financial support, and increased revenue.

## France

*Knowledge & Experience*

Over half of the farmers that we interviewed defined biodiversity as an existence of diverse crops and wildlife. Several farmers also recognized biodiversity as a means for improving their farms, benefiting soil, or increasing resilience. Many farmers indicated that they use several practices that improve biodiversity on their farms. The practices that were used by the most farmers include reduced or no-tillage, crop rotation, use of organic matter, decreased application of chemical inputs, cover crops, grass strips, and hedges. Farmers were also asked about their views on organic farming and many shared negative perceptions of it. Farmers felt that organic farming was risky, lacked financial benefits, and is ineffective.

*Limitations & Adoption Considerations*

Farmers largely expressed that cost was the biggest limitation they faced in implementing biodiversity enhancing practices. Many farmers were concerned about the surface area they would lose by adopting certain practices, the potential risks they would face in their production outputs, and the expensive costs of necessary crops and plants. One of the biggest cost concerns of farmers was acquiring the required tools and equipment for new practices. Many farmers said they would like to adopt more biodiversity enhancing practices but lacked access to equipment or the financial means to purchase equipment.

Farmers also shared the factors that motivated their adoption of biodiversity enhancing practices. The most popular motivation sources that were discussed were soil health and hunting. Farmers selected practices in response to soil erosion and declining soil quality. Additionally, since many farmers are also hunters, they have a desire to see a strong wildlife presence on their land which drives them to adopt practices that improve biodiversity. Farmers also discussed how generational influences impact the practices that are used on their farms. A lot of farms are within a family and passed down throughout generations. Some farmers said that they chose to continue the practices that their family had previously used, while others said that a change in a new generation managing the family farm led to the adoption of new practices that were supportive of biodiversity.

*Neighbouring Farmers*

Many of the farmers we interviewed indicated that they were willing to share information on the practices they use with neighbouring farmers. A few farmers even said that they had shared their equipment with neighbours, however, their collaboration did not extend beyond that. Farmers provided mixed views on their neighbours' willingness to adopt biodiversity enhancing practices. Some farmers said they believed their neighbours were open to adopting practices, despite not yet implementing them, while others said it did not appear that their neighbours were interested in shifting to practices that improve biodiversity.

*Policies & Programs*

Farmers also shared both positive and negative views on the public policies and agri-environmental programs that the government has implemented. Many farmers indicated that they are involved in Economic and Environmental Interest Groups (GIEE) and have had positive experiences with these groups. Farmers viewed GIEEs as an opportunity to share information with other farmers, experiment with different practices, and receive guidance from a technician or economic support from financers. Farmers who discussed France's Common Agriculture Policy, largely held a negative view of it and several noted that there was a disconnect between farmers and decision makers. Farmers also shared negative views of High Environmental Value certification and expressed that there were not many benefits to receiving the certification. A few farmers stated that regulatory constraints made it difficult to participate in agri-environmental policies and programs.

*Aspirations*

During the interviews, farmers also discussed their hopes for the future of their farms and their aspirations for the next 5 or 10 years. Farmers held a variety of different aspirations. A few farmers said that they would like to continue their current practices but expand their soil conservation efforts. Some farmers said that their goal for the future of their farm was to be able to pass it down within their family and that practices that improved biodiversity would be continued by new generations. Other farmers said that in the future, they would like to test out new practices on their farms and have the ability to create their own techniques.

## Germany

*Knowledge & Experience*

Many of the farmers that we interviewed defined biodiversity as a variety in species of plants, animals, and insects. Several farmers recognized that biodiversity led to greater beneficial insect and specifically pollinator presence on their farms. Some of the other benefits that were mentioned by farmers were cost savings through a reduction of chemical inputs, improved soil fertility, decreased soil erosion, decreased pollution, and increased wildlife presence. Farmers also shared their experiences with biodiversity enhancing practices and all farmers said they practiced crop diversity and crop rotation. Additionally, flower strips and a reduced use of chemical inputs were practiced by many interviewed farmers, and many viewed these practices as positive and beneficial. Several farmers also said they had permanent grassland on their farms and made efforts to decrease their energy usage. Many farmers expressed that soil testing was incredibly important and beneficial and helped them to monitor how their soil conditions are.

*Limitations & Adoption Considerations*

Farmers' discussion of the motivators and limitations they experience while choosing biodiversity enhancing practices confirmed that they are largely influenced by financial factors. Farmers expressed that they were most concerned about the costs they would incur from adopting practices that improve biodiversity and the potential losses or changes in production they would experience. Other limitations that were discussed by several farmers is that the current market is not favourable toward farmers who use biodiversity enhancing practices and high seed costs. Many farmers shared that they were motivated to choose biodiversity enhancing practices by monetary incentives and greater cost-benefits. A few farmers emphasized that they did not want to experience any financial losses by adopting a practice and that they're decision making was influenced by this concern.

*Neighbouring Farmers*

Many farmers stated that they shared their experiences with neighbouring farmers, however, a few stated that it did not lead to any positive change. Most farmers indicated that they do not coordinate their practices with neighbours. Farmers also varied on whether they believed their neighbours shared similar perceptions to them on the promotion of biodiversity. Some farmers believed their neighbours hold the same views as them, while others believe they differ. Farmers also expressed that their neighbours were often open to adopting biodiversity enhancing practices, however, they wanted to know that practices were beneficial and practical before implementing them. Farmers stated that they believed regional support for biodiversity could be gained by easing restrictions, recognizing regional differences and needs, offering financial incentives, and providing support for intercropping, flower strips, and measures that enhance bee populations such as bee banks and seed mixtures for bee pastures.

*Policies & Programs*

A majority of interviewed farmers stated that they have participated in policies and programs that are related to biodiversity, such as crop protection technology, water protection programs, the Hessian Agri-environmental and Landscape Management Measures (HALM) (die Hessischen Agrarumwelt- und Landschaftspflege-Maßnahmen[2]), organic farming subsidies, and watering programs. Farmers largely expressed that financial considerations such as costs and incentives available, were the most important

[2] The Hessian Agri-environmental and Landscape Management Measures (HALM) refer to agri-environmental measures in the state of Hessen in Germany. For more information: https://llh.hessen.de/unternehmen/agrarpolitik-und-foerderung/halm/

factors for them to participate in policies and programs. Many emphasized the importance of financial assistance to help cover any potential losses or impact on crop yield that could result from adopting measures related to biodiversity. A few farmers also stated that they considered the amount of effort that is required to apply and participate in a program. Other farmers said it was important for them to know that participating in a program would lead to beneficial results. Nearly all farmers expressed that they believed program and policy requirements were too strict and only a few farmers said they were not too restrictive.

Further, the most frequently stated change that farmers said they would like to see in current policies and programs was less restrictive regulations. Some farmers said that requirements and regulations are not always beneficial for their farms, while others said they desired more freedom in their decision making.

*Aspirations*

Farmers also shared the biodiversity enhancing practices they would like to implement if cost wasn't an issue and how they would measure future success on their farms. The practice that the largest number of interviewed farmers said they would like to introduce or expand was flower strips. Farmers expressed that the flower strips they currently have are beneficial, for instance, for beneficial insects, and they would like to increase their presence. A couple of farmers also said they would like to avoid the need for plant protection products, and when it is needed, use technologies that require fewer applications, while others shared that they would like to increase their crop diversity. Farmers said they would consider their farms to be successful in the future if direct marketing improved. Farmers also described success as happiness and an improvement in personal well-being, including for employees and families. Other less popularly determinants of success that farmers noted were an ability to maintain their farms for future generations or achieving a more efficient use of resources.

## United States

*Knowledge & Experience*

Many interviewed farmers defined biodiversity as various forms of life cohabitating in one area. The most commonly noted benefits of biodiversity were improved soil health, reduced soil erosion, and improved water quality. Almost all interviewed farmers said they have cover crops and nearly a third of farmers said they would like to increase their cover crops in the future. Many farmers also use no-tillage, crop rotations, and buffer strips. The practices that farmers least commonly stated they used are tile drainage, application of organic fertilizer, reduction in fertilizer used, and the addition of waterways.

*Limitations & Adoption Considerations*

Although it was evident that most farmers recognized the benefits of biodiversity, all farmers noted that their ability to introduce new biodiversity enhancing practices or expand current practices was challenged by costs. The costs discussed were for equipment, seeds, and additional labor. Several farmers also discussed the potential costs and risks associated with the uncertain impacts that biodiversity enhancing practices could have on profits and crop yield. Some farmers feared that implementing biodiversity enhancing practices would maintain or increase their current costs but result in decreased crop production. Many farmers also emphasized that the cost of practices and their impact on profit was a significant consideration for them while deciding on whether to adopt a practice.

Concerns about costs could potentially be mitigated by providing farmers with increased evidence on the benefits of biodiversity enhancing practices and certainty of non-consequential outcomes, or by offering more financial assistance. During the interviews, a couple of farmers expressed that it was important for them to know the long-term outcomes of biodiversity enhancing and conservation practices to ensure that the investment in the necessitated costs was worthwhile. Additionally, many farmers stated that they

believed regional support for biodiversity could be strengthened by spreading awareness and educating farmers about the benefits of practices. Regional support could also be gained by providing financial assistance to help cover the costs associated with biodiversity enhancing practices.

*Neighbouring Farmers*

Most farmers indicated that they were willing to share their experiences with practices that improve biodiversity with neighbours. Some farmers expressed that although their neighbours initially seemed interested in learning about practices, they seemed to become frustrated or impatient because they did not fully understand the management style needed or achieve immediate benefits. Additionally, many farmers said that their views on biodiversity enhancing practices differed from their neighbours and that most neighbours were unwilling to adopt these practices. Farmers stated a variety of reasons for this such as a desire to continue the practices they currently use and are comfortable with, short-term rent leases discouraging the prioritization of long-term conservation practices, and the unknown outcomes of practices.

*Policies & Programs*

Almost all farmers said that they are currently part of or have previous experience with policies and programs that support conservation such as the Conservation Reservation Program, the Conservation Reserve Enhancement Program, and the Conservation Stewardship Program. A majority of farmers expressed that they felt like they had freedom in deciding on which practices to adopt and how to implement them while participating in these policies and programs. However, a few farmers still stated that they felt like they did not have freedom in their decisions because programs are strict on qualifications, and some were ineligible to participate. Nearly half of the interviewed farmers stated that their decisions to adopt conservation policies and programs were influenced by financial factors such as incentives, payments, costs, crop yield, and ability to predict conservation practices' impact on finances. Farmers said they needed to know the policy or program resulted in a financial benefit or contributed to profitability. When farmers were asked about the changes that they would like to see on current conservation policies and programs, most said increased incentives or cost share was needed. Other desired changes discussed included a need for additional information on the outcomes of the required practices of policies and programs, and an incorporation of local input while designing the policies and programs.

*Aspirations*

During the interviews, farmers discussed their hopes for the future, their ideal farm system, and the potential challenges they face in achieving their ideal farm. Several farmers said they hoped their future farms' value and profits increase. A couple of farmers said they hoped markets improved for biodiversity enhancing practices and that costs of practices decreased. Farmers also emphasized that they hoped their future farm was environmentally safe or maintained an appreciation for conservation or could be passed down within their families. Of the farmers who discussed the issues they believe could challenge their ability to achieve their ideal farm in the future, several noted financial limitations. Farmers said that they would measure success on their farm by an increase in their return on investments. Some farmers also measured success by their ability to pass down their farms to family or whether future farmers adopted conservation practices.

## Conclusion

Across interviews in all countries, it was evident that financial factors largely influence farmers' adoption of practices that improve biodiversity. Famers' concerns in the United States about costs could potentially be mitigated by providing them with evidence about the long-term benefit of biodiversity enhancing

practices and supporting them in assessing the financial implications of alternative technologies and through offering increased financial support. Farmers in France feel most limited by a lack of access to necessary equipment and an inability to afford the expensive cost of equipment. German farmers also share cost concerns and believe that policies and programs that benefit biodiversity need to offer increased financial support; likewise, they believe they are too restrictive in their requirements. Many farmers in Brazil believe that the costs associated with practices that improve biodiversity are manageable but are most influenced to adopt practices by the potential to gain profit or reduce current costs. Farmers' willingness to adopt biodiversity enhancing practices could be increased by providing support that makes the practices more financially appealing.

Follow up interviews of a sub-set of originally interviewed French and Brazilian farmers were conducted in the summer 2022 (See summaries of results in the Supplemental Information). A workshop with farmers and other stakeholders (including, e.g., extension and local government) in the US, hosted by Iowa State University, has been scheduled for mid-November 2022.

Table 1. Interview methods used in each country

| Country | Participant Identification | Invitation Process & Acceptance | Incentives Offered | Data Recording | Number of farmers interviewed | Avg. Interview Length |
|---|---|---|---|---|---|---|
| **Brazil** | Identified participants by reaching out to companies, traders, and active NGOs who provided information on interest groups and producers who might be interested in participating. | Called and emailed recommended producers. Sent a WhatsApp message if no response was received. When possible, asked recommending company or institution to directly contact producers in order to form a relationship with us.<br><br>Contacted 60 producers. 24 did not respond. | No incentives were offered. Informed participants that they could potentially learn about the survey results at the conclusion of the project. | Most interviews were conducted on Google-Meet and some conducted on a WhatsApp phone call.<br><br>Interviews were not recorded due to hesitations from some producers. Interviewers translated their notes to English. | 16 | 60 minutes |
| **France** | Identified based on contacts already established or through the Chamber of Agriculture Nord Pas de Calais and then used snowball sampling to find additional potential participants. | Emailed or called farmers that were already established contacts. The Chamber of Agriculture also provided us with the contact information of farmers who were interested in participating.<br><br>Contacted approximately 50 farmers (not including those contacted directly by the Chamber of Agriculture). About 40 farmers did not respond and none directly declined. | No incentives were offered. Participants voluntarily did interviews. | Interviews conducted either in-person or on Zoom.<br><br>Interviews were recorded either on a voice recorder or directly on Zoom. Interviewer transcribed and translated all data. | 17 | 60 minutes |
| **Germany** | Identified through contacts provided by Bayer AG, ZALF networks, local farmers associations, and an online list of apprenticing farms. Farmers located outside of Brandenburg were identified through personal contacts. | Wrote to and called farmers associations who included interview invitation in their newsletter. Contacted ZALF departments for farmers' contact information and presented at a ZALF event to personally invite farmers. Called farmers from various contact lists to invite to participate.<br><br>Over 200 farmers were contacted from the online apprenticing farmer list. 35 farmers were contacted through the ZALF networks. 18 ZALF farmers were either unreachable, non-responsive, or declined participation. | No monetary compensation was offered. Gave participants option to be invited to a future workshop to provide their feedback on our research. | Interviews conducted over the phone except one was done on Zoom.<br><br>Interviews were recorded. Transcription and translations were done by interviewees with the help of a master student assistant. | 18 | 60 minutes |

| Country | Participant Identification | Invitation Process & Acceptance | Incentives Offered | Data Recording | Number of farmers interviewed | Avg. Interview Length |
|---|---|---|---|---|---|---|
| **United States** | Half were identified through the Illinois Soil & Water Conservation District (ISWCD) and half through personal connections of the US team leader based at Iowa State University. | Representative from ISWCD contacted half participants and the interviewer directly contacted the other half.<br>All contacted participants accepted the invitation. | Compensation of $100 was only offered to contacts that EPTD already had an established connection to (not all farmers accepted). | Interviews conducted in-person. Transcripts were composed in real time by interviewer on a laptop. (Lead interviewer believed farmers preferred this over a live recording). | 16 | 75 minutes |

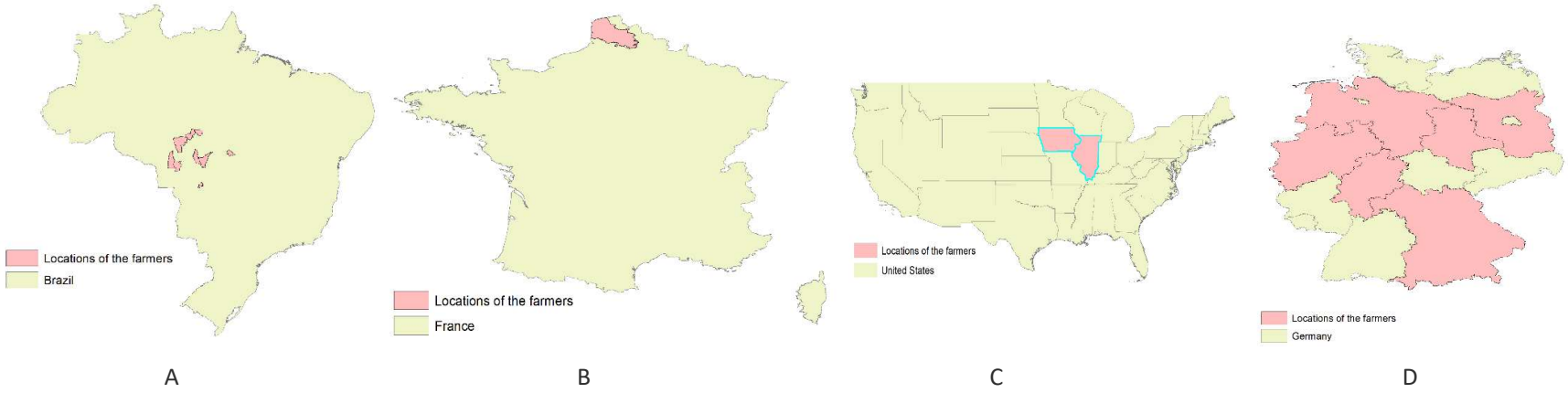


Figure 1. High-level locations of interviewed farmers: A) Brazil, B) France, C) USA, D) Germany

# WP2. An assessment framework for identifying opportunities in advancing biodiversity-enhancing agricultural practices


## Authors

Xin Zhang, Adam M. Komarek, Alicia Lee, Kevin Jackson, Wei Zhang, and Pavithra Pitumpe Arachchige[3]



## Summary

This work package proposes an assessment framework to evaluate how biodiversity-enhancing agricultural practices impact outcome indicators for the multiple dimensions of sustainability. The framework considers major impacts of agricultural practices on sustainability at the farm-scale and beyond-the-farm spatial scales, as well as at shorter-term and longer-term temporal scales. With extensive literature review and discussion with experts, we identify major aspects of the environmental, economic, and social pillars of sustainability as they relate to biodiversity-enhancing agricultural practices. We then identify performance indicators that are designed to quantify the outcome indicators of practices on sustainability within the three pillars. We use cover cropping in the United States as an illustrative example of the framework. This example highlights the trade-offs and synergies between performance indicators within and across the pillars at different spatial and temporal scales. The example demonstrates the potential of utilizing the framework to facilitate the design of policies and incentives to accelerate the adoption of biodiversity-enhancing agricultural practices. Consequently, we identified potential next steps to operationalize and utilize the framework with more stakeholder inputs.


## The framework

The proposed framework assesses how agricultural practices affect outcome-based performance indicators across three factors:

1. Three pillars of sustainability being environmental, economic, and social (1, 2). These pillars help illuminate trade-offs between multiple objectives concerning sustainability. They were adopted in our assessment because they cover the major aspects that are important to farmers and society when evaluating farmer decisions to use biodiversity-enhancing agricultural practices. The use of the three pillars reflects a “classical view of sustainability” (3), and is analogous to the triple bottom line approach of people, profit, planet (4), or Corporate Social Responsibility approach, used by corporate businesses. The use of three pillars is consistent with the European Commission’s Common Agricultural Policy that aligns their ten key objectives to the social, economic, and environmental pillars of sustainability (EC, 2022).
2. Two spatial scales of farm-scale and beyond-the-farm scale. The first scale is limited to the farm where the agricultural practice is implemented, and the other is the spatial scale beyond the farm, such as the landscape, region, and globe. Impacts at the farm-scale capture the internal and private benefits and costs for the farmer who adopts the particular agricultural practice. As externalities are common in agriculture, the actions of farmers have implications beyond their decision-making units (i.e., their land area). Therefore, we included beyond-the-farm performance indicators of agricultural practices to capture the public benefits and costs of the farmers' private actions, i.e., externalities.

[3] XM and AMK corresponding authors, with remaining authors listed in alphabetical order.

3. Two temporal scales: shorter-term (e.g., one to several growing seasons or years) and longer-term (e.g., several decades) effects of a particular agricultural practice. The time scale for shorter term and longer term is more of a continuum than a discrete distinction (5).

Figure 1 presents the proposed framework. The framework focuses on the impacts of an agricultural practice. Various socio-economic, geographic, and biophysical factors drive, influence, or enable the impacts, depending on the practice studied and its context. The purpose of this framework is to focus on the impacts as they relate to the 'relative advantage' of the practice and what it means to the farmer and beyond through a range of performance indicators of output. This 'relative advantage' is one of the five attributes that seeks to explain the diffusion of innovations (6).

The **environmental** pillar considers the impacts of agricultural practices on five aspects: Soil Health, Water Availability, Pollution, Climate Change, and Biodiversity. This consideration aligns with the major aspects assessed under the environmental dimension of the Sustainable Agriculture Matrix (7). The environmental pillar is critical to consider as the natural resource base of the earth is the ultimate means to sustaining life and must be examined closely and regularly. The ability of a farm to survive financially in the longer term will be compromised if the ecosystem and natural resources underlying the farm production system are not sustained. The **economic** pillar considers how agricultural practices affect the aspects of Productivity, Farm Profit, Regional Economic Viability, and Risks. Farm Profit is essential as it is a strong motivating factor in farm decision-making. Without positive profits, a business will not survive in the longer term. A strong motivation for investing in sustainable actions in the business world is if changes in agricultural practices have positive effects on profitability or Corporate Social Responsibility (8). The aspects within the economic pillars are closely linked as Productivity is a major component of Farm Profit, and Risk is often related to deviations in a performance indicator from an average, such as Farm Profit under weather or price variability. The **social** pillar considers how agricultural practices affect the Well-being, Rights and equality of farmers and include a range of factors such as employment, working conditions, income distribution, the Resilience of a farm and its community to shocks, and Health and nutrition for the region. These aspects also align with major features in the social dimension of the Sustainable Agriculture Matrix framework (7). The social pillar addresses the well-being of the farming community and supports the ability of future generations to maintain a healthy community.

For each aspect within a pillar, indicators will be designed to help assess the impacts of agricultural practices on performance. Accordingly, we reviewed and summarized indicators in the literature, including from EC (2021), with a focus on measuring the impacts. We then provide specific examples of indicators within each aspect and showcase an application of the framework using cover cropping in the United States as an example (Figure 2). The basic criteria for selecting indicators for each major aspect of assessment include 1) the relevance of an indicator to a major aspect of the agricultural sustainability assessment, 2) whether the indicator having a monotonic relationship with the major aspect of assessment, 3) whether the indicator measures the outcome or performance of the practice, and 4) data availability (Zhang et al., 2021).

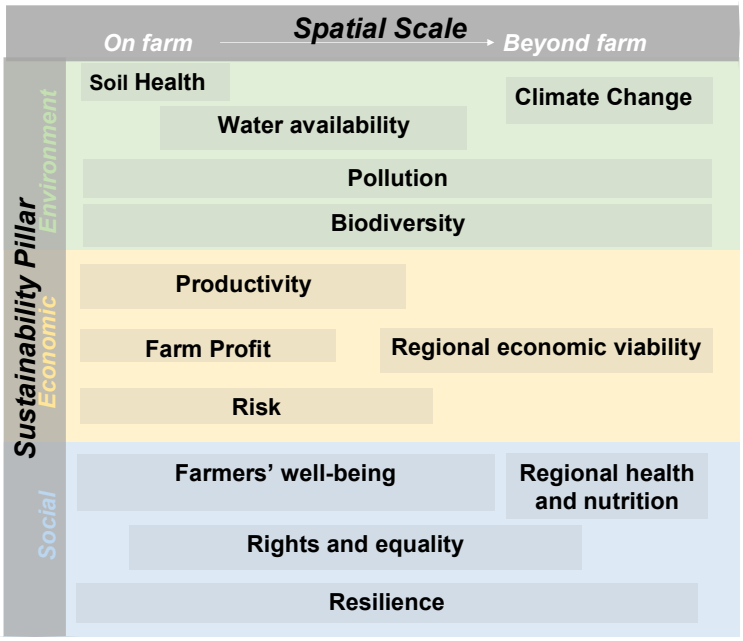


**Figure 1.** Three sustainability pillars and their major aspects for assessing direct and indirect impacts of biodiversity-enhancing agricultural practices on performance indicators at farm-scale and beyond-the-farm scale.

## Operationalizing the framework

We propose the following steps for operationalizing the framework:

- Co-identify an agricultural practice to assess with a salient stakeholder of the agricultural practice, such as a farmer or policy maker. This co-identification would involve a discussion of the stakeholder's broad vision and then more specific goals related to the agricultural practice, and potential practices available based on the stakeholder's goals, local context, and circumstances.
- Collect data for performance indicators. This data collection could include data from farmers, data from experimental fields, satellite data or simulation data generated as part of assessments.
- Calculate performance indicators.
- Assess trade-offs and synergies among indicators. This assessment will be carried out in two steps: first, quantitatively evaluate the relationships among indicators; second, the initial quantitative assessment results will be presented and discussed by stakeholders in order to evaluate the conclusion and the limitation of the quantitative assessment. The second step is important because that the qualitative analysis could be limited by the data availability and non-linear relationship, consequently, some "hidden" trade-offs may not "emerge" from the qualitative analysis.
- Stakeholder discussions to provide nuances and context to results that foster a co-understanding of practice performance.

## Illustrative application of framework to cover crop practice

Here we demonstrate how cover cropping in the Midwest of the United States could affect the aspects of each sustainability pillar within the proposed framework at different spatial and temporal scales. This will inform, but not determine, practice adoption especially within the 'relative advantage' attribute for the practice studied. The report card presented in Figure 2 is hypothetical and the colour coding is the potential impact. The traffic light system is all relative to what practices are being compared and the objective of the farmer, so for a green colour an indicator would have to move in a

more sustainable direction compared to a reference case. For example, if labour requirements in a cropping system are 5 hours per ha per season and adding a red clover into the cropping system as a cover crop increased labour demand to 5 hours per ha per season, then the colour code would be green if the increase deemed more sustainable and red if the increase is deemed less sustainable.

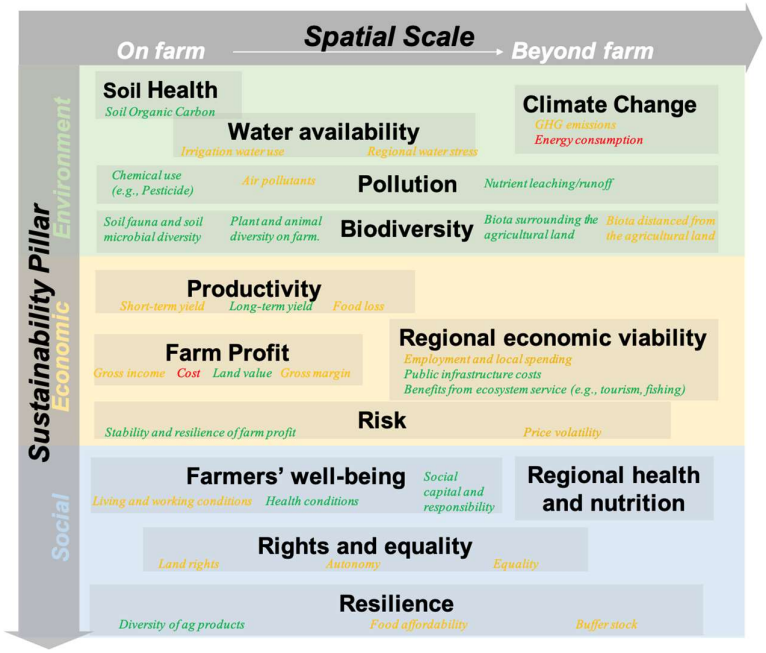


**Figure 2.** An example of a report card for assessing the impacts of cover cropping on three pillars of sustainability on- and beyond-the-farm. The major themes for the assessment are color-coded to indicate the potential impacts of the agricultural practices: green (or red) indicates that the practice improves (or undermines) the sustainability performance of the specific assessment theme; while yellow indicates the impacts are uncertain or variable.

Cover cropping has the potential to affect all three pillars of sustainability at different temporal and spatial scales. With respect to the environmental pillar of sustainability, it affects soil health, water availability, climate change, pollution, and biodiversity (Figure 2). Examples include, cover crops can improve the soil's organic carbon contents over time, an indication of improving soil microbial/faunal activities and diversity (9, 10), which can promote early crop growth and uptake of nutrients and water (see Chapter 3 for detailed review). Cover crops often simultaneously improve the biodiversity of the farm and its surroundings, such as landscape connectivity and marginally enhance the diversity of plant species on farm and extend the vegetated cover habitat for various animal species. Increasing plant diversity (i.e., legumes, C3/C4 grasses, non-legumes) on farms enhances the proliferation of soil microbial communities and also has the potential to minimize the diversity of soil-borne pathogens, though this depends on the combination by which cash crops and cover crops are implemented: a cereal cover that follows a bean cash crop might reduce pathogens, while a cereal cover that follows a cereal cash crop typically increases pathogens (11). Cover cropping can improve soil water storage and infiltration which are adaptation options for high variability in rainfall, both on-farm and beyond the farm (i.e., landscape) scale (12).

Cover cropping increases variable costs for a cropping enterprise as an extra crop is planted in addition to regular cash crops. The highest cost is often for seeds that may vary based on the variety of the cover crop (13). Even though, the seed cost of cereals is much cheaper, adding a cereal rye cover crop to a maize-soybean rotation increases the frequency of farm management activities (may require N supplements for growth compared to legumes), and therefore increases variable production costs. Extra variable costs relate to planting, managing (nitrogen fertilizer applications), and terminating the

cover crop, including costs for herbicides. Cover cropping could increase gross income via altering system-wide yields, government subsidies, and cost-share payments. Other increases in gross income could occur if the cover crop is harvested and sold or grazed or harvested for use as livestock feed. Further, cover crop residues can generate revenue when sold as biofuel feedstocks (14). While some studies have indicated a negative economic impact of cover cropping (15-17), these economic analyses often overlook the social and environmental changes, as well as potential yield gains, that cover crops can bring. Outcomes are variable and there are both positive or negative impacts on cash crop yield following cover cropping and given environmental complexities and interactions across sites it remains difficult to identify generalizable management approaches for delivering consistently positive effects. Some progress has been made in accounting these benefits and framing them into a payment scheme, and such progress has been reviewed in WP4 in this project. Some of these changes include soil erosion control, nutrient cycling, weed control, mycorrhizal fungi colonization, reduce till, increased SOM, reduced surface water runoff, and soil carbon storage (19).

Cover cropping can potentially strengthen the social pillar of sustainability, for example as an opportunity for farmers to learn new skills and participate in groups. By serving as a natural mulch and a competitor for light, nutrients and water and releasing allopathic compounds, cover crops can suppress the growth of weeds, thus reducing the number of herbicides needed. Cover cropping can also help mitigate risks (e.g., soil erosion, flooding damages, and disease outbreaks) and thus enhance the stability of farmers' income and minimize their need to work excessive hours to address these risks over the long term.

The impacts of cover crop practice on the three pillars of sustainability are interlinked. Cover crops tend to lower profits in the short run mostly as variable costs increase. United States Department of Agriculture cost-share payments are offered to reduce the opportunity cost of using cover crops, but these cost-share payments are typically insufficient to fully compensate for the lower profit, at least in the shorter term. Cover cropping may deliver public benefits such as cleaner waterways. Insurance pay-outs for flooding may be reduced if cover crops are used but still require taxpayer funded programs such as cost-share programs. The nature of these trade-offs would change over time and capturing how future costs and benefits accrue into the future are critical.

Cover cropping can have benefits, as listed in the preceding paragraphs, but most of these benefits are not given for granted in absolute terms, i.e., they only are realized under specific conditions and contexts, such by cropping system, climate, soil, and landscape, or they are not coming through every year. And this makes assessments frequently complex and ambiguous. It is currently not possible to use the report cards for a quantitative operational assessment or for ranking the practices according to their sustainability in a certain context. A research need is to implement the framework.

## Conclusion and next steps

The proposed framework and associated indicators provided an opportunity to assess the multi-scale and multi-dimensional impacts of agricultural practices, enabling the identification of several trade-offs and synergies associated with implementing an agricultural practice, and consequently offer new insights into policy and market options to incentivize and enable the proliferation of biodiversity-enhancing agricultural practices. For example, the trade-offs between the economic cost of cover-crop practice on farm and the social and environmental benefits of cover-crop practice beyond the farm indicates the need to internalize the externalities of agricultural practices.

Future efforts are still needed to 1) operationalize and improve the indicators for all major aspects of the assessment framework; 2) test the assessment framework for various agricultural biodiversity-enhancing agricultural practices in various ecological and socioeconomic conditions, and compare the result; 3) simplify the indicators and framework design, and automate the data collection and analysis, reducing the burden of on-farm data collection for farmers and researchers; 4) co-develop the

framework with stakeholders and test various application of the framework in assisting decision making by stakeholders such as policymakers and farmers.

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# WP3: Investigating habitat measures effects in the literature and farmers' attitudes, and technologies developed to manage farm interventions


## Authors

Maryam Yousefi, Johan Six, Jaboury Ghazoul


## Highlights

*Cover cropping effects on soil health and other ecosystem services*

- Benefits of cover cropping are 1) soil biodiversity and nutrient enhancement, 2) runoff and nitrogen leaching prevention, 3) soil physical properties and long-term soil organic carbon improvement, and 4) pest and weed suppression.
- Two critical challenges of cover cropping are grain yield and soil water content inconsistency.
- The literature review results are generally well aligned with farmer opinions as reported by the interviews (see WP1).
- There have been relatively few field experiments specifically designed to investigate cover crop outcomes, especially in Germany and France.
- The effectiveness of cover cropping on farmland arthropods and pest management is poorly understood, on account of limited number of studies and the consequent difficulty of undertaking synthetic meta-analyses.

*Plant diversification effect on farm arthropods abundance across field and local scales*

- Diversified cropping systems across two scales alters the structure of farm arthropod communities.
- Plant diversification significantly decreased herbivores and increased natural enemy abundance at field scales, but positively influenced natural enemies at local scale.
- Flower strips had a more positive effect on natural pest control arthropod abundance compared to hedgerow and grassy margins at local scale.
- There is no additional benefit for natural pest control populations of flower strips that are more than 10 meters in width.
- Combining flower strips and intercropping to take full advantage of crop diversification is recommended.

## Introduction

The report documents the range of biodiversity-related farm interventions as revealed in a thorough literature review and evaluates the effects of the main interventions (based on available evidence) on soil health parameters. The first section provides an overview of the main results, with a specific focus on cover cropping, followed by region-specific outcomes. The outcomes are compared to the results of farmer interviews to evaluate the extent to which farmer perceptions match scientific evidence. The second part quantified the effects of plant diversification cross field and local scale on farm arthropod abundance. The last section provides a summary of a systematic literature review on emerging technologies in smart cereal farming, which could ultimately benefit biodiversity and soil

health by improving input efficiencies and improving the targeting of management interventions, especially given the substantial contextual heterogeneities that exist across farm systems.

## Initial review of literature and determination of the range of interventions

Using a systematic review approach (based on a total of 4,354 peer-reviewed articles sourced from the ISI Web of Science Core Collection, 1900-present, https://www.webofscience.com), we identified eleven farm interventions that have been studied in relation to their effects on biodiversity in intensively managed maize, wheat, or soybean crops. These interventions include irrigation scheduling, plastic mulching, conservation tillage, organic fertilizer, biochar, $CO_2$ enrichment, crop residue, cover crops, intercropping, straw mulching, and crop rotation. Following an initial review and selection process, 3,255 studies were retained for further analysis (Table 1 in the main report describes biodiversity categories and their definitions and characteristics that were used for the search). Most farm intervention activities, based on the frequency with which they have been reported in the literature, were crop rotation and conservation tillage followed by intercropping. Straw mulching, plastic mulching, and biochar have been the least studied. This initial review process served to identify the knowledge gaps with respect to the effects of agricultural interventions on biodiversity-related ecosystem services. We were also able to identify interventions for which there have been sufficient studies to conduct a robust systematic review.

## Case study: cover cropping

We conducted a detailed review of the effects of cover cropping on various attributes of soil health, responding to the direct request from Bayer.

The search on Web of Science and Scopus in March 2022, yielded 1360 publications. The screening conducted according to two criteria: (1) cover crop treatments were compared to no cover crop controls, and (2) the effect of cover cropping on soil properties and other ecosystem services were included. A total of 148 publications were retained based on screening the titles and abstracts. The full texts of these articles were read, and a total of 44 articles were ultimately included in the synthesis. Finally, a ranking method based on Rosa-Schleich et al (2019) was applied for each indicator. We coded the positive output as 1 and a negative output as −1; if both effects or no effect were reported in the literature, we coded the result as zero. We then summed the numbers for each outcome, divided them by the number of papers for each outcome, and ranked cover crop performance accordingly.

The results revealed several factors are influential in determining the relative benefits and risks of integrating cover crops into crop production systems. These crucial factors are included farm practices (Bowles et al, 2017, Toler et al, 2019; Ruis et al, 2019), planting and termination season (Schutter et al, 2001; Ruis et al., 2019), cover crop and main crop species (Shekoofa et al, 2020), climate zone and soil properties (Kim et al, 2020), cover crop biomass (Brennan and Smith 2005), and cover crop residue management (Karuku et al., 2014) (Figure 1).

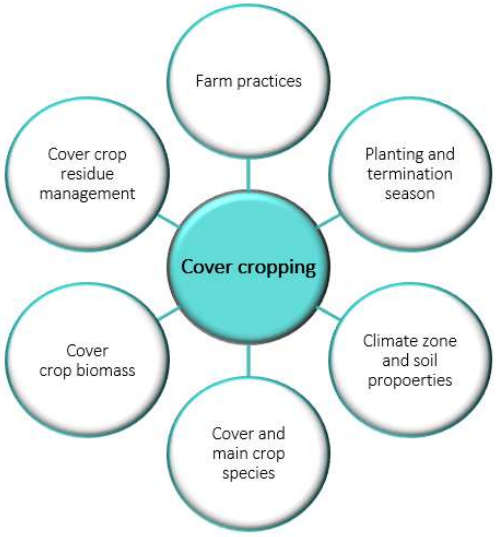


Figure 1. Factors influencing the effectiveness of cover cropping (source: literature review)

Our review evaluated the role of cover crops on soil health parameters including biodiversity status, water content, nutrient status, N leaching (NL) reduction, runoff prevention, soil physical properties, and Soil Organic Carbon (SOC). Soil health parameters and other ecosystem services measured in the study are presented in Tables 1S and 2S in the Supplemental Information.

Cover crops positively impact soil microbial abundance, activity, and diversity (Hallama et al, 2019, Kim et al, 2020). Cover crops are suggested to increase soil microbial community by supplying a legacy of enhanced mycorrhizal abundance, microbial biomass P, and phosphatase activity (Hallama et al, 2019). A meta-analysis including data from 81 available studies revealed that cover crops overall enhance microbial biomass C and N and phospholipid-derived fatty acids by 24–51% (Muhammad et al, 2021). In terms of the influence of climate conditions on cover cropping effectiveness, increased precipitation, decreased microbial community abundance and structure due to enhanced soil water content (Muhammad et al, 2021).

Under conditions such as continental climate, chemical cover crop termination, and conservation tillage, cover cropping impacts were less noticeable, showed a meta-analysis conducted by 60 relevant studies (Kim et al, 2020).

Cover crops generally reduce nitrogen leaching (NL). However, the strength of this effect depends on the timing of the release of N from cover crop and its uptake by the main crop (Bawa et al, 2021). Cover crop species also influenced this process. The results showed that non-leguminous cover crops could substantially reduce $NO_3$ leaching into freshwater systems (Quemada et al, 2013; Thapa et al, 2018). However, a meta-analysis in the Argentine Pampas region showed that Nitrate-N was decreased under both non-legume and legume cover crops (Alvarez et al, 2017). This discrepancy may be due to large differences in climate conditions and soil textures among the farming regions where this effect was assessed. The decrease in NL improves both water and soil quality (McDowell et al, 2021). The efficacy of non-leguminous cover crops in reducing $NO_3$ leaching was correlated positively with the shoot biomass (Thapa et al, 2018).

Soil water content tended to decrease under cover cropping in the majority of studies, and this varied according to soil depth, season, and climate conditions (Ma et al, 2021). Therefore, growing cover crops does not necessarily reduce soil water content under all circumstances. It has been shown that in areas with precipitation more than 800 mm, cover cropping increase the soil water content (Blanco-Canqui et al, 2015). Holman et al (2018) reported that for every 125 kg $ha^{-1}$ of cover or forage biomass

grown, plant available soil water was reduced by 1 mm. However, a meta-analysis based on 117 studies across the world showed water use efficiency of succeeding crops could be increased up to 5.0% compared to cover cropping by decreasing evapotranspiration (Wang et al, 2021).

Runoff declined significantly under cover crops, as cover cropping appeared to positively affect soil infiltration, especially in the long term (Basche and DeLonge 2019), reducing runoff volume and sediment loss (Blanco-Canqui, 2018). Blanco-Canqui (2018) indicated that cover crops increase the time to the start of runoff by 10 to 40 min and reduce runoff volume by 10 to 98% and sediment loss by 22 to 100%. However, Lu et al (2000) pointed out that water infiltration may increase the risk of high-speed leaching of Nitrogen and other nutrients out of the root zone.

The use of cover crops increased SOC content compared to fallow controls, although this was not consistent across all studies. Crystal-Ornelas et al (2021) showed no overall influence of cover cropping on SOC concentrations. However, they recorded a temporal trend that cover cropping significantly increased SOC concentrations after five years of its adoption. Soil carbon change was also affected by annual temperature, the number of years after cover cropping cultivation, geographical latitude, and initial SOC concentrations in the soil, microbial community condition, biomass of cover crop production, and soil texture (Six et al, 2006; Alvarez et al, 2017; Norris & Congreves 2018; Jian et al, 2020; McClelland et al, 2021).

Incorporating cover crop residues into the soil further accelerates Nitrogen mineralization (Kuo & Sainju 1998), while legume cover crops fix Nitrogen and thus supply significant Nitrogen in low-fertility soils (Fageria et al, 2005; Becker 2001; Blanco-Canqui et al, 2015). Therefore, cover crop application enhances available soil Nitrogen, which may reduce the required amounts of chemical fertilizer to some degree. Cover crops increased the content of hydrolyzable Nitrogen by 29% in the 0–20 cm layer, which could significantly alleviate the restrictive effect of soil Nitrogen deficiency on crop growth in northern China (Ma et al, 2021).

The results of our review show that physical properties of soil (included precipitation storage efficiency, total porosity, soil compaction, macropores, and PH) can be improved during cover cropping, but not in all circumstance. For example, Basche & DeLonge (2017) reported that continuous living cover significantly increased total soil porosity. However, Blanco-Canqui and Ruis (2020) demonstrated that cover crops could reduce bulk density about 31% and have no effect in 69% of cases. The result of their review, based on 98 studies, showed other soil physical indicators had been improved during cover cropping (Blanco-Canqui and Ruis 2020). Ma et al, (2021) highlighted that soil pH had no significant changes due to the introduction of cover crops in either the 0–20 cm or the > 20 cm soil layer.

## The overall effects of cover cropping on yield, $N_2O$ emission, weed and pests

We found nine meta-analyses that investigated the effect of cover cropping on yield. Both positive and negative effects were reported in their studies. However, Figure 2b shows that cover cropping slightly decreases crop yield due to the clear result of Abdalla et al (2019) demonstrated that cover crops significantly reduced grain yield of the primary crops compared to the control treatments. We found four factors substantially influencing direct crop yield, including both the crop and the cover crop type, farm practices and management, the duration of applying cover crop, and cover crop season (Abdalla et al, 2019; Valkama et al, 2015; Marcillo & Miguez, 2017; Fan et al, 2017, Alvarez et al, 2017).

Regarding farm practices, Miguez & Bollero (2005) pointed out that legume winter cover crops in the USA and Canada enhanced corn yield when no nitrogen fertilizer was used. There was no significant difference when the N fertilizer rate was 200 kg N $ha^{-1}$ or higher.

A meta-analysis focused on peer-reviewed studies from the United States and Canada showed that under low Nitrogen fertilizer and a no-tillage system, legume winter cover crop resulted in higher corn yields by 30% to 33%, especially when cover crop termination was late (Marcillo & Miguez 2017). Also,

Tonitto et al (2006) showed that non-legume cover crops did not significantly increase yields compared to bare fallow systems.

Abdalla et al, (2019) reported that, under conventional tillage, cover crops significantly decreased grain yield, though there was no such negative impact under conservation tillage.

Cover crops increase direct $N_2O$ emissions when residues are incorporated into the soil as compared to residue placed on the soil surface or removed from the soil (Webb et al, 2000; Abdalla et al, 2019; Abalos et al, 2022). The type of cover crop is essential. Abdalla et al (2019) reported that legume cover crops significantly increased direct $N_2O$ emissions, but non-legume and legume–non-legume mixes were not different in their effects on $N_2O$ emissions compared to no cover crop treatments.

This review demonstrated that cover crop positively affects weed suppression in the agroecosystem. However, the effectiveness of cover crops depends on management decisions such as tillage system, cover crop species, growing season and termination date (fall or spring), delay in primary crop sowing date after cover crop termination, and involving other weed control inputs in cover cropping (Osipitan et al, 2019; Mennan et al, 2020). Regarding conservation tillage, cover crops provide enhanced weed suppression in reduced tillage systems than no-tillage (Osipitan et al, 2019).

Cover crops increase the activity and/or density of several beneficial natural pest-control arthropod species (Davis et al, 2009; Dunbar et al, 2017), decreasing pest populations (Koch et al, 2015; Couëdel et al, 2019). Inveninato Carmona et al (2021) reported that the abundance of natural enemies such as Carabidae and spiders increases with the addition of cover crops into corn and soybean field, compared with the no cover crop in the United States.

## Trade-offs between the effects of cover crops on soil health and other ecosystem services

Incorporating cover crop systems into agroecosystems brings costs as well as benefits to the farm and the environment. Major concerns are decreasing crop yield, soil water content, and increasing greenhouse emissions. Nonetheless, cover crops do have the potential to provide additional ecosystem services without imposing major trade-offs in the food production system, provided they are included in a whole-farm management approach that takes account of farm and environmental conditions heterogeneities, while also considering the type of cover crop (or cover crop mix) that is most suited to the particular locality and conditions. There is potential to develop farm tools that provide guidance for this purpose, but current evidence remains limited to providing generic guidelines to a high degree of confidence.

While there are a wide range of potential cover crop species, farmers are constrained by availability and local site suitability in their choice of cover crops. The choice of cover crop typically depends on its purpose as well as its limitations because of the harvesting and planting dates of the main crops in the crop rotation. Farmers can choose a cover crop that produces abundant and nutritious forage if the cover crop is harvested for forage or grazed. If the goal of the cover crop is to increase soil organic matter, the farmer may use a high-residue cover crop. The cover crop could also be used to decrease erosion or provide nutrients to the following main crop.

Farmers may be able to more effectively weigh the likely advantages and costs of cover crop use if they can better understand (1) the benefits of cover crops and how they can be enhanced, and (2) the potential risks and how they can be minimized. Replacement cover crops with crops that provide food or feed and using cover crops plus reduced tillage approaches may also economically justify and ecologically mitigate the use of other inputs (Cherr et al, 2006).

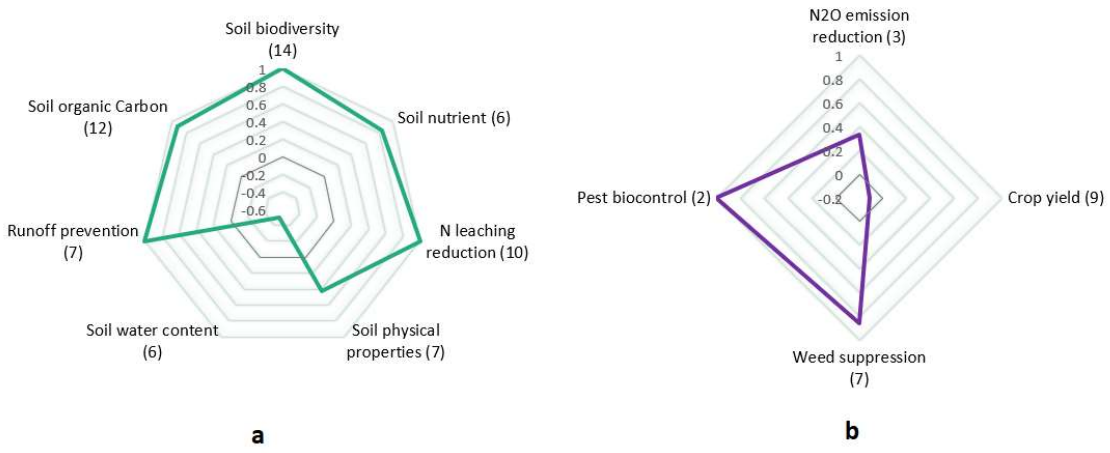


Figure 2: Cover crop effects on soil health parameters (a), Cover crop effects on other ecosystem services (b). The number in the parentheses reflects the number of studies or observations for each parameter (source: literature review)

## Country-specific cover cropping outcomes

For country-specific cover cropping outcomes, we conducted a separate search on the Web of Science and Scopus with the same search strategy (see supplementary part two) for both databases to find field experiment articles for each country. Then the first 30 articles for each country were considered to extract their results regarding the effect of cover cropping on soil, biodiversity and other ecosystem services (Table 3S in the Supplemental Information).

### Cover cropping in the US

US farmers grow cover crops primarily to reduce erosion and nutrient losses (avoided nitrate leaching and phosphorus runoff. Soil erosion is of particular concern to farmers in the American Midwest, and cover crops are implemented as a primary and self-funded strategy by farmers to mitigate this. Nutrient losses can also be mitigated by cover cropping, but this often requires cost subsidisation through government schemes to incentivize adoption by farmers. The positive effect of cover cropping has been demonstrated by the resulting increase in mycorrhizal colonization (Kabir et al, 2002; Calderon et al, 2016), and soil N (Chim et al, 2022), and a reduction in weed density (Grint et al, 2022; Mesbah et al, 2019; Davis 2010; Mesbah et al, 2019). While increasing mycorrhizal colonisation is often a benefit to crop vitality, optimal nutrition in elite maize hybrids is achieved at mycorrhizal densities somewhat lower than the maximum (Sawers et al. 2008), likely owing to indirect selection on the propensity for maize to work with mycorrhizae.

Regarding the effect of cover cropping on SOC, Chu et al (2017) reported that after three years, cover cropping did not increase SOC under a multispecies mixture of legumes, grasses, and *Brassica* spp. Jacobs et al (2022) reported inconsistent improvement in soil properties such as soil organic matter increase or maize and soybean yield in the conservation system over the three years under cereal rye, oilseed radish, and crimson clover.

Concerning grain yield, Gross et al (2022) found no effect on soybean yield despite differences in soybean stand, soil moisture, soil temperature, and soybean chlorophyll content following various winter crops under cereal rye, cereal rye–crimson clover cover crop. Chim et al (2022) reported significantly higher corn yields with oat, vetch, or a combination of three cover crops (from medium red clover, cereal rye, forage radish, and Austrian winter pea) compared to no cover crop treatments. Chu et al (2017) reported significantly increased soybean yield, gravimetric soil water content, and soil inorganic nitrogen as compared to the less-diverse treatments and a no-cover control under a

multispecies mixture of legumes, grasses, and *Brassica* spp. Organic wheat yield, however, was 20% lower than conventional cropping in the first season of organic transition, but there was no yield difference by the third year in the study conducted by Hinson et al (2022).

### Cover cropping in Brazil

Cover cropping habitat management in Brazil improved soil structure (Calonego et al, 2017), increased soil carbon contents (Rosolem et al, 2016), promoted the occurrence of edaphic fauna, and increased microbial biomass C and N, which favored cycling potential and nutrient availability (Almeida et al, 2016). A greater total organic C and N concentrations with triticale than with sunflower was reported by Rigon et al (2020). Nutrient cycling by winter cover crops reduced P and K losses, especially when the soil is not ploughed (Tiecher et al, 2017). An increasing soil organic C content and enhancing soil quality parameters to a greater extent than grasses or radish was reported by Balota et al (2014).

In terms of the effect of cover cropping on yield, Pott et al (2021) reported maize yield increased by 8.3% with vetch presence relative to the control. Calonego et al (2017) reported that in two years, the use of cover crops resulted in higher soybean yields, 17% greater following a cover crop of the forage grass *Urochloa brizantha* than *U. ruziziensis*. Nitrogen application at different times did not affect soybean grain yield in the study conducted by Tanaka et al (2019). Based on Cordeiro et al (2021), black oats are the best option to increase soybean yield.

### Cover cropping in Germany

Higher microbial phosphorus, phosphatase,fatty acids and enhancement in the potential for organic P cycling under winter cover crops and soybean was reported by Hallama et al (2021). Besides, the concentration of enzyme-labile P- organic was higher than that in control in the study conducted by Hallama et al (2022).

A mixture of cover crops demonstrated a great ability for weed control in Schappert et al (2018) study on the wheat field. It highlighted that soil conservation systems do not have to rely on chemical weed control practices

Weber et al (2019) showed that using cover crops like rye and barley can successfully suppress weeds and maintain soil quality on soybean field. No difference in weed suppression between rye and barley cover crops was reported. The highest cover crop soil coverage was measured in the no-tillage treatment.

### Cover cropping in France

Regarding the effects of cover crops on soil health, Habbib et al (2017) reported that nitrogen use efficiency-related traits were increased in the presence of cover crops both under no-till and conventional tillage. Cover crops without N fertilization under no-till led to higher microbial functional activity (Nivelle et al 2016). Total porosity and pore morphology changed little when a cover crop was grown in no-till, except that total porosity was consistently more significant in the 0–10 cm layer than without cover cropping (Carof et al, 2007). However, crops in grain-legume rotations mitigated the loss of soil organic carbon and Nitrogen under mustard, vetch, vetch – oat, and wheat (Plaza-Bonilla et al, 2016).

Meyer et al (2020) indicated that crucifer, Ethiopian mustard, crimson clover cover crops reduced water drainage by 20-60 mm compared to bare soil. They also significantly reduced soil water content (0-120 cm deep) for the next cash crop by a mean of 20-50 mm, and up to 80 mm in dry spring conditions, but early destruction could decrease this negative impact. No difference in soil water content was observed between the three cover crop treatments

Amossé et al (2014) evaluated the benefits of *Medicago lupulina, Medicago sativa, Trifolium pratense* and *Trifolium repens* on N dynamics and their contribution to the associated and subsequent maize or spring wheat. None of the intercropped legumes affected the N uptake of the associated winter

wheat; however, it significantly increased the N uptake of the succeeding spring crop, either maize or spring wheat.

Plaza-Bonilla et al (2017) reported that the insertion of cover crops in the cropping systems did not change wheat grain yield under legumes cover crop. On the other hand, Picard et al (2010) showed that the under sown *Festuca rubra* decreased wheat yield.

## A comparison between the results of farmer interviews and literature review

The results of the literature review in WP3 are generally well aligned with farmer opinions as reported by the interviews (see WP1). This is especially so concerning US farmers' opinions on biodiversity-related practices. These interviews revealed that farmers in the United States recognized that cover cropping and other interventions improved soil structure, and infiltration rates, and reduced weed pressure (allowing for lower herbicide inputs). Less soil erosion, wildlife habitat, and cleaner water were mentioned as the other benefits of habitat measures implemented on the farm. The literature review results demonstrated that using cover crops improves soil health parameters such as soil biodiversity status, soil nutrient status, N leaching (NL) reduction, runoff prevention, and soil physical properties.

Farmers emphasized that cover crops reduce soil erosion and runoff and improve soil infiltration and nutrient retention, as demonstrated by the reviewed scientific studies. An improvement in soil infiltration resulted in a significant reduction in both runoff volume and sediment loss (Appels et al, 2011, Blanco-Canqui, 2018).

Farmers also mentioned soil structural changes following cover crop use, and farmers mainly referred to reduced soil compaction, which in turn increases soil infiltration rate. This is supported by the meta-analysis of Basche & DeLonge (2017), which showed that continuous cover crops significantly increased soil porosity and reduced soil penetration resistance or compaction by up to 29%. One farmer specifically reported a "reduction of compacted layers in the field so that more rain is captured by the soil and less runoff."

Farmers identified cleaner water as a benefit of habitat creation practices (of cover crops as well as other measures). This may refer to a reduction in N leaching or high infiltration rates and reduced runoff due to the cover cropping process, but farmers did not specify this. Nitrogen leaching (NL) was another parameter of soil health that showed an overall decrease under cover cropping

Some farmers argued that every acre should have a cover crop and that there would be more experimenting with different cover crop species. This suggests considerable recognition of the value of cover crops and openness to further experimentation with cover crop species and mixes to identify the best local strategies. Selection of the proper cover crop species is crucial for maximizing the benefits of a cover crop while reducing the risk, especially in managing the allelopathic impact of the cover crop (Shekoofa et al, 2020).

Cover crops provide multiple services to the agroecosystem; however, due to biophysical, economic, and social constraints and demands, there are likely to be trade-offs among service providers. Even though some farmers reported lower herbicide inputs as a result of cover cropping, and hence less cost, there was a general perception that habitat intervention measures (including cover crops) increased costs and reduced yields, and these were the main factors that limited uptake. Our literature review (see Chapter 4) also revealed this as the main obstacle limiting cover crop adoption. One of the major drawbacks of growing cover crops in dry agroecosystems is the potential reduction of primary crop yields due to water depletion. Previous studies warn that cover cropping may put more pressure on dry agroecosystems, highlighting the need for careful irrigation and management decisions (Calderon et al, 2016). Some farmers mentioned that many tried to implement cover crops into their farm management system but stopped doing so because of increased costs and lower yields.

Farmers emphasized that seed cost is the largest cost preventing participation in biodiversity enhancement initiatives, a view also supported by our literature review. It seems that farmers apply

conservation tillage and cover crop at the same time, which can be considered as an adaptation strategy to overcome cover cropping drawbacks.

### Adaptation Strategies for cover cropping

Cover crops provide multiple services to the agroecosystem, such as regulating and cultural services. However, due to biophysical, economic, and social constraints and demands, there are likely to be trade-offs among service providers. Some of these trade-offs could be resolved by identifying and implementing appropriate management practices. If trade-offs cannot be avoided through farm management practices, decision-makers and farmers might prioritize certain ecosystem functions over others, and cover crop selection and management could play an important role in this respect, especially given local farm contexts.

One of the major drawbacks of growing cover crops in dry agroecosystems is the potential reduction of main crop yields as a result of water depletion. Previous studies warn that cover cropping may put more pressure on dry agroecosystems, highlighting the need for careful irrigation and management decisions (Calderon et al, 2016). For this drawback, maintaining cover crop biomass at 5 Mg $ha^{-1}$ is suggested to enhance the water-related sustainability of cover cropping management (Wang et al, 2021). But it is worth mentioning that high amounts of cover crop biomass are needed to exert significant changes in erosion control, weed suppression, water use, and soil biological activities (Blanco-Canqui et al, 2022). Another approach to improve water use efficiency in cover cropping is choosing cover crops that need less water to grow. Besides, leaving cover crop residue on the ground can increase soil water storage because of the lower evaporation (Wang et al, 2021). Terminating cover crops at the best time in spring (late enough to avoid nitrate leaching after spring rains but not too early to compete with the main crop) could be a technique to allow for water recharge (Blanco-Canqui et al, 2022). Besides, legume–non-legume mixed cover crops, which increase the yield had no considerable effect on N in grain, can be chosen (Abdalla et al, 2019).

## Meta-analysis of plant diversification effects on farm arthropod abundance

We conducted two meta-analyses comparing plant diversification effects across field (intercropping) and local scales (flower strip, grassy margin and hedgerow) on farm arthropods abundance. The focus was on wheat, maize, and soybean as the main crops with no restriction in geographical area. The method, inclusion and exclusion criteria can be found in the supplementary information. Detailed information will be published as a paper.

Plant diversification at field scales, represented by intercropping, across all functional groups had an overall negative but non-significant effect on arthropod abundance (Figure 3). Most available information was for herbivores, which was the major contributor to the pooled negative effect. By contrast, predators showed a positive response to intercropping. Parasitism and pollinator abundance was not significantly different between the two cropping systems at field scale.

At local scales, flower strips, grassy margins and hedgerows significantly increased the abundance of arthropods (Figure 4). Predators increased dramatically under these conditions, while herbivore abundance was not significantly affected. Flower strips, grassy margins, and hedgerows also significantly increased the abundance of parasitoids and pollinators.

The distance from flower strip and grassy margins, both of which are important components of many agri-environmental schemes (AES) was negatively associated with arthropod abundance (effect size: -0.0132, P value: 0.0094) (Figure 4). Many studies suggested that the edges of such habitats offer richer and more stable food supplies and diverse niches attributable to the diversity and abundance of plants, allowing for the maintenance of high arthropod abundance and species richness.

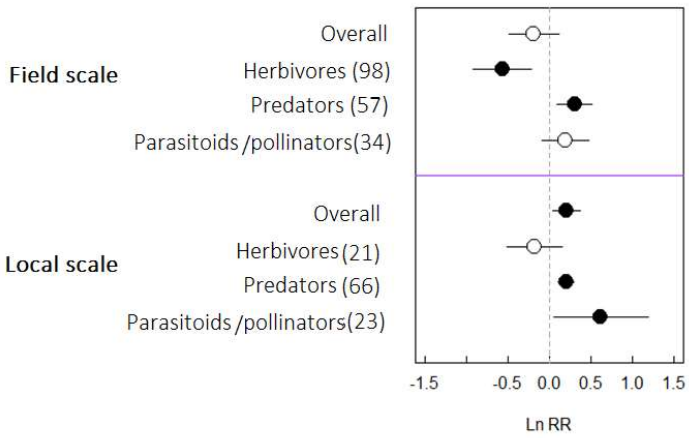


Figure 3. Arthropod abundance mean effect size and confidence intervals by functional groups across field (intercropping) and local (flower strips, grassy margins, and hedgerows) scales. The number in the parentheses reflects the number of observations for each functional group. Error bars that cross the zero line are not significant.

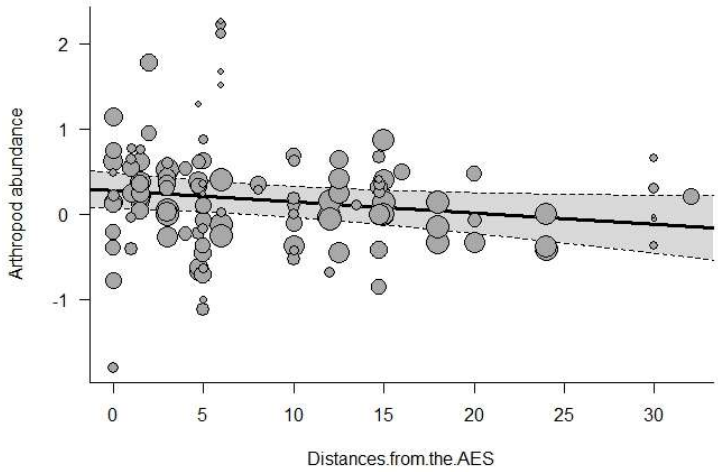


Figure 4. Correlation between sampling distance from AES and arthropod abundance. Linear meta-regressions are shown as solid black lines. The grey area represents the 95% Confidence Intervals.

## An Overview of The Emerging Technologies in Smart Cereal Farming

We briefly report additional work using a systematic review and Meta-Analyses (PRISMA: https://prisma-statement.org/; (Moher et al., 2015)) methodology to systematically review the existing literature on smart farming. This is to contribute a deeper understanding of how the Internet of Things (IoT) technology solutions might help to enhance cereal crop productivity through new developments in technologies and robotics. In this context, IoT can be understood as a network of interconnected intelligent devices capable of communicating with each other through the internet connection, generating relevant data about the environment in which they operate. Within the IoT framework, any device capable of establishing a connection to the Internet can be considered a "thing".

IoT in agriculture uses robots, drones, and remote sensors to measure all kinds of data such as soil moisture, chemical application, water levels, and crop health remotely and provide this information to the farmer in real-time. All these technological components provide a context of sharing data and information, as well as acting actively based on network inputs thanks to the development of technologies that support the application of IoT in agriculture via a wireless connection, cloud computing, artificial intelligence, and big data, which enhanced size and power consumption, the adaptation of IoT has been increased (Navarro et al 2020). A full report will be prepared in due course.

We studied a five-layer architecture of smart farming composed of perception, network, processing, applications, and user interface, and classified the application of smart farming techniques into seven groups of application types including pest and disease management, irrigation control, crop management, soil management, drought stress, leaf area estimation. The results showed that the crops most frequently studied were rice (n=31), wheat (n=11), and maize (n=11) in 16 countries in Asia, Europe, Africa, America, and Australia (Figure 5). The most common IoT applications for smart farming were crop management and pest and disease detection. Around 50% of experiments were conducted in indoor environments, and there is a need to test the use of these approaches in more realistic outdoor scenarios. The review shows that the scope of IoT in smart farming must go beyond increasing primary production or single application focus towards a more holistic embedding of IoT in farm management. These findings provide further support for researchers to realize the current status of the gaps and shortcomings of smart cereal crops production.

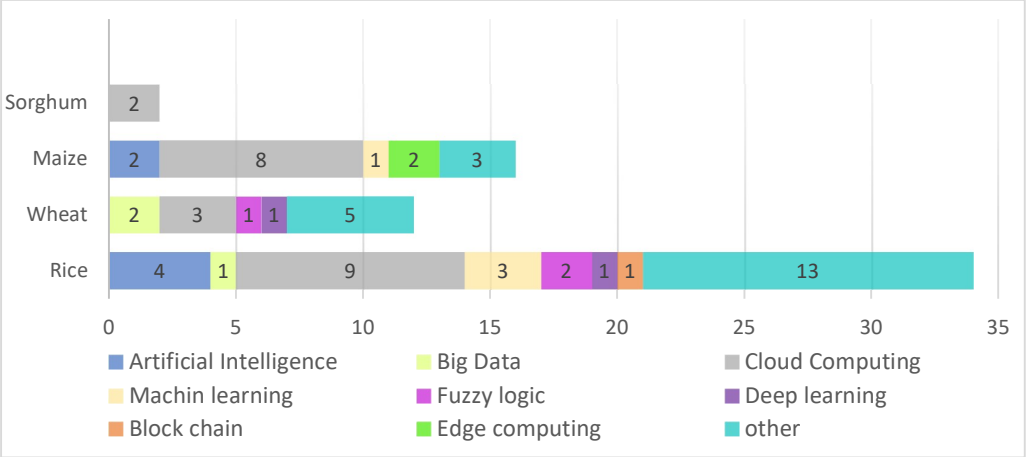


Figure 5. Techniques and technologies for data-processing in smart farming identified within the reviewed papers

Cloud computing and artificial intelligence has been mostly used in rice and maize crop production. The use of these technologies is related to their ability to process large amounts of information in a short time. Cloud computing and big data are the most common type of applications for wheat production. Sorghum production uses cloud computing as the main technology for crop and soil management.

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# WP4. Understanding farmer behaviour and business models


## Authors

Sergei Schaub, Ade Sander, Noemi Elmiger, Jaboury Ghazoul, Robert Finger


## Summary


We sought to identify and evaluate the factors relating to farmer willingness to participate in agri-environmental schemes (AES) including the influence of technical and agricultural advice, peer and network relationships, market condition, and scheme and contract flexibility

Farmer decision-making is key in leveraging innovations, while the effectiveness and efficiency of policy and industry intervention, and thus its optimal design, depends on farmers' behaviours. This WP has sought to review the opportunity costs and range of behavioural factors and influences affecting farmers' willingness to participate in voluntary agri-environmental schemes (i.e. where farmers can opt in agri-environmental measures, e.g. for biodiversity improvement, and receive a compensation). Based on an evaluation of the published literature, we aim to evaluate farmer's perceptions with regard to risk, production costs and revenues, labour dynamics, and enabling conditions such as access to information, policies, and other incentives. Social factors, perceptions, and norms as well as cognitive and non-cognitive factors and skills have been shown to affect farmers' decisions relating to environmental practices. We also give attention to broader issues influencing farmer decision making processes, including the structure of agri-environment schemes, and interactions across farmer networks.

We used a systematic review approach to conceptualize farmer behaviours with a focus on adoption of new, habitat-creating farming practices, and responses to agri-environmental schemes. A key issue is that of opportunity costs, and the potential (or perceived) risks of agri-environmental scheme uptake, and how these are interpreted and shaped by behavioural perspectives.

We addressed two overarching research questions:

**Research Question 1**: What are the opportunity costs and behavioural factors affecting farmers' participation in voluntary agri-environmental schemes incentivizing environmentally friendly practices?

**Research Question 2**: What are biodiversity indicators for result-based agri-environmental schemes currently used in practice and research, how can these be developed further?


## Key results

- A relatively small set of behavioural factors appear to contribute consistently to participation, including agricultural training and advice, clusters and peer relationships, positive attitude towards AES, and risk aversion.
- A set of factors related to opportunity costs also have a rather consistent relationship with AES participation, including market conditions (e.g., crop prices), implementation costs, profitability, and management and contract flexibility.
- Behavioural factors and opportunity costs relating to AES participation require context-specific interpretation and are not as generalizable as is often assumed.
- Other factors, including environmental attitude, trust, and farm size, had a non-significant effect overall, and yet might still have relevance in particular localities and contexts.

- Our results provide several entry points for policymakers and highlight uncertainties in relationships between factors and participation that need to be considered when designing policies.

## Introduction

Behavioural factors (e.g., environmental attitudes, trust, and peer-effect) and opportunity costs are key drivers of farmers' participation in AES as they impact the perception, evaluation, and selection of practices (e.g., Dessart et al., 2019; Knowler & Bradshaw, 2007; Schlüter et al., 2017). The influence of both behavioural factors and opportunity costs depends on the social and biophysical context (e.g., Schlüter et al., 2017). Thus, systematically synthesizing the evidence about the relationships of behavioural factors and opportunity costs with farmers' scheme participation as well as considering the context of the evidence is important for understanding the willingness of farmers to participate in agri-environmental schemes and to take-up biodiversity supporting measures.

Using a systematic review approach, we investigate farmers' behavioural factors and opportunity costs relating to their participation in AES and adoption of environmentally friendly practices. Our review focuses on the participation in voluntary AES in Australia, Europe, and North America, which are regions that have important experience with such schemes, and specialized and mixed arable crop farms. We screened 3523 articles, which were filtered to 83 articles that included over 700 factors. We focused only on incentivized environmentally friendly practices under AES, recognising that decisions can deviate considerably when compared to unincentivized environmental practices (e.g., Lokhorst et al., 2011).

Within the behavioural factors, we identified three broad categories (Figure 1): i) information, peers, networks, and relationships, ii) attitudes about the environment, farm performance, and AES, and iii) dispositional and cognitive factors. We also differentiate opportunity costs depending on their origin, i.e., related to a) market conditions, b) land and environmental factors, c) farm management, and d) AES and contract design. We also consider differences originating from economic, social, environmental, and political settings that vary within and between regions. Finally, using a systemic synthesis of the existing literature, we provide information on how often a factor was analysed in different studies, which provides an indication of the robustness of existing evidence (e.g., Lakens et al., 2018).

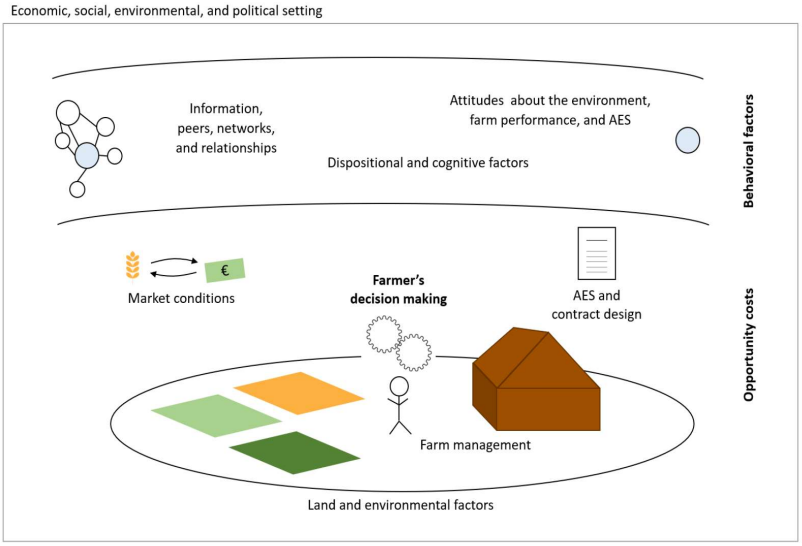


Figure 1. Schematic overview of behavioural factors and opportunity costs.

## Regional focus

We consider three regions, Australia, Europe, and North America (Canada and the USA), that have experience with voluntary AES, especially in intensively managed arable systems (FAO, 2022). Australia, Europe, and North America differ in their economic, social, environmental, and political settings, which permits some interpretation of how regional differences influence scheme participation, albeit such comparison is limited by lack of replication.

Our wider project remit also included Brazil as a focus country, but voluntary AES systems do not exist to the same extent as is the case in Europe, North America and Australia. Biodiversity conservation in cropping systems in Brazil has been mostly promoted through legal instruments to conserve and restore native ecosystems in private lands. Based on the Native Vegetation Protection Law of 2012, which replaced the Forest Code of 1965, landowners are obliged to protect and restore native ecosystems (e.g. forests, savannas, grasslands) in Areas of Permanent Protection, which are established in environmentally fragile areas (i.e., steep slopes, mountain tops, riparian buffers, water springs) and Legal Reserves (a percentage of the landholding to be maintained with native ecosystems – 80% in the Amazon and 20% in other regions of the country). Legal Reserves and Areas of Permanent Protection in smallholdings can be restored through mixed plantations of exotic and native trees for commercial exploitation and agroforestry systems. Based on this policy, the Brazilian legislation employs a blend of land sparing and land sharing approaches to promote biodiversity and ecosystem services in farmlands. As complying with legislation is a prerequisite for achieving environmental certification, access to some forms of rural credit, to export to more restrictive markets and, more often, to adhere to ESG policies, this law has established an important foundation for further government and market interventions. Another driver of transformations in Brazilian agriculture to foster sustainability has been the establishment of specific credit lines for low carbon agriculture, which have fostered the expansion of no-till farming, Integrated Crop-Livestock-Forestry Systems, and forestry in general.

AES payments in the Europe Union are mainly designed to provide ecosystem services (especially on biodiversity), and often do not differentiate among farmers with differing opportunity costs (Baylis et al., 2008). The national AES are designed and implemented by each member state. In contrast, the US system often uses auctions, which takes account of varying opportunity costs amongst farmers (Baylis et al., 2008), including factors affecting individual farmers' opportunity costs such as soil quality (Jang & Du, 2018). The Canadian system is mostly focused on cost-sharing AES and on reducing nutrient loading as well as providing ecosystem services (Eagle et al., 2015). Compared to Europe and the USA, Canada has relatively less experience with AES, and funds for such programs are rather low (Eagle et al., 2015). Similarly, comparatively low funding is available to farmers in Australian AES (Salt, 2016), and most AES schemes are focused on market-based instruments, including conservation auctions (which consider varying opportunity costs), for delivering ecosystem services (Pannell & Roberts, 2015; Salt, 2016).

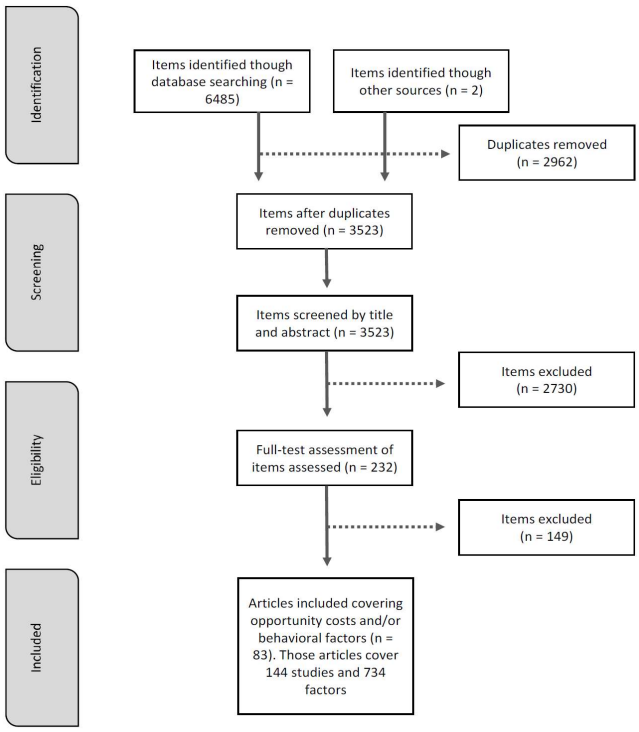


Figure 2. The literature search and screening decision tree.

# Methods

By conducting a systematic review, we synthesize results related to our research question using a systematic procedure to reduce bias (Munn et al., 2018). Our systematic review is divided into four steps and follows the PRISMA guidelines (Moher et al., 2015). 1) identification of the main research question (in our review: "What are the behavioural factors and opportunity costs affecting farmers' participation in (public and private) voluntary AES incentivizing environmentally friendly practices?"), 2) identification of the relevant studies using predefined criteria and screening process, 3) data extraction, and synthesis of the data.

An overview of the search and screening process is provided in Figure 2. Details on the methodology, and on the data extraction strategy are included in the submitted papers (Annex 1).

A total of 144 studies in 83 articles that investigated factors of AES participation were included in the review. In these studies, 246 factors were related to behavioural factors, and 488 to opportunity costs (Figure 3). Of the behavioural factors, information, peers, networks, and relationships were most commonly mentioned, followed by behavioural factors and attitudes about the environment, farm performance, and AES (Figure 3). Among opportunity costs, those relating to farm management are most often studied, followed by opportunity costs related to the AES and contract design, land, and environmental factors, and lastly, market conditions.

# Results and discussion

## Behavioural factors

### *Information, peers, networks, and relationships*

***Overview***. For simplicity, we grouped the 734 factors included in our analysis into five categories: i) clusters and peer effects, ii) association memberships, iii) advice and agricultural education and training, iv) information treatment, behavioural nudges, and framing, and v) trust and contact with agencies and others.

***Clusters and peer effects***. Peer relationships and interactions among clusters of farmers are often connected to a higher likelihood of AES participation. Clusters of farmers with the same (environmentally friendly) practices share information about practices, culture, descriptive norms, favourable biophysical conditions, or economic network effects (e.g., due to spillovers) (Arora et al., 2021; Dessart et al., 2019; Läpple & Kelley, 2015; Rode et al., 2015). Farmers were more likely to participate in an AES when it was recommended by other farmers (Villamayor-Tomas et al., 2019) or when the participation of others was important (Calvet et al., 2019). Van Dijk et al. (2015) showed that the influence of group norms and identity depends on how much a group is able to facilitate participation. The enrolment status of neighbouring plots increased the likelihood of farmer participation in a Swiss agglomeration bonus system (in addition to a base payment) (Huber et al., 2021).

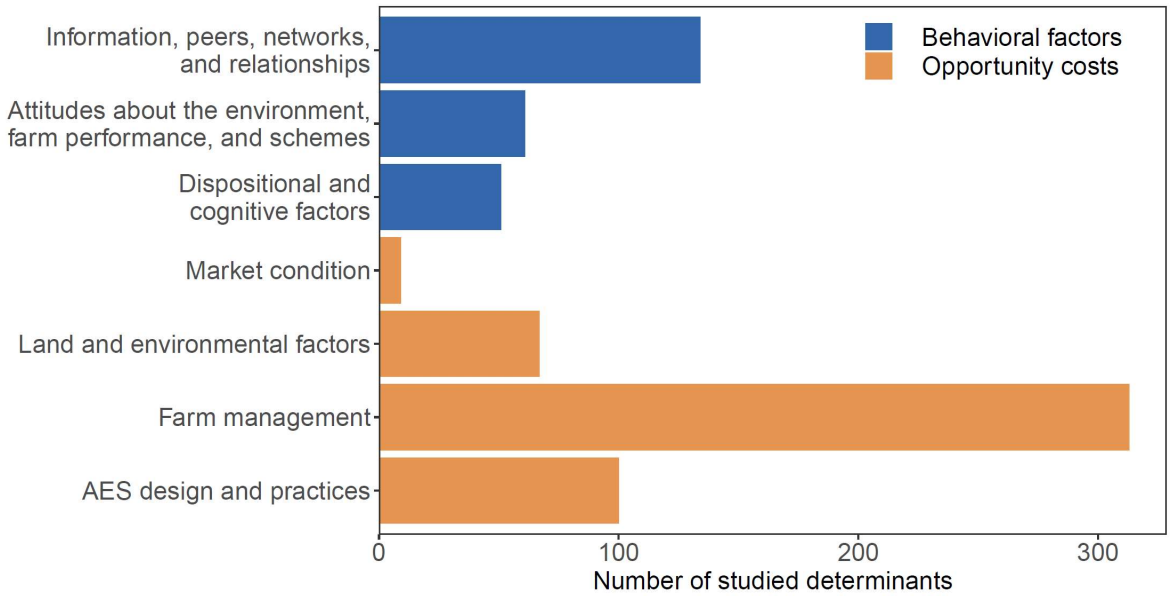


Figure 3. Number of times factors related to opportunity costs and behavioural factors were studied.

***Association memberships***. Being a member of an association (including 'farming focused', 'cooperative and discussion group', 'non-agricultural' associations) can indicate higher social capital (e.g., Peerlings & Polman, 2009; Simmons et al., 2020) and can influence the information one receives, though being a member of any of such associations does not *per se* lead to higher or lower participation rates in AES (Table 1[4]). How membership in an association links to participation might depend on the associations' focus, its services, the country, and the required scheme.

***Advice and agricultural education and training*.** Knowledge creation and dissemination were reported to have mixed effects on scheme participation, with some studies showing no effect (Ducos et al., 2009; Mante & Gerowitt, 2009), while others revealed a positive relationship (Damianos & Giannakopoulos, 2002; Espinosa-Goded et al., 2013; Yiridoe et al., 2010). In most cases (i.e., nine out of twelve cases; Table 1) providing technical and agricultural advice increased the likelihood of farmers participating in AES. Studies that found no effect explained their results on the basis that farmers want to be independent of agency involvement and wish to avoid administrative burdens associated with the scheme participation (Blackmore & Doole, 2013).

***Information treatment and behavioural nudges*.** The presentation of information to incur behavioural nudges is often used by policymakers to encourage farmers to participate in AES. Our review suggests that this factor has little (or even negative; Czajkowski et al. (2021)) effects on participation. Sending

[4] All Tables can be found in the submitted papers.

letters to farmers to promote AES participation did not improve uptake among non-participating farmers, but it did increase participation among farmers who had already had some experience with the Conservation Reserve Programme (CRP) (Wallander et al., 2017). By contrast, a field experiment within the US Conservation Stewardship Program conducted in Nebraska (where participation has been historically low) showed that letters sent to farmers substantially increased enrolment (Czap et al., 2019).

The source of information and its evaluation can influence farmers' participation decisions. Information from peers had greater impact than information from scientists (Villamayor-Tomas et al., 2019). Peerlings and Polman (2009) and Polman and Slangen (2008) found that using public extension services increased the probability of signing contracts for biodiversity protection or input reduction, while using private extension services (provided by agricultural consultants or by companies) either had no significant relationship or decreased the probability of contracting.

***Trust***. Trust in institutions and the state were connected either positively or had no effect on farmers' participation in schemes. Calvet et al. (2019) argue that trust plays a particularly important role where contract partners are companies or public agencies acting as private partners. Grammatikopoulou et al. (2016) showed that importance that farmers attributed to information from different official bodies affected their likelihood of participation in AES. The frequency of contact with the contracting agency can also increase the chances of farmers' participation in AES (Table 1). Thus a good relationship with the contracting agency can play a positive role (e.g. AES schemes in Australia) (Blackmore & Doole, 2013), but this is not always the case (e.g. AES to promote field margins in Germany) (Mante & Gerowitt, 2009).

### Attitudes about the environment, farm performance, and AES

***Overview***. Farmers' attitudes can be important for their participation decision about AES as they influence farmers' intrinsic motivation to participate in schemes and adopt practices. The observed attitudes fall into three categories: i) environmental attitudes, ii) business attitudes (e.g., production and economic farming motivation), and iii) positive attitudes towards AES (e.g., perceived efficacy and fairness of the scheme). Attitudes across all these categories, except business attitudes, were either positive or not connected to a higher likelihood of scheme participation. However, higher environmental attitudes in more than 50% of the cases did not significantly relate to higher participation, which is contrary to common belief and communication (e.g., Dessart et al., 2019; Hasler et al., 2022). In contrast, a positive attitude towards AES seemed to be more often positively related to scheme participation.

***Environmental attitudes*.** When dealing with voluntary AES, stronger environmental attitudes related to agriculture and farmers' agricultural practices were either not significantly (55%) or positively (45%) associated with farmers' participation. Positive relationships between participation and environmental attitudes is not linked to certain practices or regions (compare Table 2 and Table S2).

There is a wide range of how environmental attitudes were measured, which include questions specific to the environmentally friendly practice (Yeboah et al., 2015), whether farmers' main goal is to protect the environment (Giovanopoulou et al., 2011), composites of multiple questions (e.g., Huber et al., 2021), and factor analysis to identify latent classes (e.g., Cullen et al., 2020). We thus suggest using a unified measure for environmental attitudes that is not linked to ideological framing (see, e.g., Dunlap et al., 2000; Sparks et al., 2022), and/or stating explicitly different attitude dimensions (e.g., environmentally friendly practices specific, generally about agriculture, or in general) to make results more comparable across studies and regions.

***Business attitudes***. A strong business attitude was not significantly associated with participation in AES.

### Dispositional and cognitive factors

***Overview***. For those dispositional and cognitive factors that were studied more than once, we generally find either positive or no relationships with scheme participation (Table S6 and S7). Thus, they provide still some guidance for AES design. However, the very limited number of studies makes it difficult to generalize the results.

***Dispositional factors*.** Farmers' higher risk aversion was often associated with a higher probability of participating in AES (Table S6). AESs, such as the Conservation Reserve Program, are linked to lower year-to-year variability combined with high policy certainty, making it more attractive for more risk-averse farmers (Chang & Boisvert, 2009b). Payments of agglomeration bonuses have inherent higher risk than 'single-farmer payments' as they depend on the actions of other farmers, and these were found to be less favoured as a result (Ferré et al., 2018). Other economic preferences than risk aversion and trust, such as patience, reciprocity, and altruism, were rarely studied. Both patience and altruism did not influence farmers' participation in a Swiss case study of agglomeration payments (Ferré et al., 2018).

***Cognitive factors*.** Perceived behavioural control was positively or not connected to participation in AESs, and loss aversion was not connected to it (Table S7). Other cognitive factors, such as perception of the stability of schemes over time, showed no consistent effect (Table S7).

## Opportunity costs for farmers

### Opportunity costs related to market conditions

***Overview***. We find that market conditions have an important role in how farmers decide on AES participation (Table 3). Farmers seem to generally follow a profit maximization approach, though it is a little surprising that only a few studies investigated market condition-related opportunity costs of AES, and the spatial coverage is restricted to three countries (Germany, Switzerland, and the USA). Increasing the robustness and transferability of those findings will require more studies and a spatial extension.

***Market conditions***. Higher output prices, which increase the value of the sold output, were negatively associated with participating in AES in Switzerland and the USA (Table 3). Similar findings were shown in the USA and Germany when directly accessing the value of the output sold (output price x output). However, when an additional crop was included in the crop rotation, a willingness to pay study showed that its relative price compared to other crops in the rotation did not significantly affect participation. Higher process of agrochemical inputs (e.g., fertilizer or pesticides) might be expected to increase participation in AES, and Jang and Du (2018) found that participation in the US CRP does indeed increase with increasing fertilizer costs. However, higher land rental prices incentivised farmers not to use these lands for environmentally friendly practices, but rather to rent them out (Jang & Du, 2018).

### Opportunity costs related to land and environmental factors

***Overview***. The relationships between opportunity costs related to land and environmental factors and farmers' participation are often not generalizable across regions, environmentally friendly practice, or even on the specific study (Table 4). Those land and environmental factors that were linked to 'institutional' statues (e.g., land classified as less-favoured area or zoned for agricultural purposes and Environmental Benefits Index) were most consistently related with higher participation. Overall, the empirical literature looked at a set of different factors that can be separated into those that are related to i) potential productivity, ii) potential production costs, iii) institutional statues, and iv) the riskiness of relying on stochastic production outcome compared to fixed payments (e.g., weather risks).

***Productivity***. Factors that influence potential productivity, and consequently opportunity costs, include growing degree days and soil quality. Jang and Du (2018) found that more growing degree days were linked to lower participation in the US CRP, while higher soil quality at the field level led to higher participation. Similarly, others found a positive relationship between regional land quality and CRP participation (Chang & Boisvert, 2009a, 2009b). Within those regions, more productive land might still be used for agricultural production (Chang & Boisvert, 2009a, 2009b). There was similarly a

negative relationship between participation and county soil quality in Ireland and Switzerland (Isik and Yang (2004) and Mishra and Khanal (2013)).

***Production costs.*** Factors that influence the potential production costs are more widely studied than those influencing potential productivity, including the variables distance of plot to farm, the slope of the plot, the size of the plot, and if the eligible area is drained. The relationship of those factors with participation is either according to what we would expect given the opportunity costs or not significant (Table 4). Fields more distant from a farm were less likely to be enrolled in a Swiss alpine agri-environmental agglomeration scheme (Huber et al., 2021), as this scheme incentivizes practices with lower travel costs. A German scheme incentivizing a more work-intensive environmentally friendly practice compared to the baseline found a negative distance-participation-relationship due to higher travel costs (Lakner et al., 2020). Therefore, both findings align with profit maximization considering opportunity costs when setting them into context, even if the findings are oppositional.

***Institutional statutes****.* Farmers that own land that is considered less favourable due to its natural condition (e.g., mountain location or lack of water) can receive payments in the European Union that compensate for higher production costs. Farmers owning such land and receiving payments for less-favoured land are often more likely to participate in AES or at least not significantly different likely as farmers who do not own such land or receive such payments (e.g. Bostian et al. (2020)).

In the US CRP, the maximum payment farmers can receive for enrolling land depends on the land's Environmental Benefits Index. The index depends both on land characteristics and farmers' management proposal (Jacobs et al., 2014). Thus, farmers with higher scores due to land characteristics have lower opportunity costs for enrolling their land. Farmers with higher scores are indeed often observed to be more likely to participate in the CRP. Furthermore, land zoned for agricultural purposes (e.g., due to participation in voluntary farmland preservation easement programs) decreases farmers' likelihood to enrol their land in the US CRP, which results are explained by farmers' wish to sustain agricultural production (Chang & Boisvert, 2009a, 2009b).

***Riskiness of production.*** Lambert et al. (2007) studied the enrolment of land in the US CRP as retired and working land. If soil erodibility of land was high, land was more likely to be enrolled as retired land but not as working land. In contrast, a study looking at the perceived soil erosion risk in Poland found no connection to participation in AES (Wąs et al., 2021).

### Opportunity costs related to farm management

***Overview***. It is difficult to generalise management-related opportunity costs, and their contextualizing is important to understand if a positive or negative relationship with scheme participation is expected. Relationships between many management practices confounds clear relations with likelihood of AES adoption mediated by opportunity costs. For example, how management intensity influences opportunity costs also depends on associated production costs. We distinguish opportunity costs related to farm management by whether they belong mostly to i) change of farm management, ii) directly related implementation costs of environmentally friendly practices, and iii) flexibility and scale feasibility at the farm.

***Change in farm management***. Whether subsidies other than agri-environmental subsidies increase or decrease the opportunity costs depends on their purpose. Subsidies that support increased productivity or direct income payments for farmed land generally increase the opportunity costs of implementing environmentally friendly practices. Government payments per area linked to land in production either decreased (Chang & Boisvert, 2009a, 2009b; Isik & Yang, 2004), or had no relationship with (Lambert et al., 2007) AES participation (Table 5 and Table S4). Moreover, when European Union farmers received rural development subsidies (including adopting environmental standards and using extension services), the likelihood of participation in AES was higher (Gailhard & Bojnec, 2015).

We find that higher farm profitability, and thus, higher opportunity costs, was linked to lower participation in AES (Table 5). In contrast, the relationship between productivity and participation in

AES is less consistent: eight studies found a positive (Cullen et al., 2021; Gailhard & Bojnec, 2015; Murphy et al., 2014; Trenholm et al., 2017), five a negative (Finger & El Benni, 2013; Gailhard & Bojnec, 2015), and four an insignificant (Blackmore & Doole, 2013; Trenholm et al., 2017; Unay-Gailhard & Bojnec, 2016; Wąs et al., 2021) relationship between participation and productivity. Management intensity (measured on the basis of fertilizer use, pesticide use, hours power, stocking rate, and/or irrigation) seems to have a negative or no significant relationship with participation in AES (Table 5). Furthermore, the relationship between production costs (per area) and enrolment in the US CRP was found to be positive (Table 5).

***Implementation costs***. Organic farms and farms that already use environmentally friendly practices are presumed to have a system that makes implementing environmentally friendly practices easier and cheaper, and hence we expect these farms to have lower opportunity costs (e.g., Mack et al., 2020). Our review revealed that these farmers are indeed more likely to participate in AES. Similarly, Mack et al. (2020) observed that organic farmers had a higher likelihood to participate in action- and result-based payments but not in multi-actor-based payments.

***Flexibility and scale feasibility at the farm*.** Opportunity cost can also be linked to farm size. Economies of scope (lower cost to produce a variety of outputs, including those incentivized under schemes) provide for lower opportunity costs for larger farms. Larger farms are also more likely to have some land of low productivity which has lower opportunity costs. Most studies (58%) found a positive relationship between farm size and agri-environmental scheme participation (Table 5), although no significant relationship was observed in about a third (38%) of the cases. This relationship might also depend on scheme requirements: Lakner et al. (2020) found that farm size in Germany increased the participation probability for incentivized less-restrictive measures but not for incentivized more-restrictive measures. Mack et al. (2020) showed for Switzerland that farm size increased the likelihood of participation for action- and multi-actor-based schemes but not for result-based schemes.

Previous studies analysed various aspects of labour related to opportunity costs. The amount of hired labour can influence opportunity costs as it allows for flexibility of labour assignment. The total available labour was, indeed, often positively associated to participation in AES in Europe (Table 5). Presumably, farms that have limited access to labour lack the human resources or flexibility to implement AES. In contrast to the European studies, two studies from the USA found that amount of full-time farm work reduced the likelihood of participation in the CRP (Chang & Boisvert, 2009b; Jang & Du, 2018). Indeed, farmers might use the CRP (a long-term scheme) to reduce farm labour requirements (Jang & Du, 2018).

### Opportunity costs related to AES and contract design

***Overview***. We find that AES and contract design features often predict farmers' choices of scheme participation according to opportunity cost-based expectations (Table 6). These features can be distinguished into three main categories: i) management flexibility, ii) contract inflexibility, and iii) environmentally friendly practices required under an AES.

***Management flexibility.*** Management flexibility (e.g., the flexibility of choosing the environmentally friendly practice and area enrolled) allows farmers to adjust the management to their farm condition, which reduces opportunity costs resulting from changing management practices. Seventeen out of nineteen studies showed that management flexibility has a positively effect on farmers' participation in AES (Table 6).

***Contract inflexibility.*** Contract inflexibility (e.g., contract length and contract restrictions) reduces farmers' options to adapt to changing markets, and was in most studies (79%) linked to lower willingness to participate in AES. Moreover, other factors might interact with how inflexibility affects participation. For example, it was shown that renting land, being impatient, risk aversion, and coordination requirements with other farmers were associated with lower willingness of taking up

more inflexible schemes (Bougherara et al., 2021; Le Coent et al., 2017; Vaissière et al., 2018; Villamayor-Tomas et al., 2019).

***Required environmentally friendly practices***. Farmers are less responsive to AES when environmentally friendly practices are more comprehensive, e.g., multiple requirements such as growing alfalfa in addition to leaving cereal stubble after the harvest (Alló et al., 2015; Bougherara et al., 2021; De Salvo et al., 2018; Ma et al., 2012; Sponagel et al., 2021). Moreover, the choice between environmentally practices and their opportunity costs can also depend on labour availability in certain periods (Palm-Forster et al., 2017). The choice between different practices can differ between countries and farm types as, for example, cultural preferences vary (Czajkowski et al., 2021; Hasler et al., 2019).

## Summary and conclusion

We systematically synthesized the existing knowledge on the relationships of behavioural factors and opportunity costs with farmers' participation in voluntary AES in Australia, Europe, and North America on mixed and arable crop farms. Understanding these relationships can help to adjust public and private incentives and target certain farmer groups and thus increase AES participation and reduce pressure on our agroecosystems and biodiversity. We find that many relationships are more complex than is often hypothesized and communicated. Many relationships are context specific and require considering the regional settings and the design features of the scheme. While many results are consequently more ambiguous than expected, some factors show consistent patterns, and can inform the promotion of AES.

Important behavioural factors include i) agricultural training and advice, ii) cluster and peer relationships, iii) existing positive attitudes towards AES, and iv) degree of risk aversion. Many of these aspects can be directly taken up in policy designs, by providing training and advice to farmers, and building positive perceptions towards AES. Agricultural training and advice can become more important over time as we experience changes in public, administrative, and governmental farming requirements (e.g., Ehlers et al., 2022; Pe'er et al., 2020; Schaub et al., 2020), which creates new challenges and requires additional information to cope with those challenges. Additionally, the existence and promotion of clusters and relationships amongst farmers in a region can facilitate AES participation and might be especially important for schemes requiring cooperation amongst farmers. Furthermore, if environmental outcomes are considered as a result of farmers' skills, then farmers might increase their social capital and standing among peers when participating in AES (e.g., Burton & Schwarz, 2013). Such "conservation as a product" perspective could further strengthen the relationship of clusters and peer relationships with AES participation. This perspective could be enhanced by using, for example, result-based payment schemes (e.g., Burton & Schwarz, 2013).

Opportunity costs with rather consistent patterns are related to i) market condition, ii) environmental and land factors related to institutional statutes and implementation costs (i.e., organic farmers and farmers with already some environmentally friendly practices in place), iii) profitability, and iv) AES and contract design. Tailored design of AES can reduce opportunity costs, especially by increasing cost-efficiency of AES (see, e.g., Claassen et al., 2008; Latacz-Lohmann & Breustedt, 2019). This could be achieved by using conservation auction or schemes with different payment levels depending on farmers' opportunity costs. Moreover, using inflation-adjusted payments to consider general price movements without distorting the market might increase farmers' AES participation.

Increased management and contract flexibility or providing different environmentally friendly practices from which farmers can chose could increase participation, although providing such flexibility might make the delivery of policy targets more difficult (e.g., Isbell et al., 2011; Kiehl et al., 2010; Schaub et al., 2021). Management and contract flexibility or stable income from AES payments might especially increase the participation of more risk-averse farmers.

Factors that were mostly as expected or unrelated to AES participation can still be useful for policymaking given local circumstances and contexts. These factors include farmer environmental

attitude, trust, farm size, management intensity, total labour, and other subsidies. While we find no relationship between environmental attitude and participation in more than half the studies, environmental attitudes might be more relevant for unincentivized AES or for AES with lower payments (e.g., Lokhorst et al., 2011; Wang et al.). Environmental attitudes might also be important in determining the quality of AES implementation (see, e.g., Graham et al., 2018; McCracken et al., 2015). Building trust in agencies and government can also be an important tool for increasing participation, but is dependent on the setting. For example, trust is especially relevant when farmers are less familiar with a scheme, or where the scheme depends on other farmers' actions, such as in agglomeration payments and multi-actor-based AES. Opportunity costs related to farm size, management intensity, and available labour might also be used to inform policy development.

Policymakers can also learn from ambiguous results on information dissemination, provided this is placed in context. For example, sending letters to encourage participation is more likely to be successful if participation in a region is low. Informing farmers about the value of the environmental benefits that they could produce might also increase their demanded compensation.

Our review highlights several important future research avenues. Opportunity costs of AES related to market conditions have, surprisingly, only been rarely studied, and increasing the spatial coverage could improve the robustness of the existing evidence. Our review has been geographically constrained to a few developed countries, and expanding the analysis across a wider range of countries could generate more insights and improve the confidence in the outcomes. It is also clear that there are many interacting factors which makes it difficult to interpret the results with clarity. More research on these interactions would be useful when designing policies. Finally, how different factors are measured varies substantially across studies, and the development of standardized measures would help compare results across studies and regions.

In an additional paper, we investigated biodiversity indicators for the use in result-based agri-environmental schemes, which connects (public and private) policy design with the behavioural factors described here (Elmiger et al.)

### Detailed outputs

For more details and references please refer to the papers:

**Paper 1**: Sergei Schaub, Jaboury Ghazoul, Robert Huber, Wei Zhang, Adelaide Sander, Charles Rees, Simanti Banerjee, and Robert Finger. The role of behavioral factors and opportunity costs in farmers' participation in voluntary agri-environmental schemes: A systematic review. Under Review.

**Paper 2**: Noëmi Elmiger, Robert Finger, Jaboury Ghazoul, and Sergei Schaub. Biodiversity indicators for result-based agri-environmental schemes – Current state and future prospects.

**Note: we presented here extract of the above-mentioned original papers, which are cited below.**

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# WP5. Spatial distributions and patterns of crop production in the four focus countries


## Authors

Zhe Guo, Liangzhi You, Wei Zhang


## Introduction

Addressing global sustainability challenges requires high-quality, interoperable, spatiotemporal information on multiple land-use variables (Nowosad & Stepinski, 2018). In biodiversity and environmental analyses, spatially explicit data on land use and land-use change are critical as important drivers such as deforestation, agricultural intensification, and land degradation need to be analyzed at the landscape scale (Fritz et al., 2019; See et al., 2015; You et al., 2014). Over the past twenty years remotely sensed data and spatial analytical tools have expanded considerably, making it easier and cheaper to incorporate the spatial perspective in estimating and mapping cropland and crop types with higher temporal frequency and spatial resolution (Pradhan, 2001). The remote sensing technology has been widely applied in studies of land cover and land use changes including agricultural land use at different spatial and temporal scales. Remote sensing together with Geographical Information Systems (GIS) and Global Position Systems (GPS) can be used to detect and identify characteristics of land cover types and their growing conditions. In recent years, the rapid development of remote sensing technology especially the improvements in spatial and temporal resolution makes it more suitable to monitor agricultural activities in a precise and timely manner(Gao et al., 2017; Hunt et al., 2019; Lobell & Burke, 2010). Series of land cover and land use products are produced by European Space Agency (ESA), US National Aeronautics and Space Administration (NASA), and US Geological Service (USGS). The detailed spatial datasets fill in the data gap for exploring the social, economic and environmental consequences of agricultural production at a highly disaggregated scale.

The remote sensing-derived cropland product has enabled the investigation of how land use diversity and agriculture intensification at the landscape level could lead to ecological and environmental consequences (Larsen, 2013; Larsen & Noack, 2017, 2021). This refined spatial perspective provides a unique understanding of how ”simplified” versus “complex” landscapes influence biodiversity-mediated ecosystem services (Meehan et al., 2011; Zhang et al., 2018). While the benefits of increased food production are difficult to dispute, simplification, at both the local and landscape level, has fuelled declines in biodiversity and ecosystem services.

## Methods

### Datasets

#### Land cover and land use dataset

For this study, we reviewed a variety of existing global land cover products from different satellite including MODIS land cover from NASA (Friedl, 2015), Worldwide croplands maps from Global Food Security support analysis data program, USGS (Thenkabail, 2012), Global land cover from Climate Change Initiative (Lamarche, 2017), Europe Space Agency, and the Global land cover 2020 product from Esri (Karra, et al. 2021). We considered the product that is publicly available, at high spatial resolution, and produced in the most recent year that is best suitable for our analysis. After comparing all the products, we selected the Global land cover 2020 product. The global datasets are released by Esri, the global leader in location intelligence with Esri Silver Partner Impact Observatory, as well as long-time partner Microsoft. For the first time ever a new high-resolution, open, accurate, timely, and comparable, 2020 global land cover map as part of the company’s Living Atlas was built using

European Space Agency (ESA) Sentinel-2 satellite imagery and developed using a new machine learning workflow.

### Protected area

IUCN's Protected Areas Management Categories, which classify protected areas according to their management objectives, are today accepted as the benchmark for defining, recording, and classifying protected areas. They are recognized by international bodies such as the United Nations as well as many national governments. As a result, they are increasingly being incorporated into government legislations. These guidelines provide as much clarity as possible regarding the meaning and application of the Categories. They describe the definition of the Categories and discuss the application in particular biomes and management approaches.

IUCN protected area includes six categories: *Category Ia: Strict Nature Reserve, Category Ib: Wilderness Area, Category II: National Park, Category III: Natural Monument or Feature, Category IV: Habitat/Species Management Area, Category V: Protected Landscape/Seascape, Category VI: Protected area with sustainable use of natural resources*

### Crop type maps

The Copernicus program, and Sentinel-1 (S1) in particular, offers the opportunity to monitor agricultural land at a European continental scale and in a timely manner. Capitalizing on the unique LUCAS 2018 Copernicus module, the ESR presents the first continental crop type map at 10-m spatial resolution for the European Union (EU) based on Sentinel S1A and S1B Synthetic Aperture Radar observations for the year 2018. The overall accuracy for the map is reported as 80.3% when grouping main crop classes and 76% when considering all 19 crop type classes separately. In the United States, The Cropland Data Layer (CDL) is a product of the USDA National Agricultural Statistics Service (NASS) with the mission “to provide timely, accurate and useful statistics in service to U.S. agriculture”. The CDL is an annual crop-specific land cover classification product of more than 100 crop categories grown in the United States.

## Analysis

We propose to adopt three steps in the analysis. The first step includes a spatial analysis at a macro level to identify where, how, and the extent to which the cropland is clustered in simplified landscapes in the key regions, using existing spatial datasets and building on collaborative work that the consortium member organizations have been undertaking. The second step is to overlay the density map of cropland extent with the protected area of different categories and visualize the spatial patterns between the cluster of cropland and the protected area in the country. Lastly, the spatial clusters of focused crops, namely wheat, maize, and soybean that are the focus crops of the proposal are examined to identify the dominant areas and spatial clustering of the three crops in the countries. In addition, we also intended to select similar crops that exists in all four countries so the spatial patterns of crop types could be compared. As more crop type data are made available (such as oilseed rape), the spatial patterns of country specific crops could be addressed in the future.

The original Global Land Cover 2020 is organized by 10 degrees by 10 degrees tiles. The mosaic function in the data management toolbox in ArcGIS software is used to merge all the tiles into one entity. There are nine classes in the mosaiced Global Land Cover 2020. Since the study is focused on cropland, we will reclassify the method to convert the land cover map into a cropland map. The reclassification tools reclassify or change cell values to alternative values using a variety of methods. In this application, we reclassify all the non-cropland classes into 0 at once and classify the cropland pixels into 1. The output delivers a cropland extent map at a 10-meter resolution. The Aggregate function is then applied to produce the density map of cropland. The Aggregate function generates a reduced resolution version of the raster. Each output cell contains the sum of the input cells that are encompassed by the extent of that cell. The scale factor of the aggregation is set to be 100 in order to generate the density map of cropland at a 1km resolution.

Lastly, we also calculate the percentage of maize, wheat, and soybean in the cropland pixels using the Global Land Cover 2020 and specific crop maps collected from different sources. Following XXX, we defined simplified landscape as the pixels having a high percentage of wheat, maize, soybean, or a combination of three crops. The maize, wheat, and soybean data are firstly reprojected so they could overlay with the Global Land Cover 2020 data perfectly. Using a similar approach mentioned above, the maize, wheat, and soybean density maps are aggregated to 1km spatial resolution which Figure 9. is the same as the crop density map produced from the Global Land Cover 2020. The area percentage of an individual crop is defined as the total area of each crop divided by the total area of the cropland area at 1km pixel level. To simplify the process, we use majority rules which are defined as pixels that have more than 50% of individual crops or any of the three crops in a pixel.

## Results

It is challenging to compare spatial patterns of the four countries as the sizes of the countries are different from each other. The crop density maps in Figure 9 are developed using the same 10 meter grid and the same symbology schema is adopted among the countries so the maps are more comparable. The spatial distribution of cropland in Germany is much more homogeneous although there are clusters of forest or other land cover types in the country, the cropland density in the country is relatively high. In France, the density of cropland is higher in the north compared to in the south although the southwestern region of the country has high cropland density too. However, the cropland is highly clustered in the United States and Brazil. The cropland of the United States is concentrated in the corn belt and along the Mississippi River. There are some clusters of cropland in California and along the east coast. In Brazil, the cropland is highly clustered in the southern regions of the country.

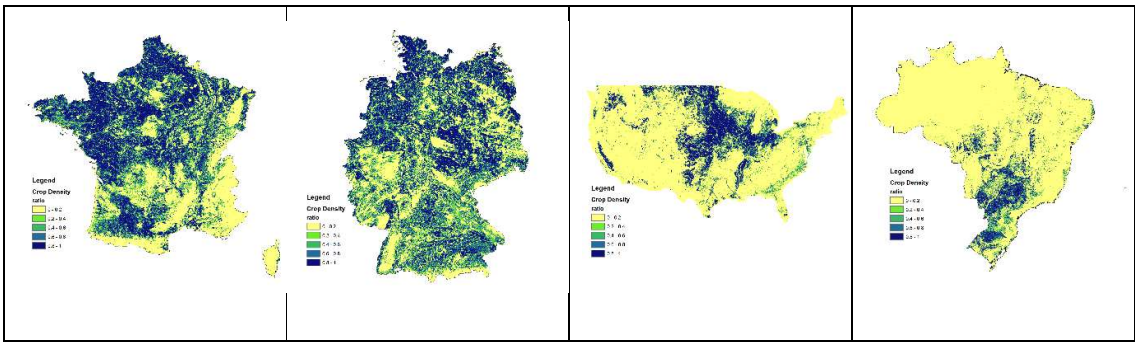
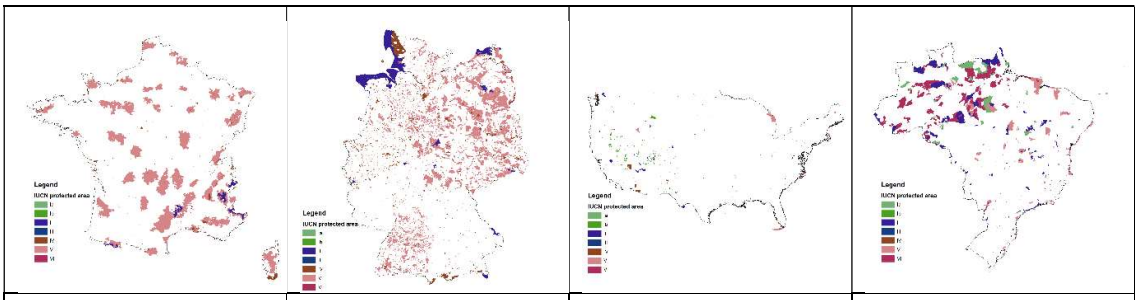


**Figure 9**. The spatial distribution of cropland in the four focus countries using the processed data from Global Land Cover 2020 (Top-left: France, Top-right: Germany, Bottom-left: Brazil, and Bottom-right: United States).

The next step is to map the protected area in the four countries. The following figures show the distribution of protected area in all six categories.

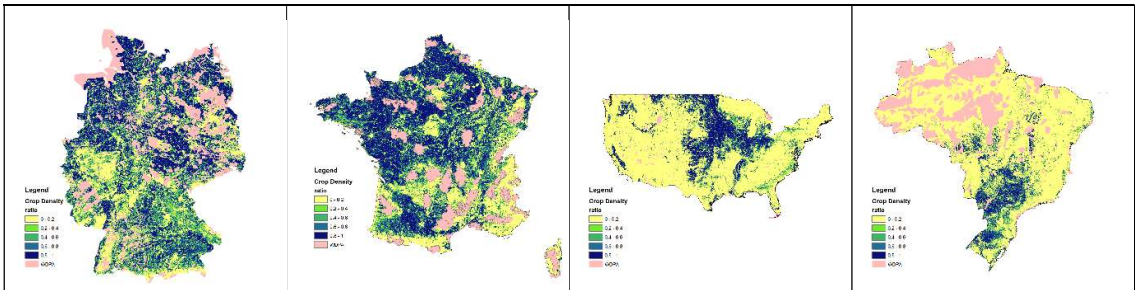
The spatial distribution and area share of different categories of the protected area vary substantially among the four countries (Figure 10). In France, most of the protected area are in category V which is over 90% of the total protected area. Germany only has three categories of protected area which area II, IV, and V. Among them, category V is dominant. USA The has almost 80% of the protected area in category IV. The area of protected I is minimal. Brazil has the largest area share of the category I among all four countries.



| IUCN protected area in France | IUCN protected area in Germany | IUCN protected area in the United States | IUCN protected area in Brazil |
|---|---|---|---|

**Figure 10**. Distribution of IUCN protected areas.

In the next step, we overlaid the cropland density maps with the identified protected area to visualize the distribution of both products (Figure 11).



| Cropland density overlaid with protected area in Germany | Cropland density overlaid with protected area in France | Cropland density overlaid with protected area in the United States | Cropland density overlaid with protected area in Brazil |
|---|---|---|---|

**Figure 11**. Cropland density maps in relation to protected areas.

The overlay analysis reveals different patterns of distribution among countries. In Germany and France, most of the protected areas are adjacent to cropland and some of them are next to cropland areas with high density. On the other hand, the cropland parcels are relatively far to the protected areas in USA and Brazil. Especially in Brazil, the majority of the protected areas are located in the Amazon Forest regions in Northern or Central Brazil while Brazil cropland is more clustered in the south of the country.

Lastly, we investigate the perspectives of the simplified landscape on individual crops and crop groups. We calculated the crop area percentage of wheat, maize, and soybean in the cropland at the pixel level. To simplify the process, we use majority rules which are defined as pixels that have more than 50% of individual crops or crop combinations. In Figure 12, we identify the pixels in which any of the three crops has a cultivated area of over 50%. Although the spatial patterns of wheat, maize, and soybean individually could be different, here we focus on identifying the spatial distribution of these three crops as a whole.

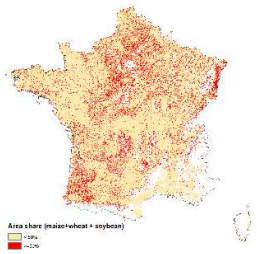
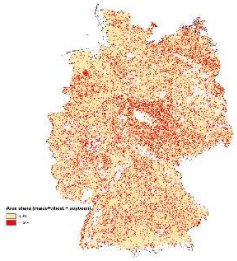
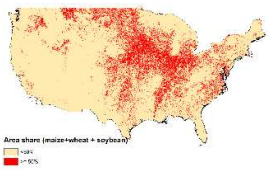
| | | |
|---|---|---|
|  |  |  |
| The area share of maize, wheat, and soybean (France) | The area share of maize, wheat, and soybean. (Germany) | The area share of maize, wheat, and soybean (U.S.) |

**Figure 12**. The area share of maize, wheat, and soybean. Brazil is not included in this Figure because data is not available for all three crops for Brazil.

The patterns of specific crops in the country are quite different. In France, the hotspots of maize are located mainly in the north-eastern area and there is a cluster of the high density of maize in the southwestern part of France. The wheat is less clustered compared to maize and the central region has a high percentage of wheat. There are very few pixels with an area share of soybean greater than 50%. When three crops are combined, there are three hotspots with high crop density that could be easily visualized. They are located in the north-eastern, central, and southwestern regions of the country as displayed in Figure 12. In Germany, the pattern of soybean is similar. The maize has a high density in the west compared to other regions. The wheat is mostly clustered in north-eastern and central Germany. When combining all three crops, the clusters are concentrated mostly in the northern and central parts of the countries as displayed in Figure 12. In the United States, the location of soybean and maize are highly overlapped and located mostly in the corn belts regions and along the Mississippi River. Unlike in Europe, there are many pixels that have an area share of soybean greater than 50%. The wheat with a high area share is mostly located west of the corn belt regions.

## Conclusion

We collected, processed, and harmonized spatial datasets from different sources including Global land cover 2020, individual crop maps, and protected area from IUCN. Furthermore, the density of cropland area, percentage of individual crops, or combination of crops are produced and used in the analysis. There is strong spatial heterogeneity of the distribution of cropland area, and individual crops. Each country shows unique spatial patterns, and the "hotspots" or clustering patterns are clearly demonstrated. We believe such assessment would complement WP2 and WP3c; by, for example, substantiating how simplified the cropped areas really are, identifying the potential for connecting existing "habitats", and pinpointing areas where "habitats" adoptions make more sense in terms of both biodiversity and agronomy. Furthermore, such coarse-scale analysis could potentially link to Bayer's FieldView system on a landscape scale. Such potential extension of the spatial analysis could be to support Bayer Crop Science (BCS) in identifying the simplified landscape areas for subsequent implementation if there is an interest/request from the donor and would be handled in a possible follow-up phase of this project.

In addition to the spatial analysis of existing cropland and crop types that are demonstrated in this study, it is also important to study spatial patterns of potential cropland distribution and crop type distribution which has been left out in this study. The maps of potential crop land area help assess natural resources for finding suitable agricultural land utilization options. It identifies resource limitations and opportunities based on plant eco-physiological characteristics, climatic and edaphic requirements of crops and it uses these to evaluate suitability and production potentials for individual crop types under specific input and management conditions. Managing the constraints imposed by

agro-ecological conditions and knowing what the most viable crop options are, facilitates planning decisions. In this way choices can be made, which are not only more productive, but also sustainable and resilient to climatic variability. The Global Agro-Ecological Zones (AEZs) datasets from FAO uses well-established land evaluation principles to assess suitability of individual crops including cover crops globally. The potential variables include agro-climatic potential yield and suitable area. The results are presented in a regular raster format of 5 arc-minute (about 9x9km at the equator) grid cells which make it very suitable for studies at large scale. Meanwhile, the cover crop potentials at local scale can be also assessed with online cover crop calculators such as the tool developed by the Virginia Tech University (https://soilhealth.spes.vt.edu/CoverCropCalculator.html). Although maps of cover crops do not yet exist at large scale, the maps of individual crops are largely available such as the products of IFPRI's Spatial Production Allocation Model which can map more than 42 existing crop types and the FAO's AEZs product which provides more than 50 crop suitability maps. Potentially, the individual crop or crop combination maps can be used as a proxy to develop a spatial map of cover crops.

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# WP6. Outreach and communication

Statistics up until September 30, 2022

## ETH Zurich

**Main website**

https://worldfoodsystem.ethz.ch/research/special-collaborations/enhancing-biodiversity.html

Launch: 17 May 2021

2021 Views: 1058 Users: 898

2022 Views: 577 Users: 440

**Announcement 17 May 2021**

https://www.ifpri.org/news-release/new-research-collaboration-takes-action-restore-biodiversity-and-increase-resilience

Views: 572 Users: 469

**First blog 20 May 2021**

Rethinking Agriculture

https://worldfoodsystem.ethz.ch/news/wfsc-news/2021/05/biodiversity-blog-rethinking-agriculture.html

Views: 335 Users: 278

**Second Blog 27 January 2022**

Feed the microbes

https://worldfoodsystem.ethz.ch/news/wfsc-news/2022/01/feed-the-microbes.html

Views: 115 Users: 101

**Webinar 28 June 2021**

Bending the curve of biodiversity loss: How can agriculture become part of the solution?

Summary: https://worldfoodsystem.ethz.ch/news/wfsc-news/2021/07/bending-the-curve.html

Participants: 100

Video views: 66

**Webinar 04 May 2022**

Bending the curve of biodiversity loss: How can agriculture become part of the solution? Part 2

Info: https://www.zalf.de/en/aktuelles/Pages/PB3/Webinar-Biodiversity-and-Resilience.aspx

Participants: 170

Video views: 93

## IFPRI

### IFPRI.org webpage stats:

- New Research Collaboration Takes Action to Restore Biodiversity and Increase Resilience in Agriculture Systems – created on May 17, 2021.
    - All time : May 17, 2021 – Sep 30, 2022 : 687 / 639 {pageviews / unique pageviews}
    - 2021 : May 17, 2021 – Dec 31, 2021 : 561 / 528 {pageviews / unique pageviews}
    - 2022 : Jan, 2022 – Sep 30, 2022 : 126 / 111 {pageviews / unique pageviews}
- Feed the microbes - created on Jan 28, 2022
    - All time & 2022: Jan – Sep 31, 2022: 256 / 230 {pageviews / unique pageviews}

### Social media stats:

- For the IFPRI press release ("New Research Collaboration Takes Action to Restore Biodiversity and Increase Resilience in Agriculture Systems"), we don't have any social media data because we don't usually promote press releases on socials.
- IFPRI blog post ("Feed the microbes"), here are the social media metrics:

| Platform | Post link | Date posted | Impressions (as of 10/11/2022) | Engagements (as of 10/11/2022) |
|---|---|---|---|---|
| IFPRI Facebook | https://www.facebook.com/ifpri.org/posts/pfbid02pdcEXt2VYPtvBH1Tw7xtWBrVKCCb2CeG7eEE7q32ZKUnj5q7Es7HjfHzvsYpCWoml | 2/3/2022 | 1,717 | 28 |
| IFPRI LinkedIn | https://www.linkedin.com/feed/update/urn:li:activity:6895016782256820226/ | 2/3/2022 | 2,358 | 55 |
| IFPRI Twitter | https://twitter.com/IFPRI/status/1488565321468456964 | 2/1/2022 | 791 | 39 |
| IFPRI Twitter | https://twitter.com/IFPRI/status/1490460323379298312 | 2/6/2022 | 723 | 9 |
| IFPRI Twitter | https://twitter.com/IFPRI/status/1494720878201954313 | 2/18/2022 | 690 | 14 |
| | | **Total** | **6,279** | **145** |

# Supplementary information for WP1

## Part 1 Definitions of biodiversity enhancing practices or measures

# Supplementary Information Item for WP1: Definitions of Biodiversity Enhancing Practices or Measures, Part 1

Supporting: Enhancing Biodiversity and Resilience in Intensive Farming Systems

# Definitions of biodiversity -enhancing practices

## Brazil

Source of definitions: Embrapa

### No-tillage systems

No-tillage System is the most conservationist method of working the land for agricultural purposes. It is characterized by the incessant search for the profitability of the productive agricultural system through the maximum expression of genetic, edaphic and environmental potential. It is the form of conservation management that involves all the techniques recommended to increase productivity, conserving or continuously improving the environment. It is based on the absence of soil disturbance, on its permanent cover and on crop rotation. It also presupposes a change in the way of thinking about agricultural activity from a socioeconomic context with environmental concerns.

### Coverage cultivation

Cover crops are plants grown for the purpose of creating a protective layer in the soil and improving water infiltration. This layer on the soil helps to characterize the no-till, resulting to have more moisture and less erosion on the soil. Straw also helps to suppress weeds due to its physical, allelopathic (they can release substances that harm weeds) and biological effects. The species used in this practice are numerous, but each of them has a specific function. Cover crops have some advantages in soils, among them we can mention the main ones:

- Ground cover with a large amount of green mass;
- Soil protection against sudden temperature variations;
- Reduction of weed infestation, with some studies indicating that no-tillage reduces infestation by up to 85%;
- Increase the nutrient retention capacity of the soil;
- Soil protection against erosion and nutrient leaching;
- Improvement of soil biodiversity.

### Crop rotation

means the ordered, cyclical (temporal) and seasonal alternation of different plant species in a specific productive space. For example, on a plot of land, three cycles of a two-year crop rotation system can be adopted for six years, in which, in the first year, there is soybean in spring/summer and wheat in autumn/winter, while in the second year there is corn in spring/summer and oats or sunflower in autumn/winter. This illustrates that in crop rotation, in a given season, there is an alternation of plant species in different years.

### Integrated Crop-Livestock-Forestry (ICLF)

when cultivation/breeding systems for different purposes (agriculture or farming, livestock and forest) are integrated with each other, on the same plot, with the aim of maximizing the use of the area and the means of production, and also diversifying income. In this context, four possible types of integrated systems stand out:

- crop-livestock (e.g.: corn and brachiaria or sunflower and brachiaria). In these examples, it is important to emphasize that, if Brachiaria is not used for grazing, but

for other purposes, such as the formation of straw in the no-tillage system, this production system is not characterized as integration, but as a consortium;

- forestry farming (Ex.: soybean between the eucalyptus lines);
- livestock-forest (Ex.: cattle on pasture in eucalyptus reforestation);
- crop-livestock-forest (Ex.: corn cultivation followed by pasture with cattle entering a eucalyptus area).

## Organic fertilizers

Organic fertilizer is a product of a fundamentally organic nature, obtained from raw materials of industrial, urban or rural, plant or animal origin, enriched or not with mineral nutrients. As they are rich in microorganisms, they benefit soil health and increase long-term productivity.

Composed mainly of plant and animal remains from agricultural activity, organic fertilizers protect crops against pathogenic organisms while increasing soil quality, nutrient absorption and the efficiency of mineral fertilizers. Organic compost is a fertilizer that is routinely used in organic properties, especially in small ones.

## Habitat restoration and conservation

Brazil has a large amount of degraded areas that are currently unable to play their ecological role or generate income. These are areas of low agricultural productivity, which suffered deforestation and were poorly managed or abandoned. Forest restoration is human intervention to trigger, facilitate or accelerate the natural process of ecological succession. Therefore, involves the gradual reconstruction of the forest, rescuing its biodiversity, ecological function and sustainability over time, determined by the rescue of several different species, including other forms of life besides trees (herbs, shrubs, lianas, fauna, etc.) and also the functions that each species performs, individually or together. While restoration is a good measure to protect the soil, improve the climate, improve water quality and protect biodiversity, it also develops a forest economy. Planted forests can generate income for rural producers with the production of wood from native species, non-wood products such as fruits, nuts and seeds – and combat illegal deforestation.

## Biological products

Biological inputs are agro-industrial products or processes developed from an active ingredient that is natural, considered a biological asset, such as enzymes, extracts (from plants or microorganisms). These actives, for the most part, are of low toxicity and act with the objective of eliminating the target pest without harming the environment, allowing the maintenance of beneficial insects in the crop (natural enemies) and reducing dependence on constant applications of other products. Macrobiological agents (mites, insects and nematodes), microbiological agents (viruses, bacteria and fungi), semiochemicals (pheromones) and biochemicals (hormones) are considered biological actives and are part of the formulation of different biopesticides, intended for use in production, storage and processing of agricultural products.

## Agroforestry systems

Agroforestry systems - or SAFs - are production models that associate perennial elements such as trees with agricultural crops and, sometimes, also with animals, simultaneously or sequentially. An agroforestry system is a form of land use and occupation in which trees are planted or managed in association with agricultural or forage crops in the same area. This classification encompasses forestry systems (forest and agricultural species), silvopastoral (forest species and livestock activities) and agrosilvopastoral systems (agricultural, forestry species and livestock activities). SAFs optimize land use, reconciling environmental preservation with food production, conserving the soil and reducing pressure for land use.

### Intercropping

When two or more crops occupy the same agricultural area in the same period of time. As an example, the producer can adopt an intercropped system with beans grown between the corn row, which is more common in family farming areas. It is noteworthy that intercropped systems can be inserted in crop succession or rotation systems.

## Germany

The interview team did not have an opportunity to ask farmers to provide definitions for the biodiversity-enhancing practices. However, it is believed that most farmers have approached the measures as defined in the Common European Agricultural Policy and German federal government policies. In the absence of official definitions, the team used its own definition.

### Maintenance/ Implementation of Agroforestry System (incl. hedgerows and wind breaks)

Up until 2023 there has been no official definition of agroforestry (AF) as there generally were no subsidy schemes available in Germany.

According to Germanys Strategic Plan, the definition of AF (as an eco-scheme) is as follows:

- Area share of the wooded area on the arable or grassland plot has to be between 2 and 35%
- Wooded area has to be planted in to form of tree strips
- An AF system has to have at least 2 tree strips
- Width of the tree strips has to be between 3 abs 25m
- The maximum distance between 2 tree strips is 100m
- Minimum distance of tree strips to each other and the edge of the plot is 20m
- If the tree strips are next to a body of water the minimum distance may be small
- Wood harvest only allowed in January, February and December
- There is a negative list of tree species

Hedges are defined as follows in the strategic plan:

- Linear structural elements, mainly consisting of woody perennials
- Minimum length 10m
- Average width of up to 15m
- No specification of where to plant them
- Cutting is only allowed in specified times of the year

### Maintenance/ Implementation of buffer strips next to bodies of water

Buffer strips to bodies of water are required in the upcoming CAP in GAEC4. A buffer strip next to water has to be 3m wide and no pesticides or fertilizers are allowed to be applied there. There are however federal stated that have additional laws when it comes to buffer strips. E.g., Brandenburg requires that no fertilizers or pesticides are applied in on the 10m that are directly adjacent to bodies of water. These requirements apply to arable land and grassland.

### Maintenance/ Implementation of buffer strips not next to bodies of water

We defined this internally as all buffer strips that might be implemented to roads, paths, neighbouring plots or houses.

### Flowering strips/areas

According to the strategic plan flowering strips have to fulfil the following requirements:

- Min size of 0.1 ha for flowering strips
- Min length 20m, maximum width 30m for strips, otherwise they count as flowering area
- Flowering area is not shaped in a strip but an area of min 1ha
- Seed mixtures are accredited by the federal government or prescribed by the federal states
- No fertilizer of pesticide use
- Seeding before the 15th May
- After September 1st it is allowed to work the soil and plant new seeds for the following year if the farmer chooses so

### Establishing new kinds of habitat (e.g. forest, wetlands, structural elements, etc.)

Wetlands are e.g. kettle holes, ponds, sinkholes or other biotopes that are defined through the Federal Act for the Protection of Nature.

Structural elements are protected and cannot be agriculturally used or cut down. They can only be managed during the winter months with specific restrictions.

### Management of field shrubs and kettle holes

Field shrubs are defined according to the strategic plan as an area with mainly woody perennials that are not agriculturally used with a minimum of 50 square meters in size and maximum size of 2'000 square meters. There are no specifications on how they can be planted. Maintenance is limited to certain months during the year, usually in the winter.

Kettle holes do not have an official definition.

## The United States

Here Professor Michael Castellano provided his definitions of the biodiversity-enhancing practices that interviewed farmers in Iowa implemented. We plan to ask farmer participants of a stakeholder workshop tentatively scheduled for November 18, 2022 about their definitions. We will share notes on the definitions once the information has been collected.

### Cover crops:

US farmers generally consider a cover crop to be a crop with the near-term direct production revenue from uses that exceeds the near-term costs. For example: seed, herbicide, and labor costs exceed any potential near-term revenue from grazing or harvesting the cover crop as hay. Yet, many farmers recognize a cover crop may generate long-term revenues that exceed long-term costs due to the positive impacts on soil health that take many years to accrue.

Note my use of 'direct' is to distinguish between harvest revenues whether grazing or hay etc. vs near-term revenue from increased following cash crop yield perhaps due to things like weed suppression.

### No-till:

farmers may have very different definitions of no-till soil management. For example, many farmers till the soil following corn but not soybeans. Some farmers may refer to this system as no-till. Other

farmers might only refer to a system as no-till when both phases of the corn-soybean rotation are managed with no-tillage. Reduced tillage is a related term that is often used to reference strip tillage or other tillage systems that are relatively limited in space or time. The most common tillage systems is likely fall chisel plow followed by spring cultivation following corn with no tillage following soybean. Note, it is not possible to use no-till soil management in continuous corn systems.

### Crop rotation:

Any system other than continuous corn. The two most common cropping systems in the state of Iowa, accounting for approximately 23 of 30M acres of farmland, include only corn and soybeans. Of these 23M acres, approximately 20M rotate corn and soybeans to some extent while 3M plant only corn.

### Buffer strips:

Farmers generally refer to buffer strips as edge-of-field native perennial grass plantings between crops and waterways. They serve to provide bank stabilization and increase biodiversity. In the case of ephemeral waterways, where grasses are planted completely through the waterway, farmers may refer to these as 'grassed waterways'. Some farmers in the survey may have included grass waterways in their discussion of buffer strips.

## Part 2 Interview finding summaries

# Supplementary Information Item for WP1: Interview Finding Summaries, Part 2 – Brazil | Synthesis of Interview Notes

Supporting: Enhancing Biodiversity and Resilience in Intensive Farming Systems

# Bayer Project: Brazil | Synthesis of Interview Notes

## Current Management

**Information Sources**

Farmers shared the main sources that they receive information from. Seven farmers expressed that they receive information from a vast variety of sources which could include sales representatives, university extensions, magazines, YouTube, and neighbors.

Six farmers specified that they get information from other farmers such as their neighbors, colleagues, exchanges within their union, farmer groups, and cooperatives. Five farmers specifically noted that they receive information from sales representatives, while four farmers said they receive information from consultants. Two farmers mentioned that field days were a main information source for them. Additionally, two farmers said they receive information from university extensions and two other farmers cited the internet.

**Soil Fertility and Disease Control**

Farmers also shared their management techniques for soil fertility and diseases.

For soil fertility management, seven farmers expressed that they use chemical fertilization. Six farmers said they practice soil corrections. Five farmers said they practice no-tillage and six said they use soil analysis to determine their fertility management. Five farmers shared that they practice precision agriculture. Two farmers said they practice AG for their fertility management.

For disease management, six farmers shared they use some form of monitoring. This could be a formal monitoring system, private monitoring, pest monitoring, visual monitoring, or use of field monitors. Five farmers said that they use biologicals for their disease management. Four farmers said they practice an integrated management system. Four farmers also said they use chemicals. Seven farmers mentioned integrated pest management (IPM) for their pest management and three farmers said that they use consultants.

**Other Practices Currently Used**

Farmers were also asked if they practice no-tillage systems or waste management, use coverage cultures or organic fertilizers, or rotate cultures.

Fourteen farmers said they have no-tillage systems, while thirteen farmers said they practice waste management. Additionally, seventeen farmers said use coverage cultures and only nine farmers said that they used organic fertilizer. Fourteen farmers said they rotate cultures.

## Biodiversity Understanding & Views

**Definition & Benefits**

Interviewed farmers were asked about the meaning of biodiversity and how it relates to their farm. Farmers also shared biodiversity enhancing practices that they believed could improve their farm and the advantages that result from biodiversity.

When asked about their understanding of biodiversity and its relation to their own farms, eight farmers emphasized its impacts on soil. Farmers highlighted life and microorganisms within soil, conservation, and management. Seven farmers noted that they supported biodiversity through no-tillage systems. Seven farmers also expressed that they viewed biodiversity as the maintenance and restoration of preservation areas. Additionally, seven farmers indicated that biodiversity meant an equilibrium of existing variation of plant, species, and soil. Two said that the presence of some animals indicated enough habitats. Two different farmers said that diversification of production benefits biodiversity. Four farmers emphasized that chemical inputs should be thoughtfully and minimally used to support biodiversity.

Farmers were also asked what interventions, leaving cost and practicality issues aside, do they believe would improve biodiversity on their farm. Four farmers expressed they thought reducing the use of chemical inputs or using organic and natural products would increase biodiversity. Four farmers referenced crop rotation and three noted the maintenance of preservation areas in their response. Four farmers said the use of biological products would help biodiversity while one farmer said biological control would be a beneficial intervention. Two farmers indicated the Integrated Crop-Livestock-Forestry Systems would improve biodiversity.

Responses on the advantages that biodiversity practices generate varied. The most popular advantages noted by farmers were reduced costs and yield gains. Farmers stated that there was an economic advantage to using biodiversity enhancing practices because the reduction of chemical inputs lessened costs for them. Eight farmers highlighted the impacts that biodiversity could have on their soil such as conservation, reduced erosion, and existence of microorganisms. Seven farmers stated that biodiversity enhancing practices generated increased productivity. Three farmers highlighted biodiversity enhancing practices as a disease and pest control method. Four farmers also noted the positive impact that biodiversity has on the environment and with sustainability efforts.

**Costs, Risks, and Local Efforts**

During the interviews, farmers were asked to share the risks and costs that they believed were associated with using biodiversity enhancing practices on their farms. Questions also asked about biodiversity within the region, such as what changes should be made to lead to increased adoption and if neighbors held similar perceptions on biodiversity.

Nine farmers stated that they believed there were no risks involved with biodiversity practices. A majority of farmers also noted that costs of such practices were minimal and reasonable. The specific costs that interviewees did reference were alternatives to chemical inputs, poultry waste, rock dust, hiring of a professional to assist with fauna protection, and expenses associated with initial deployment. Five farmers stated that there was a risk in the unpredictable nature of biodiversity enhancing practices and the impact it could have on crop production or making an investment to implement with no return.

Farmers shared a variety of ideas on what could be done throughout the region to support biodiversity. Five farmers stated that best practices or positive results produced should be shared to encourage the adoption of biodiversity enhancing practices. Three farmers also noted that further research was needed on biodiversity enhancing practices. Three farmers stated that local and farmer input should be encouraged to support biodiversity efforts. Three farmers emphasized the need for financial support and incentives to help generate more regional acceptance of biodiversity enhancing practices. Two farmers highlighted the need to increase efforts to protect against forest fires.

Nine farmers stated that they believed neighboring properties shared similar perceptions with them related to biodiversity enhancing practices. Six farmers noted that shared perceptions in their region were mixed; some neighbors do hold similar views while others don't. Three farmers said no, they did not believe neighboring properties held the same perceptions as them.

## Biodiversity Experience & Adoption Considerations

**Motivations & Adoption Criteria**

During the interviews, farmers shared the motivations that drove them to adopt practices that support biodiversity. Farmers also shared the criteria that is most important for them to consider while choosing to adopt such practices.

A strong majority of farmers interviewed stated that they have adopted practices that benefit biodiversity. Farmers provided different responses on the main factors that motivated them to adopt such practices. Three farmers said it was to maintain or preserve water resources. Three farmers expressed that they were driven to adopt biodiversity enhancing practices to improve soil quality. Four farmers noted they were motivated by environmental considerations. Four farmers also noted that economic factors served as a motivation for them, such as, profitability, cost reduction, financial return, and market trends.

Farmers also responded with a variety of considerations for the criteria they use in their decision-making for adopting biodiversity enhancing practices. The most commonly received response was financial factors such as implementation costs, ability to reduce costs, and ensuring that practices were economically viable. Nine farmers noted this. Five farmers expressed that they considered the impacts on the environment while making a decision. Seven farmers stated that they considered practices' ability to improve and maintain farm productivity. Three farmers noted that it was important to them to choose practices that they knew increased efficiency.

**Reflections & Sharing**

Farmers were asked if in hindsight, there was anything they would have changed about the way in which they adopted biodiversity enhancing practices. They were also asked whether they have or would like to share their experience with neighboring farmers or coordinate practices with them. Additionally, farmers were asked about the reactions that they received from farmers when sharing practices.

Seven farmers said that they would not have changed anything about the way they adopted their biodiversity practices. Eight farmers said they would have made changes to their adoption of

biodiversity practices. Many farmers expressed that they wished they had started sooner, and a couple of farmers said they would have used biological products.

Sixteen farmers noted that they shared their experiences with neighboring farmers. Six farmers noted that the experiences they shared were well received, five farmers received mixed responses, and only a couple of farmers noted that sometimes neighbors were not receptive toward learning about their experiences.

## Policies & Programs

**Experience**

The interviews also included questions about farmers' experience with policies and programs that are designed to support biodiversity. Farmers were asked about how they accessed information related to such policies and programs, whether they received training, and if anyone convinced them to participate.

Most interviewed farmers stated that they had experience with biodiversity enhancing policies and programs. Only six farmers stated that they did not have any experience with these policies and programs. Five farmers said that they had experience with the Round Table on Responsible Soy (RTRS) and two farmers specified that they had experience with Soja Plus. Both RTRS and Soja Plus are private initiatives to strengthen conservation efforts as the compliances for the Forest Code. Seven farmers indicated that they had accessed resources from in Brazil's Low Carbon in Agriculture Plan (ABC) or the ABC plus plan. Other policies and programs that interviewees said they had experience with but were less commonly mentioned include financing for irrigation and Rabobank financing.

Farmers provided a variety of answers as to who convinced them to participate in biodiversity enhancing policies and programs. Answers included personal curiosity, consultants, Bank of Brazil, capital demand, and neighbors. Five farmers said they received information related to policies and programs from bank managers or the Bank of Brazil. Three farmers said they received their information from consultants, while two farmers indicated that they received information from the news. Of those who shared about their experience with trainings, two farmers said that they never received training, one farmer noted that National Rural Learning Service mandated training, and another farmer said that market requirements made them do an annual training.

Farmers were asked if they had experience or are aware of programs that either require coordination with other farmers, include high-value territories for conservation, or are designed to reduce habitat fragmentation. Eight farmers replied that they did not have experience or knowledge of such programs. Of farmers who indicated that they had experience with or knowledge of these programs, they referenced Soja Plus, RTRS, and Araguaia League.

**Perceptions & Adoption Considerations**

Farmers shared their views on the requirements of biodiversity enhancing policies and programs, decision-making freedom in adoption and implementation. Farmers also shared factors that were most important to them in their adoption consideration as well as perceived benefits and costs. Farmers were asked about the changes they would like to see occur in current policies and programs.

Of farmers who shared their opinion on policies and programs' requirements, a few stated that they believed the requirements were reasonable and fair. When farmers were asked whether they felt like they had the freedom to decide on which preservation practices to adopt and how to implement them, ten farmers responded no and said it was the law or required regulation and that they were restrictive. Seven farmers stated that they felt like they had freedom and could choose what practices to adopt.

When farmers were asked about the factors that are most important for them to consider while choosing to adopt biodiversity enhancing policies and programs, most reference economic reasons. Farmers noted capital demand, market pressure, payments for environmental services, and interest rates as economic factors they consider.

Farmers were also asked to share the cost and benefits that impact their decisions to adopt biodiversity enhancing policies and programs. Farmers noted that the benefits received are marginal, payments for environmental services are not yet a reality, and that resources from the government programs often arrive late. Several farmers noted that their adoption decision is influenced by initial investment costs. Farmers also stated that they are influenced by financing help, reduced interest rates and costs, grace period, and risks.

Throughout the interview questions that were asked related to policies and programs, criticisms were brought up by a few farmers. Three farmers stated that more financial incentives should be offered, and another farmer noted that there was no efficient government action. A different farmer voiced that although policies are reasonable, propagation in the field is absent. This farmer suggested that a stronger government budget and more university research on biodiversity would be helpful.

Farmers had several suggestions for changes they would like to see in the implementation of biodiversity enhancing policies and programs. Many farmers voiced that there was a need for more financial incentives for those who adopted such policies and programs. Incentives could come in the form of additional lines of credit, attractive interest rates, and market rewards. One farmer also noted that incentives should be provided to encourage the development of technology for agriculture. Three farmers expressed that there was a need for more resources to support farmers in adopting policies and programs. Five farmers said that they would like to see greater disclosure, articulation, and publicizing of biodiversity enhancing policies and programs. Many farmers shared that they would like to see changes in governance. Comments received related to governance include a misunderstanding between programs, a need to understand specifics of each location rather than generalizing the entire region, lack of in-depth explanations and monitoring, government simply not doing its part, and bureaucracy issues.

## Ideal Farm, Aspirations, & Challenges

**Desired Property Template**

Farmers were asked to share their vision of their ideal property template and a variety of answers were received. Four farmers expressed that their desired property incorporated new technology as Integrated Crop-Livestock-Forestry Systems. Several farmers shared their ideal farm would be one that is more profitable, has lower costs, or better meets the market. Three farmers mentioned that they would like a biological factory on their farm. Two farmers said that their ideal property achieves improved soil quality. Five farmers noted that their current farm is close to are already at their ideal state.

**Obstacles to Desired Farm**

Farmers were asked about the obstacles that prevent or delay them from reaching their desired future view of their farm.

Six farmers said that economic obstacles prevented them from achieving their desired future farm. This includes maintenance costs, price of inputs, inflation, difficulty accessing a line of credit, and challenges within the market for smaller production farms along with multinationals monopoly. Five farmers noted that governance was an issue and cited problems such as existing laws potentially challenging technological development in agriculture, bureaucracy, lack of government incentives, unclear laws, political-admission insecurity, and unfavorable politicians creating uncertainty. Two farmers noted a need for increased knowledge and awareness on more sustainable practices. Other obstacles mentioned by farmers include bad weather which results in crop frustration, land title issues, inability to access resources, regional labor difficulties, conflicting interests from producers, climate change, and chemical restrictions.

**Future Farm & Success Factors**

Farmers were also asked to imagine that their property was twice as successful in five or ten years. Farmers then shared the main factors of their envisioned success and how they measured success.

Eleven farmers expressed that they measured success through economic factors. This includes reduction in production costs, profitability, market visibility, greater financial support, and revenue. Eight farmers stated that they would consider success as their ability to maintain or improve their current levels of productivity. Three farmers stated that success would be determined by the incorporation of new technology and a different three farmers noted improved management. Two farmers view success as increased biodiversity and two farmers consider improved soil quality to be a measurement of success.

## Appendix: Survey method questionnaire

- how were respondents identified? What criteria for identifying and selecting/screening respondents were used, if any?

At first, a selection was made based on the production pole regions in the State of MT, seeking to cover different hydrographic basins and biomes.

| # | Type | Hydrographic Basin | Biome | Municipality | Justification |
|---|---|---|---|---|---|
| 3 | Properties adhering to RTRS (Round Table on Responsible Soy Association) | Teles Pires | Amazônia | Sorriso | Municipality with high landscape fragmentation. Consolidated area (deforestation until 2008) and high agricultural production. There is a regional pact, which is part of the jurisdictional strategy of sustainability to achieve goals for Production, Conservation and Inclusion (PCI). |
| 3 | Properties associated with the Rural Union of Sorriso - CAT (Amigos da Terra) | Teles Pires | Amazônia | Sorriso | |
| 3 | Properties associated with the Querência Rural Union | Araguaia | Amazônia | Querência | The Municipality is home to 2 indigenous territories, one is the Xingu Indigenous Land. Located in an agricultural frontier region, among the 10 largest soybean producers in Brazil |
| 3 | Partner producers certified by the AMAGGI Responsible Standard developed to meet international recommendations, such as the FEFAC Guidelines | Juruena | Amazônia | Sapezal | The territory has a scale performance by large companies like Amaggi, which has production standards and certifications for the entire chain. It is considered the sixth largest soybean in the country, occupying the fourth position in the state ranking. There are 3 Indigenous Lands: TI Utiariti, TI Enawene Nawe and Ti Tirecatinga. |
| 3 | Properties associated with the Rondonópolis Rural Union | Paraguai | Cerrado | Rondonópolis | Main grain producer located in the Paraguay river basin, which forms the largest floodplain in the world, the Pantanal. |

Secondly, to identify the respondents, the main companies, trades and active NGOs were contacted, which supported us by indicating possible interested groups and/or producers.

- What were the steps for inviting farmers? (e.g., who, and through what channel, reached out to farmers)

The way of contacting the indicated producers followed the recommendations of the company/institution that nominated them. When possible, we asked them to contact the indicated producers directly, making a bridge with us.

Contacts were made mostly via email or phone call by the local team (Ana Paula / Adelaine). If there was no response, a message was sent via Whatsapp.

We also made use of an invitation letter signed by Prof. Pedro Brancalion.

- Were any forms of incentives (both monetary and non-monetary; both positive and negative) used to encourage farmers to accept the invitation? (e.g., financial or in-kind compensation, prospect of advisory support or other services, opportunities to ask

experts questions, peer pressure, network inclusion/exclusion, the chance of learning about survey results later, etc.)

No financial incentives were used. The only form of persuasion used was the invitation made through the partner institution. They were also informed about the chance of learning about survey results later, but only at the end of the interview.

- How many did you invite? How many declined?

1. Institutions contacted:

| | | |
|---|---|---|
| NOT SUPPORTED | 6 | 40% |
| SUPPORTED | 9 | 60% |
| **Total contacts** | **15** | |

2: Producers contacted:

| | | |
|---|---|---|
| NOT ANSWERED | 24 | 40% |
| NOT PARTICIPATED | 20 | 33% |
| PARTICIPATED | 16 | 27% |
| **Total contacts** | **60** | |

- Are there any common characteristics of farmers who declined?

We can identify some similar aspects:

- In general, producers are reluctant to participate in interviews, mainly, if it is for any kind of environmental project.
- Large groups (Amaggi, Bom Futuro, Bom Jesus) have strict internal policies and commercial partnerships that do not collaborate (the process is time-consuming and complex, in their words). All denied the possibility of granting interviews.

- How were the interviews conducted? For example, face to face interview or phone/zoom; one-on-one or as a group, etc.

The majority of the interviews were conducted by G-meet, if not possible, we used Whatsapp phone call.

- How long did an average interview take?

Approximately 1 hour. But in some cases, it took longer than that.

- How was the data recorded?

Unfortunately, we couldn't record the interviews because we didn't have any opening for that. As we already mentioned, we faced some resistance from some producers that would not agree to record. If we said we were going to record it, they wouldn't do the interviews.

- Profile of people who conducted the interviews (e.g., training/background, academic or extension or private consultant, etc.)

Private consultant with local experience and academic background in the area.

- Did the same people who conducted interviews do the translation?

Yes.

- Any issues or challenges or surprises worth highlighting? How did you attempt to resolve the problems? Did it work?

Unfortunately, there was low availability due to the harvest and planting period (summertime). There was a surprise in which the interviewee associated us with the left-wing political group (PT) for wearing a red shirt at the time of the interview.

Another curious fact was when one interviewee told us that he would not continue the interview if there was a reputational risk for him, telling us that he once participated in an interview with foreign researchers who completely misrepresented what had been said.

There was a case in which the interviewee did not understand the more technical questions and had to ask the superior for help (her father).

# Supplementary Information Item for WP1: Interview Finding Summaries, Part 2 – France Interviews | Response Analysis Summary

Supporting: Enhancing Biodiversity and Resilience in Intensive Farming Systems

## Biodiversity Experience

***Knowledge, Experience, and Views***

At the beginning of each interview, farmers were asked to share their understanding of biodiversity and how it relates to their farm. Farmers were also asked about local biodiversity related trends and the specific practices they incorporate in their farm management. The answers to these questions provide insight on the existing knowledge of biodiversity at the regional level and the techniques that farmers have already chosen to adopt.

When farmers were asked for the definition of biodiversity, most referenced an existence of diverse crops and wildlife. 10 responses highlighted this diversity.

"So I have a lot of definitions. Genetic biodiversity in terms of the seeds and seed varieties we use and the diversity of species in the crop rotation. There is biodiversity in the broad sense, so all plant species, whether they are floristic, woody, insects. Insects, soil life, microbiological and macro. There will be invertebrates, such as carabids and others. There will be birds, game species and harmful species."

"For me, biodiversity means having a maximum number of animal and plant species in the same place."

"For me, biodiversity on a farm scale is already the diversity of the crop rotation. Having varied and diverse crop rotations. Biodiversity also applies to our soils in my opinion, with the diversity of fungi that can be found in the soils, bacteria that can be found in my soils and the fauna in general, birds, game that I can have on my land."

Several farmers also described biodiversity as the beneficial interactions that occur in soil.

"And then the second point is on the arable land, we are rather in a diversity under the ground, which we don't see visually, but which we try to understand how our soils work."

"So, by changing the system, you really put life back into the soil. Now I have all the notions of bacteria, soil and fungi. But it's not something you can see with naked eye, you don't see it."

"So that's what we're looking at in terms of biodiversity, mainly the relationships between pests and auxiliaries and the whole soil life compartment with the effects on nutrition and plant health..."

Four farmers' answers emphasized that biodiversity was a means for improving their farms.

"My father had planted about 2 km of hedges and I am continuing because I can already see the benefits of what he planted, so I am continuing to plant on the farm. So we can already see the benefits, on erosion and then on the return of many species. So I see that there is more life."

"For me, biodiversity is the link between good agricultural sense. It's doing things that make sense, good economic sense, because if we do things that don't make sense, that are not profitable, or that are cruelly lacking in sustainable economic sense over time, biodiversity means respecting the fauna and flora on the farm."

"For me, when we talk about biodiversity, I don't think first of crop rotation techniques. I'm more interested in how we can have insects or plants that could help us not to fight against other insects and other plants. That is to say, how to improve the system in general, with less need for intervention because we will have created a more resilient ecosystem."

"I noticed that one of my best plots has reached a plateau in terms of productivity. The soil with every rainfall tended to clump together, and I had my neighbour who had been doing conservation farming for

at least a decade and when I spaded his plot, I saw that it was very, very different. You could easily see earthworms, whereas in mine there were far fewer. I told myself that there was a problem, that I had to review my system."

Three farmers also referenced biodiversity as a way to achieve increased resilience.

"Biodiversity has been my goal for about thirty years. The idea was to limit my impact on the environment so as to have much more resilient plots."

"That is to say, what, through nature, can allow farmers to have less dependence on phytosanitary and chemical products, thanks to nature and therefore thanks to a certain biodiversity which will allow them to recover essential points."

Additionally, farmers were asked how they managed and maintained soil fertility on their land. A variety of strategies were referenced. Of interviewed farmers who responded to this question, five noted reduced or no-tillage, four used organic matter, three conduct a soil analysis, and three rely on crop rotation. (Note: Many of the farmers referenced in this description noted more than one method).

Interviewees were also asked about the ways that they management pest and diseases on their farms. Answers varied and methods that were referenced in multiple responses included the use of chemical inputs or decisions support tools, strategic landscaping and sow timing, incorporating variety, and conducting observations.

The interviews also asked farmers to share the biodiversity enhancing practices that they currently use. A majority of farmers (14) stated that they practiced reduced or no-tillage.

"I've been doing no-till for at least 30 years, except that I only plough to rebuild the structure in case of accidents, so it happens once in a while."

"Pre-mounting, no-till for potatoes. For beetroot, for the moment, I'm in a rather classic system of no-till with green manure, with some Actisol behind."

"Concerning wheat. We sow in no-till and have a direct seeder, without working the soil at all. Knowing that it is a bit complicated for us not to work the soil at all."

"I started no-till while I was thinking of reducing phytosanitary products and tillage. Plowing has its advantages and disadvantages, and I find more disadvantages than advantages. So when we can limit it to the maximum, we do."

Crop rotation was also a popularly noted method that farmers stated they practice on their farms and was referenced by 13 farmers.

"You never put in the same cover crops every year. For the past five years I've been trying to grow different crops depending on the crop I'm going to grow afterwards. That is to say, for beetroot, we put in a lot of sunflowers for example, then we use legumes to capture the nitrogen in our manure, with sunflowers, mustard and clover. On average, we use 4 or 5 varieties in the mixtures."

"In terms of crop rotations, for example, the different crops we grow. It is very common to grow monocultures in our sector. We have always had crop rotation on our field, composed of wheat, beetroot, potatoes and field vegetables, maize. Crop rotation is good for the bees, for all these things, it's great. We have a production where, in terms of bees, insects and all that, we are not so bad."

"In terms of crop rotation, we have potatoes, wheat, grain maize, fiber flax and sugar beet and we have been growing alfalfa for the past two years. With a main rotation of 4 years before, now it is a bit more complex. We'll say maize, potato, wheat, flax and beet in the main rotation."

Additionally, 12 farmers said they used organic matter on their farms. The use of one organic matter, green manure, was frequently referenced and a few farmers noted that this practice is mandatory.

"After each harvest, we tile the soil superficially and afterwards we put a green manure, so we don't plough like before."

"Pre-mounting, no-till for potatoes. For beetroot, for the moment, I'm in a rather classic system of no-till with green manure, with some Actisol behind."

10 farmers noted that they had reduced the application of chemical inputs on their farms.

"So, we do semi-direct, cover crops, we are voluntarily going to reduce phytosanitary products. We're trying to reduce our mechanization costs to gain a little profit on this and stop using insecticides."

"Yeah, we're going away from easy forms of fertilization, i.e. there's no more chemical fertilizer, except very occasionally if we can't use organic fertilizer. The base fertilizer is treated so that there is no more potassium chloride, no more phosphoric acid, and possibly no more potassium sulfate."

"And with regard to the reduction of pesticides, we had already largely reduced them and we took the last step with a MAE. And what I was saying earlier is that the reduction of pesticides is very important for biodiversity, and we use far less than our neighbors."

"The fact of having hives also allows me to be more vigilant about my practices, about the hours of spraying, about the products I use. I always try to reduce the use of pesticides."

The use of cover crops was also frequently brought up. 11 Farmers indicated they have cover crops on their farms.

"So, we do semi-direct, cover crops, we are voluntarily going to reduce phytosanitary products."

"My father set up his business about 30 years ago. Thirty years ago, the objective was production. They had to feed the world and they succeeded. Today, the problem is that we have to feed the world, but in a healthy way and as respectfully as possible. So since then, we've planted what Dad had already started, but we've planted cover crops, with more varieties, and we've left them for longer, we've reduced tillage a bit."

Grass strips and hedges are also commonly used biodiversity enhancing farmers. Each method was referenced by 10 farmers when describing their farm practices.

"We have grassed strips because we have ditches. We are located in a rather bocagère zone. We have embankments. It's not like the plains of Beauce or the plains of Champagne, where you have hectares with no diversity."

"Well I tell you, the first thing is the game. And in one place, it plays a role in controlling soil erosion. These are the two main things, because we have silty soil, so if it's dry it flies away and if it rains it gullies. So we put in grassed strips to cut off certain plots and to avoid the risks of erosion."

"The main practices are what we mentioned earlier, the intelligent re-establishment of hedges, the re-establishment of grassy strips in places where, for example, we have a 50-hectare plot of land, we cut it in two."

"We use the farm to hunt small game, and in particular we had a project to reintroduce the grey partridge, which had disappeared in the Oise region due to the uprooting of hedges, the reduction in insects and so

on. So we rearranged the landscape, we replanted hedges, we made kilometers and kilometers of strips between the fields."

"Yes, I have put in hedges, I have put in flower strips, and miscanthus strips. And I replanted hedges again this winter."

"And what we've also done is that, with the neighbours, we've put up hedges along the sides, between two neighbours, precisely for the wildlife."

Farmers were also asked to share the trends in biodiversity that they have witnessed over the past 30 years. This question received mixed responses and no single trend was dominantly referenced.

A few farmers indicated that they believed there had been an increased focus in farming practices to protect biodiversity.

"My father set up his business about 30 years ago. Thirty years ago, the objective was production. They had to feed the world and they succeeded. Today, the problem is that we have to feed the world, but in a healthy way and as respectfully as possible."

"I really started putting things into place 5 years ago. In potatoes, I do autumn pre-mounting, putting in a green manure when I create the mound. The green manure develops throughout the autumn and part of the winter, depending on the winter temperatures. First, I destroyed it at the beginning of January, which was far too early. Now I leave it until at least the beginning of March. So, the mound is still protected. You can see that there are many more earthworms. You can see that the soil is more easily drained. With this technique, we realize that we no longer see difficult zones."

Other farmers highlighted how farming practices used to only focus on production outcomes. However, objectives have since expanded to be more mindful of biodiversity.

"Well, 30 years ago, we were much less concerned about biodiversity and the objective was to produce. At the time, it was systematically the treatment of a particular problem. I think that today we see the treatment with a bit more distance. When I started, it was the treatment that was there to solve all the problems. Then this question came up today, and we have seriously stepped up our game in terms of treatment. Thirty years ago, treatment was a precautionary principle. It was the technicians who came to sell the products. So we also did the treatments that were recommended to us. You should also know that the prices of products at the time were much lower than they are now, and biodiversity was not a concern. The treatments were recommended, so we just did them. Then the price of products rose and we had to start thinking differently, towards a more economical option. I know what I realized was that we have been scammed the whole time. Their objective was simply commercial."

"I remember when I was a kid. It's true that in the 1970s, my father was part of a technical group for years. I don't remember much about the 1960s, but in the 1970s, I remember very well, we had to produce, produce, produce. The farmer was told: the more products you put on, the more yield you'll get. So the farmer followed the recommendations. In the 1980s, they started to think about it, but it was research that made the farmer change his practices too. We realized that just because we were going to put a lot of fertiliser on beetroot or potatoes, we were not going to have a higher yield. It all started with nitrogen management, I think that's what it is. I remember very well, I'll take the case of a beet, they used to put 300 kilos of nitrogen. So today, we're down to half that on average. What happened? They realized that the nitrogen curve had reached a plateau at a certain point, and this is the result of research, so the engineers."

"I would say that if we look at the post-war period, we can talk about land consolidation which created large plots of land, for example here in the Baspaume sector, we have plots of 30, 40, 50 ha on which the embankments were removed, creating an agricultural and industrial lowland. And for 10 years now, I would say that the phenomenon goes back to about ten years, that we have started to question. We're in the

process of going backwards, be careful, we may have gone too far, we have erosion problems, we've lost a certain biodiversity, so insects, game, and we have a landscape that is rather monotonous. So there was an awareness, about ten years ago, with this desire to reshape the landscape. But unfortunately, not everyone takes this into consideration. We do it on our farm, since we have about 4 km of hedges, but my neighbours have not done it, for example. So we realize that today, the incentive to recreate this biodiversity, to restore a landscape, remains a problem because, once again, the industrial and financial aspect always takes precedence over the purely agroecological aspect."

Two farmers discussed how a trending increase in biodiversity practices is due to an implementation of regulatory requirements which support biodiversity.

"Since 1991, the practices. What we didn't do in 1991 systematically, was everything that was green manure, so now it's done systematically (because mandatory), which is very good. It's true that bees and biodiversity were not really taken care of. But we've always been in a system where we had several crops."

"Yes, we use them in a more reasoned manner. After all, we didn't do anything foolish at the time either. But now it's a bit more monitored, seriously. And the nitrogen residues mean that we use the nitrogen at the right level. We don't waste it. We try to do our best. We also have the tools to work better."

"It was the obligations that came along that made some people start to become aware. There are people who block themselves as we saw yesterday and who see no interest in the situation, and there are others who start to try to look for new solutions on their own. And then these paths intersect and we manage to do something. I am somewhat aware of this, but on the other hand, we cannot necessarily say that the agricultural sector is the dominant one."

Three farmers expressed that they believed biodiversity was both increasing and decreasing. One of these farmers noted that an increase is currently happening after a long period of decrease occurred.

"Well, genetic biodiversity I think has increased and then decreased. It increased with the varietal selection of the companies. And then I have the impression that for the last 5 or 10 years, varietal selection has decreased a bit. There are few new varieties coming out on the French market. The plant diversity of cultivated species has been reduced and I have the impression that for the last 5 years it has been going in the opposite direction, rotations are getting longer. And in relation to woody and floristic biodiversity, it has plummeted in 30 years, especially with all the land consolidation and the uprooting of hedges. And for the past 5 years, it has had a slight tendency to increase with all the hedge-planting projects that can flourish just about everywhere, either by the ministry or by federations, hunters who finance projects. So it's starting to increase again after having decreased drastically."

"How did it evolve? There were specializations, there was more and more wheat, more and more rapeseed. Less and less of practically everything else. So the biodiversity of crops is necessarily decreasing. On the other hand, there is a new interest in the use of auxiliaries for crop protection. Today, with the Ecophyto plan, we can't say that it has been a great success, given the evolution of pesticide consumption in France since it was set up, but on the other hand it has made things move, it has made research moves, it has made a lot of players move. So I think that from this point of view it's not a total failure. So biodiversity has become a much more interesting subject for a whole bunch of agricultural development stakeholders with whom I work."

"I have the impression that it is decreasing. I'm not a hunter, but I come from a family of hunters, and despite everything, I can see that game is disappearing. To the benefit of others perhaps, but clearly, we can see that, for example, the partridge is disappearing from our plains and I find this a somewhat worrying sign. Then there are other things that are revealed. Overall, my soils are living better and better, or at least I have the impression that they are living well. I mean, I have the impression that we were going down the wrong path and we are trying to turn back, or so I think."

Two farmers said that they felt biodiversity was decreasing. However, one noted he believed there was an awareness of this decrease present and changes were beginning to be made.

"For the past 30 years, it is obvious that biodiversity has tended to decrease drastically, we still have so much work to do."

"I have the impression that it is decreasing. I'm not a hunter, but I come from a family of hunters, and despite everything, I can see that game is disappearing. To the benefit of others perhaps, but clearly, we can see that, for example, the partridge is disappearing from our plains and I find this a somewhat worrying sign. Then there are other things that are revealed. Overall, my soils are living better and better, or at least I have the impression that they are living well. I mean, I have the impression that we were going down the wrong path and we are trying to turn back, or so I think."

One farmer indicated that they were uncertain whether biodiversity was changing within the region.

"In terms of monitoring biodiversity, at the farm level, we monitor migratory birds and small game. Overall, it's not too bad for us, but it's less in other sectors. It's difficult to see if there is an erosion of biodiversity or if in certain places, in certain compartments, it's improving. It's difficult to answer this question at the regional level."

## Decision Influencers

**Benefits**

The interviews also aid our understanding of the factors that may drive or discourage farmers' adoption of biodiversity enhancing practices. Throughout our conversations with farmers, advantages of biodiversity and supportive farming practices were discussed. The knowledge of these advantages was largely based on personal experiences or sometimes witnessing benefits others received.

Across interviewed farmers, the most commonly referenced advantage of biodiversity was the benefits it created for soil. 10 farmers brought up soil benefits during our conversations with them.

"It is to protect biodiversity. To reduce erosion, to increase biodiversity and to communicate with regard to the image of farmers."

"Biodiversity also applies to our soils in my opinion, with the diversity of fungi that can be found in the soils, bacteria that can be found in my soils and the fauna in general, birds, game that I can have on my land."

"So we can already see the benefits, on erosion and then on the return of many species."

"I realized that by putting 2 and a half hectares of extra strip we could have an effect on biodiversity, on the fauna and flora, and in the end, we could really do things to combat erosion."

"Biodiversity also means earthworms and all the microbial life in the soil."

Another advantage of biodiversity that was recognized by many interviewed farmers was a decrease in the application of harmful inputs, such as pesticides and fertilizers. Ten farmers said that biodiversity supported a reduced use of chemical inputs.

"And for the moment I can't see it very well yet, but it should help us to reduce insecticides and allow the auxiliaries to regulate the pests, but we still have to be patient."

"That is to say, what, through nature, can allow farmers to have less dependence on phytosanitary and chemical products, thanks to nature and therefore thanks to a certain biodiversity which will allow them to recover essential points."

"Because I think that the monoculture or specialization situations in which agriculture is oriented is something that is extremely unfavorable to both soil fertility and the use of pesticides, we can grow

monocultures of wheat or soya, using pesticides. And pesticides are the opposite of biodiversity, because they are designed to kill."

Farmers also expressed that an increased wildlife presence was another benefit gained through biodiversity enhancing practices.

"There's a mixture that provides food for insects, which is the flower strip, and there's a mixture of grasses that provides shelter for partridges. So these are strips designed to bring back partridges. So it's good for pollinators but also for all the auxiliaries."

"The objective is to try to have as many species as possible in our plots."

"So I see that there is more life. In the plots there are quite a few animals, with everything they do. I find that very interesting, so we feel that it's beneficial."

Other benefits of biodiversity that were brought up in interviews but less frequently mentioned include cost savings, resilience, time saved, and improved water quality.

"After 5 years, I can clearly see the difference in terms of soil erosion and infiltration, and the ease of working the soil. You don't have to work the soil several times. And what happens now is that when there is more rainfall than usual, the industry calls us first for the first crops. So conservation agriculture is a big cost reduction."

"Well, up to now I've only reduced my inputs and my phytos. So a reduction in costs. I can't say that it's cost me much in terms of equipment. It's not impossible that it will cost me more in the future because I will use other things."

"It's cheaper, it's less risky. It's cheaper because you spend less on inputs. And in terms of yield, it's quite often equal, there are even years when we do better than conventional. We've done wheat, this year at 90 quintals hectares, without a single treatment. So I think it's profitable."

"We can see that this land is much more resilient both to excess water and to excess dryness. It's the same, when there are dry spells, my plots suffer, but much less than the ones in traditional agriculture."

"It saves time because it means fewer passes of products and less soil preparation. We use semi-direct on wheat and barley crops and for spring crops we have two passes, but in the traditional system, they use 3 or 4 passes."

"In particular, I corrected the quality of my water. I tried to have optimal spraying."

**Motivators, Support, and Information Sources**

The interviews also asked farmers about the factors that encourage them to implement biodiversity practices on their farms. Additionally, farmers shared their main sources of information which could indicate the channels that may have the ability to influence farmers' land management methods and choices.

Farmers were asked about the triggers that caused them to implement biodiversity enhancing practices and also referenced motivators throughout the interview. The motivators that were referenced most by interviewed farmers were soil health and hunting.

"I realized that there was a lot of sediment at the bottom of the plots, in fact all the sediment that had arrived in the end there was nothing growing. And so I put a figure on it. I said to myself that in the end I had lost 2 hectares of land which were stored in the lower parts of my plots and I said, but if I cut all my plots perpendicular to the direction of the water, I realized that by putting 2 and a half hectares of extra

strip we could have an effect on biodiversity, on the fauna and flora, and in the end, we could really do things to combat erosion."

"We'll say we followed the father. Twenty-five years ago, we had problems with erosion on certain plots, and our father trained himself in soil conservation agriculture and biodiversity. So he was already well into these techniques. I am 32 years old and I followed."

"I noticed that one of my best plots has reached a plateau in terms of productivity. The soil with every rainfall tended to clump together, and I had my neighbour who had been doing conservation farming for at least a decade and when I spaded his plot, I saw that it was very, very different. You could easily see earthworms, whereas in mine there were far fewer. I told myself that there was a problem, that I had to review my system."

"Well, I tell you, the first thing is the game. And in one place, it plays a role in controlling soil erosion. These are the two main things, because we have silty soil, so if it's dry it flies away and if it rains it gullies. So we put in grassed strips to cut off certain plots and to avoid the risks of erosion."

"Besides, I'm also a hunter, I like to take care of all the wildlife in my plots and that's why if I can continue to change my practices in favor of biodiversity, I will."

"These were observations, the fact is that I am a hunter. A hunter has to love nature at least a little. I realized that there were no more partridges in our fields. I realized that there were no more hares. So there you have it, things that we didn't see before."

"A lot of things have been put in place on the landscaping side. For several reasons, one of which, I think, was the main trigger, is that we hunt. We use the farm to hunt small game, and in particular we had a project to reintroduce the grey partridge, which had disappeared in the Oise region due to the uprooting of hedges, the reduction in insects and so on. So we rearranged the landscape, we replanted hedges, we made kilometers and kilometers of strips between the fields. We completely divided our agricultural plots to make them long and narrow."

"Well, I'm a hunter, so I pay attention to the game. Because games are something sacred. In our region, it's the hare, the partridge, the pheasant, and a little bit of rabbit, and today we see that, year after year, the partridges are unfortunately disappearing little by little. Well, there are also many predators, more and more predators. But there are also agricultural practices, such as the consolidation of land, which raise questions. So a certain number of things have been put in place to protect the game. We set up flower strips, grass strips, we try to avoid having too large fields with only one species."

Another motivator that was frequently referenced was generational influences. A few farmers indicated that their practices were adopted/continued from previous generations of family members who had initially started the practices on their farm.

"Well, I have an affinity for developing my farm in favor of biodiversity. My parents had already started planting hedges at the time of the land consolidation in 1996. My father had planted about 2 km of hedges and I am continuing because I can already see the benefits of what he planted, so I am continuing to plant on the farm."

"We'll say we followed the father. Twenty-five years ago, we had problems with erosion on certain plots, and our father trained himself in soil conservation agriculture and biodiversity. So he was already well into these techniques. I am 32 years old and I followed. We took over the farm five years ago, and he was the starting point."

"So it's true that it's quite rare to see a drastic change in a farm. There are plenty of people who have gone organic and now regret it. If a child follows or there is a partner, let's say an outsider who arrives, who has other desires, who sees other things, that will make you evolve at the same time. When you start to get older and you let the next generation try things out."

Other famers indicated that a generation change in farm management led to the implementation of new practices and ideas that were supportive of biodiversity.

"It's a bit of a coincidence. I don't know how to put it. I'm quite curious about a lot of things. At the beginning, we were rather close to my father's model. I'm going to learn and know how to do things first, before questioning everything. Now we're putting our own ideas in place, and once we've put our own ideas in place, we're starting to look around a bit, thinking things through."

"The change for me was when my father left me the farm and I had to start finding viable economic solutions. At that time, I had learned to be a bit economical. And then I realized that it wasn't impossible to reduce ploughing and plant protection products, in order to reduce costs. So that was quite comforting. And today we manage to achieve correct yields while being economical."

"When my father retired, when we were done, he said to me, listen, next year you have to find a solution because I'm not coming back. So I took a paper and a pencil, and I started to calculate to find a solution that was adequate and that's how the first year I did no-till wheat, since 1997. But nobody was doing that around me."

"Well, basically, I wasn't always a farmer. Before, I was a construction engineer. I had another job before I became a farmer. We took over my wife's family farm because I was also from the farming world but I wasn't a farmer at first and so I came in with new eyes. And I'm not the one who always listens to his father about these practices and generally speaking, when people tell me that it's inevitable, that the Ph is rising or the plant is resistant and there is no scientific explanation, I get exasperated, and I want to explore different options. I don't see why we should just use ready-made recipes that have been imposed on us for years. So I don't have this kind of preconceived notion of what should be done, or what shouldn't be done. I'm really in the process of rethinking a system. We are faced with a problem, how do we overcome it? So, yes, there is a way to do better and I am convinced of that. So it's a certain personal satisfaction. And there is also a personal satisfaction in progressing differently."

Two farmers indicated that it was a financial motivator that pushed them to adopt biodiversity practices.

"For me, at the beginning, it was purely economic. At the time, we didn't talk much about the environment. We were not aware of the negative effects we could produce on the environment, so it was purely economic in the sense that I was always waiting for the thresholds to have to intervene with chemicals, whether it was for weed killers or fungicides or insecticides."

"Well, it's consumer pressure that has led to a reduction in the use of plant protection products. And also from an economic point of view, because the price of products has increased. Both plant protection products and seeds. And today we are working on the economic side. And we have a great help, which is genetic progress."

Some farmers also indicated that social pressure influenced their decision to adopt biodiversity practices.

"In recent years, social pressure on farmers has increased every year. It is very clear today that consumers and citizens have a say in the impact of agriculture. This cannot be denied."

"We, at the trade level, will propose this framework with commitments and remuneration. And then we will recruit a certain number of farmers to meet these specifications, which will be non-production specifications. This means that we will put in place practices that are linked to environmental services, but independently of the fact that it is wheat, potatoes or not linked to production. And one of the reasons for this pressure is also green-bashing, with cases of communication that is not very positive and that farmers experience quite badly. So projects like this also give farmers the tools to communicate better with their fellow citizens and their commercial partners."

"We must not forget that farmers are business leaders. They like to be able to make decisions and see the results and be valued for the results of their decisions. So the system of payments for environmental services, when it's well in place, will say, look, this is the contract, it's up to you to show us that you know how to preserve the environment, to provide us with proof, and we will value these results."

from them anymore because, in the end, we know very well that they are disconnected."

One farmer expressed that social pressure did not have a large impact on them because they communicate with neighbors well.

"For the moment, it's fine, I'm not saying anything, but honestly, we're not the most bothered about it. We're more bothered when we want to put up a new building. And on the plain, people see that we do things, and we encourage people to ask, we have to give explanations. Afterwards, we must also respect the walkers when we do a treatment, we do it very early in the morning. If we want to be respected in our job, we must also respect people, and the regulations, that seems obvious to me. On the other hand, it's more complicated for people on the edge of town. Those who have plots on the edge of large towns are really very, very, very annoyed. So it all depends on the proximity of the living areas."

***Risk and Limitations***

Farmers also discussed the existing risks and barriers that are associated with biodiversity enhancing practices. This provides insight on why some farmers may choose to limit their biodiversity practices or choose not to implement them. Understanding risks and limitations also helps identify areas where potential support can be provided to achieve increased biodiversity.

The biggest issue with biodiversity enhancing practices is their costs. Many farmers interviewed noted that the necessary expenses to implement biodiversity practices were difficult to meet or a burden.

"In the end, yes, to put it on. But I think that what limits me is the loss of surface area, which means loss of production. Because we're talking about several thousand euros per year. And I think that this is the limiting factor. Today I think that I have reached the maximum surface area that I could do, I don't think that I could do much more development, but we must also remain reasonable. Because we're talking about a loss of 5,000 to 6,000 euros per year in turnover. So it's quite substantial."

"For the constraints of cover crops, it's a bit more money, we're on 45€ per hectare. The constraints are the destruction of these crops, because it's either the use of glyphosate or ploughing. So we're moving forward little by little, and we're trying."

"It's shameful or not, but it's very economical. Because either the tool is very expensive, or the crops I'd like to plant are too expensive, or I don't have irrigation and financially I'm not at ease, and I can't take any more risks. I'm already thinking that we've taken a lot of risks with 52 hectares of organic farming, that's a third of the farm."

A couple of farmers stated that implementing biodiversity enhancing practices created a risk for their crop yield outcomes.

"I believe in semi-direct farming, but it's too risky for me at the moment, with a loss of yield. It's like organic farming, the transition is complicated, and I'm not ready to take that risk for the moment. And once I have better cover crops, I could look more at direct seeding. So I'm training, I'm training a lot, but for the moment direct seeding is not compatible with organic farming."

"In my opinion, agriculture is a recipe business. We always apply the same recipes. You plant potatoes, you have to put in so many kilos of potash, phosphorus, nitrogen. And then you start planting again. From such and such a date you have to plant, etc. So, from that point of view, when you do things differently, well, generally you have to take the risk alone. You're a bit alone when making decisions and it's a bit difficult to

get good advice, to have someone to challenge you. So we take the risk of making mistakes, clearly. Because when you take risks, you have to be as precise as possible, but I am not immune to making a mistake and having to take half a harvest."

Two farmers noted that biodiversity practices impacted their crop's presentation which effected their ability to sell it.

"Yes, but with all the associated constraints, because growing potatoes, I work mainly on the fresh market, which has very important presentation criteria. so we sell products so that they are visually beautiful. The big problem we encounter in potatoes with the implementation of soil conservation practices is the development of soil parasitism. If we put back green manures and increase the rate of organic matter, we will have soil parasitism that will develop, so how do we do it?"

"So we have to plough plots, we have plots that we haven't ploughed for a long time, because we have problems with lupines in particular and weeds, which we would have to manage more simply because we would have to use round up again. I have two choices, either ploughing or glyphosate. So I have to choose on certain plots to plough. And then for potato cultivation it's easier because the consumer wants a clean potato. If the consumer accepts a potato that is not clean, I am willing to do no-till, except that the consumer doesn't do it. So I'll stop working with potatoes, and I'll be able to concentrate on much less ploughing."

Another farmer noted that although they experienced income loss, the monetary support that they received from the government mitigated this loss so it was no longer an issue. However, other costs still existed such as time and maintenance.

"We have a loss of income on areas that are more than 15 million wide, over many kilometers, so on the surface that is no longer productive. But that shouldn't count, because with the CAP, we have 5% of the uncultivated areas, which corresponds to all these strips, except for the fact that theoretically I don't lose anything because I remain at the minimum CAP level compared to another farmer who uses 10% or 5% of uncultivated areas and converts a whole plot of land into fallow. But fallow land is not very interesting in terms of biodiversity. On the other hand, the same area in a strip, it brings an added value. So basically, there is no economic loss, but it is more complicated. It requires more maintenance, it takes more time, so it has a cost. Finally, in terms of time and then a little bit of seed."

The farmer continued to note that the benefits gained from biodiversity practices also created an increase in earnings.

"Nothing. But in the end, I win because we market grey partridge hunts and as they no longer exist anywhere, people pay a lot of money. So when we manage to do 8 hunts a year with 12 hunters who pay €1,200 a day, that gives us an extra income of €400 per hectare which more than makes up for the time we spend on it."

One farmer recognized that although there were high costs associated with biodiversity practices, the investment was still worthwhile.

"Well, technically, that's for sure a hindrance. There's a loss of surface area, and that's my biggest obstacle. It's at the economic level. Because I have devoted about 1% to 2% of the farm's surface area to these developments. And when I explain it to my neighbours, they find it difficult to understand. They don't understand the interest behind these practices. I think I see it as an investment, and they see it as a loss of land, a loss of area, a loss of money. But for me, it's a long-term investment in terms of the return of biodiversity, of the auxiliaries, etc. that could come back to the farm."

A different farmer indicated that the new biodiversity enhancing practices that they chose to implement did not pose a risk or create income loss.

"No, no, there is no risk-taking. It's an idea of other farmers in fact, who say no, we can't do that, we'll lose money. But that's not true."

One of the biggest limitations of implementing biodiversity enhancing practices noted by farmers was access and costs of equipment needed.

"I could possibly get some help if I buy a new equipment. I've been looking for a while for what would suit me well. At first, I was going for an off-head seeder to sow wheat and then potentially use it for green manures too. Now I have found what I really want to. The problem is that this type of seeder would costs between €60,000 and €70,000 for a new machine. Whereas second hand, today you can find some for 30,000€ and that would suit me very well. The problem is that if you buy it second hand, you won't get any aid. There are currently plenty of aid for a certain equipment for hoeing for instance. But is hoeing really a very agro-ecological practice? I doubt it. I don't dare to say it out loud."

"The costs are related to different categories. There are equipment costs, as we saw when we went into the shed. We've just got a new, more precise seeder, so it obviously costs more, it's more technology. If we want different equipment that is a bit more specific, for example for mechanical weeding. We will look for equipment with a specific action. We'll buy a sprayer which is used for herbicides on the one hand and then a special machine for mechanical weeding which will only be used for weeding, so it's a heavy financial investment."

"I would like to set up a very specific itinerary, something that is not commonly done. But the problem is that it would require some investment into equipment, and at the moment I can't. I'm too financially burdened to do so."

Limitations on required time for implementing new practices was also a challenge that farmers noted, although it was not referenced as much as previously stated limitations.

"On the other hand, I don't have the impression that I'm doing the same level of work as before, i.e., when you want to pay attention to the long-term fertility of your soil and you want to work on your organic matter, well, in the end, it's an expense in terms of time and work, because you're going to get the benefits in the long term. But from my point of view, I still have the impression that I'm getting there. So, more time for observation in the field."

"It's not an overnight process, it's a long process. Knowing that the farmers that we are accompanying today in the process, we estimate that it takes 5 years between a farmer who starts from nothing, i.e., from a blank sheet of paper with a 100% chemical, to switch not completely to become organic, but not far from it. He will have to acquire technical skills, change his model, stop thinking in the same way, and therefore take a risk."

When farmers were specifically asked if there were practices they would like to put in place but face limitations in doing so, costs and equipment were the two biggest issues noted.

"There are many things I would like to put in place. I have no pleasure in spraying pesticides, it's a burden. For me, it's a burden, it's a constraint, it's a financial burden, it's a financial burden."

"At the moment, it's a cost, with no guarantee of better agronomic results or even diversity. Then I would like to explore more grass strips. The current strips, leaving them with seeds or flowers to encourage biodiversity."

"Well, concerning hedges, I could have done more. But it's costly and require some maintenance. I'll certainly do it, but for the moment it hasn't gone any further."

"As far as mechanization is concerned, we are trying things out with the group. We have partners who make equipment available to us. After that, we discuss it regularly. If we want to move forward more quickly, we'll have to buy our own equipment so that we don't have to depend on someone else. And I think that this will happen quickly during the year, we might start buying equipment together."

"Well, there are many things. I was interested in hoeing, plus weeding, so in fact hoeing between the rows and just weeding on the row like maize. In short, it would have reduced the use of Phyto products by 3, except that to have equipment like that it's very, very expensive. And this equipment would be subject to technical controls, so we add another transposition of standards and regulations."

"Today, the big point I would like to improve is Soil Conservation Agriculture (SCA), with direct seeding. But to develop these practices today, you need very specific equipment. It's very expensive because in fact the technology involved is very advanced. So it's expensive and the problem is that you can't buy it to try it. So either we find rentals or we make them ourselves, it's not as advanced as what you can find on the market but it works. After that, sharing equipment is not really in the mindset of the farmers in the area."

## Neighbors

**Interactions with Other Local Farmers**

Farmers were asked several questions about their interactions with neighboring farmers. Interviewees shared information about neighbors' views, information sharing, and collaboration.

A few farmers noted that neighboring farmers were open to adopting biodiversity enhancing practices, even if they had not implemented them yet.

"So they all want to do what we do, especially at the moment, because diesel is very expensive. The problem is that we are already very far along in our methods and we already have the feedback, and they want to skip some fundamental steps and so they sometimes fail, because there are steps before they stop working the soil completely."

"Yes, it is. In fact, it's the second generation because I'm 63 years old and it's the second generation. The generation of the children who say: 'Look at XXXX, he's doing well, he uses three times less products than us. It doesn't mean that they do what I do, they continue to plough but they are questioning a lot, and come, ask me what I think."

"They look, they look, they are curious, they ask questions."

"We feel less and less marginal, less and less so because there are a few others who have adopted similar practices, there are even a certain number who go further and continue towards organic farming, but that is a minority. And on our side, we know very well, because things are known in the countryside, that people say that if we do this, it's because we have a side salary related to our researcher positions. So we can afford to lose money on the farm, it's not a big deal."

A few other farmers noted that neighbors typically did not implement biodiversity enhancing practices and did not appear to have interest in it adopting such practices.

"Most of them remain in conventional agriculture, some of them are in conservation agriculture and regeneration agriculture, but very few. Today, the public's view of this type of agriculture is very positive. But it is still marginal in our country."

"For rapeseed, we haven't used a single insecticide for 15 years, whereas all our neighbours treat their rapeseed. They have much shorter rotations, such as rape, wheat and barley. Some of them even treat their oilseed rape with insecticides 3 or 4 times."

"On agroforestry, we were taken for fools. But I think that in 4 years, things have really changed. The discourse has gone from nonsense to curiosity, and it could become practical. But at the beginning we were taken for fools."

Several farmers indicated that they were willing to share information on their practices with neighboring farmers.

"Yes, yes, yes. Well, I've been a pilot farm since this year, and for the moment we've opened up the farm to all these producers by invitation, and those who have come are those who are already motivated and who already have a foot in these systems."

"As I'm an elected official in my commune, I communicate about what I'm doing so that I can also change the image that the community has of farmers."

"Today, we are starting to communicate, we are starting to do training on my plots. We are starting to communicate at general meetings. To tell you the truth, tomorrow I was invited to the annual technical meeting for potatoes. There are always about 2000 producers for the Haut-de-France region present. There is always about 2000 growers from the Haut-de-France region present, where we do a technical point on the regulatory and technical evolutions of the year. So there are always a lot of producers, and I was asked to speak. However, due to COVID, it was cancelled. And I think that the COVID aspect tends to slow things down a bit too."

A few farmers indicated that they shared equipment with neighbors, however, their collaboration did not extend beyond that.

"We are using specific equipment from a neighbour and maintain it ourselves. I mean, we do it together."

"Indeed, it was rather with a neighbour who was equipped. It makes a lot of things easier, and we have a good relationship too. In addition, he had the material for maintenance, so it was ideal to do with him."

"We can see between neighbours, regarding equipment acquisition. On hoes, on seeders. Beet seeders, with equipment that is not used for a long-time lapse. So rather than investing alone, we invest with several people. But exchanges between neighbours are mainly limited to that."

"Not so much because we were already quite well equipped. My father-in-law already had a lot of equipment. There are things I'd like to try but then I have neighbours who have the equipment, so we lend it to each other. We have very little experience of semi-direct, and it's true that I've never done it, but I have some ideas. But I mean overall, I don't think we're limited by the material. After that, helping each other is not very natural in our region, but we can help each other more."

"The farm covers 180 hectares. It is essentially a field crop rotation. Our involvement is essentially in decision-making because the work is done by neighbors taking part in a cooperative for shared agricultural equipment (CUMA). We have no equipment of our own."

## Views

**View on Organic Farming**

Farmers were asked about their perspective on organic farming. Many provided their views on this farming method.

A majority of interviewed farmers expressed a negative view of organic farming. Many noted that they believed the practice was risky or lacked financial benefits.

"For the moment it's much too risky. I think that, economically, it's much too risky. At the moment, the outlets are not reliable, it's very difficult to get contracts. I have two brothers who are farmers, and I have

one who is an organic farmer with whom I speak. So I can easily compare. And I see these difficulties, and I won't get involved in this, because it's economically risky, compared to the market at the moment. Yes, yes, the market is saturated, for everything that is an organic industrial crop, the market is saturated."

"It's a whole other ball of wax. A group of farmers and I went to visit organic farms in Holland, but Holland's land is built on old polders, so their weed content is tiny compared to ours. So even though there are some who are doing organic today in our area. The guys are all giving up, because they're finding it hard to get paid to convert. The problem is also that organic milk, for example, has no added value for the farmer compared to conventional milk. Afterwards, in March, we have an organic carrot producer whose storage is full, but at the end of March he will throw it all away, because there are no outlets on the market."

"Economically speaking, I don't believe in organic. For the simple reason that supply is catching up with demand and supply is now balanced and any additional organic supply risks lowering the price and profitability compared to conventional, so I think it is risky to have new organic farms in terms of profitability."

"And then the last point, it's expensive to do organic. The day the market turns because there are too many of them, and this is already the case, the financial risk is also important. Because it's also expensive to produce organically, and they need a price that is much more remunerative than the conventional one."

"100% organic is not possible for economic reasons. We can't imagine, on the scale of the Lille metropolis or on the scale of a country, continuing to subsidies agriculture because we imagine that it's "the right agriculture". A farmer must be able to live off his own harvest. And secondly, because the market has reached a saturation point. We say that the market is mature, which means that today, as soon as the threshold of 10% is passed, it is between 10 and 15%. We realize that the organic market is no longer attracting consumers to the same extent."

Other farmers shared that they don't believe in the effectiveness of organic farming.

"No, no, no, no, it's not an objective, because there are still disease pressures that we can't treat without phytosanitary products. Going organic for the sake of going organic is an image we want to give ourselves, but years ago, I produced wheat full of disease and neurotoxins and it was extremely dangerous for the consumer, and even with phytosanitary products we couldn't stop it, so I wouldn't have liked to be organic. It's like potatoes and mildew, those things are carcinogenic. So we prefer to stay conventional if necessary, if we can do without phytosanitary products we do without and we adapt as much as possible. Because it's not with pleasure that we go and get our phytosanitary products."

"I don't really believe in organic farming. More globally, I think that from a purely ideological point of view, I think it's a shame, I think that the organic specifications are restrictive from an ideological point of view. At the moment, when I take my residue analyses, I don't have any residues in my products and they are no worse than organic I think. "

"I don't believe in organic farming, in the sense that, economically, we won't be able to feed the planet with organic food alone. On the other hand, we can do much better than what we are doing now in conventional agriculture. So, the idea is to get closer to that, but not to get into any dogma. We shouldn't have a dogma and say 0 pesticides, 0 chemicals. It's like saying that in order to treat a human being, we have to stop using chemicals, no more antibiotics but just herbal tea. It's exactly the same approach. I put myself in the position of not having to use agrochemicals, but when I have to use them, I don't want to be forbidden to use them."

**Resident Views**

Interviewed farmers were also asked how the residents in their neighborhoods felt about their farming practices. This question specifically focused on farmers' neighbors that are civilians and not neighbors who were also farmers.

Farmers who responded to questions about their non-farmer neighbors shared that they were generally happy about the new practices they were implementing on their farms.

"When it's non-farmers and we explain it to them, people are generally happy. When it's farmers, most of them are afraid.

"That is to say, with the ZNTs we planted the honey fallow and people asked us: "Why did you do that?" They are interested. And you can feel that they are smiling, they don't come, fists in the air. They are happy. They are happy to see these things being implemented."

"No, no, I'm quite happy when there are walkers, they often stop, they ask questions. I think they don't realize what we're doing. Afterwards, I don't highlight it anywhere."

One farmer said that although they do not feel any pressure from their non-farmer neighbors, they try and take them into account in their practices.

"I don't have any pressure with the local residents, but probably because I take them into account in my ecosystem. Because if a road is put in, I'm the one who has to go and clean it up straight away. After we had a big storm in the village three months ago, and the results of our actions are clearly tangible, on the impact of erosion, on biodiversity too."

## Policies and Programs

**Experience and Views**

Farmers were also asked about policies and programs that exist in their region that are designed to encourage and support biodiversity enhancing practices. Farmers shared their experience with these policies and programs and their thoughts on their effectiveness, limitations, benefits, and regulation.

When farmers were asked about their views on France's Common Agriculture Policy (CAP), many who answered this question largely held negative perceptions of the plan. Several noted a disconnect between farmers and decision makers.

"So the politicians, I often use them and I often communicate with them, for example, we spoke to the sub-prefect of Hauts-de-France. We spoke to the sub-prefect of the Hauts-de-France region, for example, and we came up with this topic of conversation: "What does a farmer mean to you tomorrow? Because everything is being taken away from us a little too quickly for my taste, products, techniques, barriers are being put in our way. So we called on them to communicate about all this. But all these politicians, they don't know how to do CAP files, they are not aware of the reality on the ground, and they have realized that it is completely absurd."

"Well, as long as it's not done with the farmers, I don't expect anything from them today. So I think that there are things that are going in the right direction, but the obligation for farmers, for spring crops, to have to sow green manure, it was made compulsory and I think that it makes sense. It's great, it's a really good decision because the farmer wouldn't have done it otherwise. But it's a drop in the ocean. And we're not represented in the unions either. For me, it's not the farmers, it's people who are there to get elected. So I don't hear much."

"So I'm a bit like you, the administration bores me. I go through your experience all the time and frankly, it's like moving mountains to give birth to a mouse. Every time, it's the same. It's mind-boggling. It discourages me. It's a waste of energy on all levels. So, we manage without."

"Well, it's discouraging, you spent days making a file and getting three peanuts at the end. I think you understand, from the experience you've told me just before starting the interview. It is exactly what we go through every time we have to take a step."

Many farmers also expressed that they also were involved in Economic & Environmental Interest Groups and shared positive experiences. Benefits of these groups are the opportunities for information sharing, experimenting with different practices, and receiving guidance from a technician.

"We have a technician in the region who is quite well known, Ludovic Favre, who advises on the use of plant protection products, the reduction of doses and many other things. He has an agronomic view behind his work and I have just joined his advisory group this year. And then there is a certain passion in our profession and we like to share our practices on what works, what doesn't work, what we have tested. So in the end, we quickly have telephone numbers, people we call who take enough time to tell us what worked, what didn't work, to explain. So really what works is the support between farmers. It's really a motivating power, a driving force."

"In my GIEE, we talk about agronomy even on completely different systems. We each do our own trials and we have a technician for that."

"So the aim of creating GIEEs is to have a group spirit and to exchange on each of the practices that have been developed by each person. The aim is to have a facilitator who can guide them, to change people's state of mind. So the aim is to be together."

"Technical exchanges, fieldwork and visits. But what counts most in the end is the 2 or 3 hours together in the field to discuss. Afterwards, we have winter meetings. So this is the second year where we also exchange on the failures and successes of each one."

"So the advantage of the GIEE is to be part of a group, not to be alone. We have technical monitoring, we work together on techniques. But it's above all the strength of the group. It is also, even if the techniques are not brand new, more democratic."

"So the fact that the farmers are getting together means that at some point they have decided to share, to communicate. to enable the transposition. We're going to get together, we're going to imagine techniques, we're going to test these techniques, adopt them or not, and then communicate about these techniques to the other farmers so that they can use them. That's what the creation of an GIEE is all about."

"In our case, yes, within the GIEEs, the guys trust each other. They have finally learned to trust each other. They have learnt to know each other's systems or the way they work and today, at last, they call each other to motivate each other, to take risks together, and that plays a huge role. It's reassuring when it comes to taking risks."

"I belong to several GIEEs, two of which are more about: support, sharing and progress."

A few farmers also highlighted the economic benefits of GIEEs.

"So in this case, it's a system that fell right into place, in response to a request, or the financiers of the Hauts-de-France region were right on the money. They used public aid, well national aid, but it was readapted to the regional level. Finally, all this was well presented."

"And then, it's also a way of getting some funding because these GIEEs are 90% funded. For the technician, for the trials, for the visits, there are soil analyses with technicians who can analyze the results..."

"The GIEE is the creation of a collective within which we will receive between 50 and 80% of aid from 2 financers. The first financer is the State, which generally contributes from 20 to 30%, and the second financer is the water agencies, which complete the round table with 50%. And they partly finance the agro-ecological transition."

A couple of farmers noted the time constraints of participation.

"When we set up a GIEE, we benefit from European subventions, which pays our technician. On the other hand, it's very time-consuming."

“Today, the only disadvantage I have is that I have to drive an hour each time to go there and we still have meetings quite often. But it's a very pleasant group, in the sense that it cogitates, we ask ourselves questions.”

“So the main obstacles that we find today are that we oblige farmers to meet regularly. At least once or twice a year. There are some who come 5, 6, 7, 8 times. That's the first thing. The second thing is to need to share.”

A few farmers indicated that they are or are trying to become HVE certified.

“We joined ecophyto four years ago, with the aim of becoming HVE certified. We have been HVE certified since 2020, so there is already this group there.”

“For me, what interested me in terms of HVE was to join a group of agreement to try to lower my phytosanitary charges. I sometimes use alternative methods, only to the condition that they don't cost more than a conventional method.”

“It is a certification normally with 3 levels. After the HVE, we may have it, we may lose it too. It will surely evolve over the years and it will depend on the climatic conditions. It's an objective to keep it at 100%, but it may vary.”

A majority of farmers shared negative views of HVE. Many farmers noted that there were no financial benefits of HVE.

“Well, for the moment it's not an objective, because it's not financially rewarded. Afterwards, if it becomes a constraint, particularly for McCain potatoes, perhaps we'll get there, but for the moment, it's still additional constraints that are not rewarded.”

“For the moment, there is no financial bonuses. There is McCain. The potatoes I produce are delivered to McCain. Today. They are reviewing their specifications to put a number of things in place, in favor of agroecology. For next year, they are currently looking at notions such as regeneration agriculture, HVE. They are looking at it, but they realize that it is something very complicated and I think they don't know yet how to really take the problem, and how to implement it in their specifications so that it is still accessible to the greatest number. “

“I discussed this not long ago. It's very complex, we no longer have the right to make mistakes, especially concerning phytosanitary products. So it's still too complicated for nothing in the end, because there are no economic benefits.”

“The problem with an HVE, is that this option is not financially valorized. So, the farmer who takes this approach, unfortunately, will not have a better valorization of his yield. Typically, for market gardening, following the regulation of an HVE would work, and farmers could financially profit from it. But it doesn’t work for every crops. In our case, the industrial would benefit the most from this transition.”

“Well, I don't know, I'm a bit dubious about the thing, it's a bit too much again, it's very restrictive, there are many standards, it costs money again. There is an audit every 3 years, the audit cost 2000 euros, so it's always the same, if you have a farm of 30 or 2000 hectares it will be the same audit, the same cost of audit. So, if I have to pay €1,500 or €2,000 every three years, to be audited, to get nothing extra, there is no point.”

“Bad, because the HVE is very old and was reintroduced 2 or 3 years ago, whereas it is very binary and very basic. There are aggregations of scores that don't make much sense based on obligations of means that don't have much in the way of environmental results, and in the end, it has no environmental value. And it's coming back into fashion because it's been communicated about and because it's easily controlled by the government. The problem is that the government doesn't necessarily do very intelligent things because they need to control and report on simple specifications.”

A couple of farmers expressed the difficulty faced in receiving HVE certification.

"So the biodiversity part of HVE is not too complicated. But the blocking point is the reduction of pesticides. Well, in the end it seems possible, but it's perhaps a bit more complicated with a farm, when you are on pure mineral fertilization, no organic nitrogen is added to your overall balance. All this is penalizing in the HVE calculation. So there are quite a few farmers who don't go in the direction of HVE. So I think that there is a way to make efforts, and we may succeed, but it's more complicated."

"Last year, I did not meet the criteria to achieve HVE. I stopped at the CO2 level because I had some problems to solve, particularly in terms of beet weeding. Well, I knew that was my weak point. Last season, for a long time, I thought I would achieve HVE because I had solved my problems with beet and cereals. But, this year, we have mildew pressure in potatoes, which means that in potatoes. I've exploded the counters. I haven't done the summary yet, but I think that this year I won't get the HVE, because of the very high disease pressure we had on potatoes."

A few farmers shared their challenges with regulatory constraints with agri-environmental programs and policies in general.

"All these policies, at the beginning, are always new constraints. For example, many farmers still see it as a constraint, whereas it shouldn't be. Then it depends on the personality of the farmers. Some will take it as a challenge, others as a constraint and will apply the rules to the minimum. So some will have a blast with the new rules that are put in place, and some will just go against the rules. There are a lot of people who see cutlery as a constraint, but they don't think about it or they don't bother to think about what the cutlery is for."

"We have requested machines from the Cuma for mechanical weeding. We also have a scalping stopper for potatoes to weed potatoes mechanically. And in relation to the business we have set up with our colleagues, we are in the process of applying for a mill and an oil press, to develop more locally, and transform our products. So these public policies also allow farmers to be supported in their choices. After the policy in general, there are a lot of constraints that could be removed. There is always red tape, but it is not a hindrance for me at the moment."

"Too much red tape, it's recurrent. It's always complicated and then we take a long time to submit applications only to be refused without knowing why. We call people who finally answer, that's it. So that's an example. We especially have a lot of problems with CAP declarations, with innovative things that we can't put in the boxes. I'm not too afraid of controls, but I have neighbours with whom we have hunting rights, where I have agreements with them. I pay them for the loss of income to make strips in these crops, and I have some who have accepted and others who have refused because they are afraid of the CAP declaration."

## Influencers

**Supports & Information Sources**

Throughout the interviews, farmers brought up other factors related to their land management and farm practices. These factors include decision support tools and information sources; both are influencers which may impact choices surrounding biodiversity practices.

Eight interviewed farmers stated that they used decision support tools to make their decisions.

"Yeah, some tools, and then I did nitrogen reliquats myself. We have never applied complete fertilizer, that is to say that we manage our nitrogen crops as we work with cover crops, we try to bring up all the elements as much as possible. I do a lot of weighing for rapeseed, but I don't use everything that is satellite."

"Yeah, it's a big help because in years when there's no need to treat, it transforms an intuition into something more concrete."

"But I use software, decision support software. I don't know if you know them? Yelloh for example for the yellow wheel, septolyse for septoria. Hence, I only treat if I see the disease pressure rising. My neighbours don't use it, they treat blindly."

When farmers were asked about the main sources that they received information from, the most popularly received answered was information exchanged in collaborative spaces. This includes working groups, conferences, neighbors, farmer groups, and most frequently mentioned was GIEEs. The second most referenced sources of information were from advisors and the internet; both sources were noted by five farmers. Trainings were mentioned by four farmers and magazines were referenced by three farmers.

As previously mentioned, hunting plays a large role in the adoption of biodiversity enhancing practices in the region. Another influence a few farmers mentioned was the support that they received from the Hunting Federation.

"We've also put in a strip of soil and we hope to be able to compensate it with wood chips to be burnt in the boilers. In terms of cost, we're helped by the Hunting Federation, which wants to develop this and this is not negligible, because the planting of miscanthus is very expensive"

"I said to myself that in the end I had lost 2 hectares of land which were stored in the lower parts of my plots and I said, but if I cut all my plots perpendicular to the direction of the water, I realized that by putting 2 and a half hectares of extra strip we could have an effect on biodiversity, on the fauna and flora, and in the end, we could really do things to combat erosion. So I worked with the hunting federation, the Nord Pas de Calais hunting federation and the chamber of agriculture. We really tried to build things by associating the fight against erosion and biodiversity."

"And for the past 5 years, it has had a slight tendency to increase with all the hedge-planting projects that can flourish just about everywhere, either by the ministry or by federations, hunters who finance projects. So it's starting to increase again after having decreased drastically."

"Five years ago I was part of a programme called AgriFond, the aim of which was to make a diagnosis of all the plantations in terms of biodiversity and erosion. It was a programme that was supported by the Water Agency and the hunters' federation, where they sent a technician. They go through the territory and they map the farm and highlight the problem areas. And they put all this in parallel with everything that could be developed or not. So that gave me a bit of a starting point with the developments that I could make."

## Future of Farms

**Aspirations**

At the end of each interview, farmers were asked about their hopes for the future state of their farms and their aspirations for the next 5 or 10 years.

A few farmers expressed that in future years, they would like to continue the farming practices they currently have.

"The aim is to continue with what I have started, with soil conservation, grass strips, there is still some work to be done."

"It's to stay like that as long as possible in the momentum of soil conservation agriculture."

"Ah well, I'm trying to continue like this. But after that, I would like to be more involved in a conservation agriculture approach. After that, I still find it hard to grasp all the techniques, I can make them evolve, but

I've tried things that didn't work because the equipment is expensive and I have a small farm. But I am open to everything."

A couple of farmers mentioned a generational component and a desire to pass their farm down to family.

"It's a system that can be transmitted and perpetuated. And the only thing I ask of my daughters is to keep this land, as a tool, as a heritage, because once it's gone, it's gone. Today, that's why I've taken up an outside activity, the maintenance and repair of agricultural equipment. It's still in the agricultural field. But in the end, it's not the same job at all."

"The idea would be to perpetuate it so that it can be passed on to children, nephews or nieces or someone else. Because we are the eighth generation on the farm. And so the objective is to improve the life of the soil, reduce tillage without losing yields. So in 20 years' time, we'll have more communication, a bit more space and we'll still be having fun in our job."

"So that's a good question. My son may take over the farm, well he's more of an artist than a farmer. I hope that this agro-ecological approach will go even further in the virtuous circle. If I wasn't in industrial farming, I wouldn't question so much. The problem is that these famous industrial crops require tillage."

Other farmers expressed that they would like farmers to be able to try out new practices.

"I want my farm to be a testing ground. I want to make my land available. I want to make my equipment available. I'm lucky enough to have an event venue where I have eight meeting rooms, or I have coworking offices and everything. So tomorrow, if you want to launch a conference, you could use my operation as a support for experimenting etc."

"I think we should give up the idea of creating an ideal system. Our goal should be to try to help each actor in the field to invent his own solution. I call field actors, farmers or agricultural advisors, the people who directly or indirectly decide what happens in the fields. So there you have my answer. I think it's, you have to help them invent their solution, you can't tell them, this is what you have to do. You have to tell them, this is how you can. Create your own way of doing things. And a way of doing things which will be virtuous because we will give them indicators, tools to measure and appreciate the intentional and unintentional effects of their choice. I am a great believer in empowering farmers."

## Appendix: Survey method questionnaire

- How were respondents identified? What criteria for identifying and selecting/screening respondents were used, if any?

Respondents were identified either directly or through our contacts at the chamber of Agriculture Nord Pas de Calais, and then using a snowball effect sampling to find new participants. We identified respondents according to the size of their farm (large farm over 100ha), their cropping system (with a large surface dedicated to wheat), and their "progress" in transition towards more practices to enhance biodiversity (all farmers interviewed have to a certain extend started to modify their practices).

- What were the steps for inviting farmers? (e.g., who, and through what channel, reached out to farmers)

There were 2 ways to invite farmers. 1. We contacted directly farmers via email or phone call. 2. We contacted our contacts at the Chamber of Agriculture, which were coordinating working groups. Then, our contacts gave us the contact of farmers who were interested in participating in the survey.

- Were any forms of incentives (both monetary and non-monetary; both positive and negative) used to encourage farmers to accept the invitation? (e.g., financial or in-kind compensation, prospect of advisory support or other services, opportunities to ask experts questions, peer pressure, network inclusion/exclusion, the chance of learning about survey results later, etc.)

No forms of incentives were ever used to convince farmers to participate in the survey. Farmers participated on a complete voluntary basis.

- How many did you invite? How many declined?

I have contacted approximately 50 farmers directly, not taking into account farmers who were directly addressed by our contact at the chamber of Agriculture. No one directly declined, we simply never received any follow up to our emails or call. But if we count the lack of answer for a decline, then about 40 farmers have never replied.

- Are there any common characteristics of farmers who declined?

Farmers who were less motivated, and had not yet taken step in changes of practices. The way of communication (via email) could have also been a limitation factor.

- How were the interviews conducted? For example, face to face interview or phone/zoom; one-on-one or as a group, etc.

Interviews were almost systematically conducted one-on-one, at the exception of 1 case of a farmer who was accompanied by his consultant. Half of the interviews were conducted in a face to face interview, and the other half via zoom.

- How long did an average interview take?

On average each interview took 1hour.

- How was the data recorded?

Data were recorded directly via Zoom, or using a voice recorder.

- Profile of people who conducted the interviews (e.g., training/background, academic or extension or private consultant, etc)

The person in charge of conducting the interviews is a trained scientist in social sciences, with experience conducting interviews and using participatory methods.

- Did the same people who conducted interviews do the translation?

Yes

- Any issues or challenges or surprises worth highlighting? How did you attempt to resolve the problems? Did it work?

No particular issue has to be reported while conducting the interviews.

In terms of translation, there is 2 terms which were difficult to translate as they only refer to the French context: 1. GIEE, working groups standing for Environmental and Economic Interests Groups, which seems to be a key element of the agroecological transition. 2. HVE certification, which stands for High Environmental Value certification, which is considered as an alternative, a third way between conventional and organic agriculture.

# Supplementary Information Item for WP1: Interview Finding Summaries, Part 2 – Germany Interviews | Response Analysis Summary

Supporting: Enhancing Biodiversity and Resilience in Intensive Farming Systems

## Farm Operations

***Sources of Information, and Management***

To gain general knowledge on interviewees' farms and current management practices, farmers were asked a series of questions about the sources that they gain agriculture knowledge from and their strategies for maintaining soil and handling detriments.

For sources of information, all farmers noted they received agricultural information from multiple outlet such as consultants, events, farmer associations, government offices, journals, magazines, newsletters, newspapers, the internet, and research institutes. The most common source noted was farmer associations.

"We are, I would say, strongly connected with the district farmers' association here. My father is also the chairman there and is also connected with the state authorities."

"We work together with the farmers' association and also with the state farmers' association, not only with the district farmers' association here in the Uckermark."

"So, the classic is just the newsletter from the farmers' association, so we are also a member and always get the weekly email with what is currently new. In principle, everything is in there for the long term."

Top Agrar and ZALF were also popularly referenced.

"Through the ZALF, of course, because we also have contacts there, if there is something new, we also make tests ourselves."

"ZALF, farmers' association, top agrar, farmers' newspaper, a bit of the internet perhaps."

"We read Top Agrar. We also get mails regularly from these, so from Top Agrar and Agrar Zeitungen and all that. Yes."

A couple of farmers noted that they are aware of information sources but do not review it often.

"Oh, I don't read it that often, but I have a subscription to Agriculture without a plow, LOP (Landwirtschaft ohne Pflug) is the name of it."

"Top Agrar and other magazines we had once, all in all I unfortunately don't have the time to read them too often."

"Farmers' newspaper in any case, relatively important and you get a lot of advertising from all the industry representatives. You get a lot of stuff in there, I'd say, but I don't look at it very often."

Six interviewees explained that they received information by speaking with other farmers.

"So, the main source of information is, I think, the interprofessional exchange with other farmers."

"You take this kind of information into account and, of course, you also exchange it with your colleagues. That is an honest exchange. You can exchange information with many, but you also have to have someone who tells you the truth. Sometimes that's not nice, but it's the only way that helps."

"Internet or even ask neighboring farmers. If you try something new that your neighbors are already doing, ask around."

“Mostly online at agrarheute.com and sharing experiences with other farmers. You can't underestimate what online forums and Telegram chat groups with hundreds of participants make possible. So, specialist topics.”

Farmers were asked how they managed pests and diseases. Many noted they used chemical inputs to protect against pests.

“So, let's take rape cultivation, the rape seed beetle and such things are done chemically.”

“As far as possible, we try to use chemical pesticides according to damage thresholds.”

“Then I'll look there, and I'll find aphids there too. And then I go in there with an insecticide, unfortunately. You're not alone somewhere in the field, but you also have field neighbors who influence it. Apart from that, we make sure that we don't cause ourselves any problems.”

Several farmers noted they used diverse and resilient crops to manage risks of diseases.

“So, with diseases. In order to have them as far as possible under control we have a wide crop rotation that means no monoculture, means corn on corn on corn or wheat on wheat, and damage threshold principle.”

“Well, very specific varieties anyway, because we don't have such a high yield level here, and we don't usually have such high disease pressure. Because it is rather dry, it is always enough if I take healthy varieties.”

“So, you grow varieties where you have good experience with little diseases. Okay, and as far as any diseases prevail or bridging resistances. Then the varieties automatically fall out of cultivation, because it then becomes too expensive.”

Farmers were also asked about how they managed or maintained the fertility of the soil on their farms. Many responded stating they used crop rotation, catch crops, and intercropping.

“Then we do intercropping and under sowing in corn so red fescue under sowing in corn and crop rotation in any case.”

“One tries to achieve a reasonable crop rotation. Tillage, of course, you also try to protect the soil as much as possible. Plowing is done only once every three years, and so on. And catch crops are more or less mandatory.”

“We also have catch crops, so rape is definitely a catch crop.”

“We try to cultivate catch crops, so before corn come catch crops.”

“Then I have a relatively wide crop rotation of about 6 years. I cultivate catch crops before all summer crops. Everywhere where it is possible.”

“Yes, in principle it is straw up to 99 percent, so there are very few areas where we leave straw and then intercrop and digestate.”

“Yes, we do intercropping and for a few years reduced tillage. Now we have plowed a little more, we hardly plow at all. We have been intercropping for 15 years or almost 20 years. We have been growing lupine for 15 years. Yes, the whole range.”

The use of fermentation residues was also a popular response received.

“We also use our fermentation residues, which are produced in the biogas plant, as fertilizer on our land.”

“We use fermentation residues from the biogas plant for soil fertility. Straw manure, i.e., the straw from barley and wheat is mainly not removed. It is incorporated into the soil to positively influence humus formation and the fermentation substrates from the biogas plant.”

“Then we also use the fermentation residues from the biogas plant again.”

"We always have fermentation substrate due to the biogas plant. Then we try conservation agriculture. In general, everything here is plow less. And since last year we have started with compost."

Several farmers also said they used manure to fertilize soil.

"The main focus is on organic fertilization. There I do relatively much, also with dry manure and prepared fermentation residues."

"Through our cows we have relatively much manure also by the calves. This is applied where it fits. Every year we have soil samples taken, so that we test the whole area that we manage every 4-5 years. And with this partner we see where we can apply the manure, where we apply the liquid manure, do we need break somewhere and we try where it is possible, to leave the straw on the field for have humus and soil nutrients which we don't need ourselves."

"Yes, we have a benefit due to the dairy cattle facilities, through our dairy cows we of course have farm manure, and that's the first thing."

"We have the liquid manure and digestate from the biogas plant. Manure, which is then also worked into the soil for the corn or also for the rapeseed, as far as it is allowed."

One farmer noted they would like to use manure, however, it was not available to them.

"Would like to use organic fertilizer, but we do not have any here. So, we don't have any livestock, don't have any manure surplus in town that would be falling off for us."

## Farmers' Perception of Biodiversity

***Understanding and Advantages***

Farmers were first asked about their understanding of biodiversity and how it relates to their farm. Through answering this question and speaking on personal experiences, farmers expressed their views of the benefits they believe are associated with biodiversity enhancing practices.

A majority of farmers emphasized diversity in their understanding of biodiversity. 10 farmers stated that biodiversity is a variety of crop and insect species.

"What comes to my mind is just as much diversity as possible, which is a story of plants and animals. So whether that's insects or even larger animals that have a habitat."

"For me, biodiversity means, having a variety of insects and plants. So you don't have to spray every cornflower, corn poppy or weed in the field to death. You need to see if it is relevant, when does the weed occur. The field does not have to be always 100 percent clean. I learned that if a field is 100 percent clean, you have spent too much money. Not every bug or every insect is necessarily a pest and must necessarily be controlled. You should accept a certain number of pests and to prevent other insects from being affected."

"In principle, biodiversity is the variety of species in nature, if you want to translate it roughly. But some people always interpret it differently. For example, it's of no use to me if I have a large biodiversity in pests, because I also have to distinguish between pests and beneficial organisms. "

"Species diversity in the cultivated landscape. First of all, there is the diversity in cultivation, the diversity of the agricultural structure, the diversity of flora and fauna, i.e., bird life or insects. This is all spatial structure. Hedges, field margins, curbs, ditches. All of this is also biodiversity."

A few farmers also explained biodiversity as a connection with nature.

"Biodiversity is simply the interaction with nature."

"So intervene as little as possible in nature. So we do intervene in nature, but cause as little damage as possible to insects, to plants at the edge of the field, which are not necessarily still burdened with fertilizer and pesticides."

In recognizing the advantages of biodiversity enhancing practices, several farmers stated that biodiversity has led to greater beneficial insect and pollinator presence.

"The good thing about the flowering strips is that you then have more insect occurrence, especially if you are flower rich. This is a great advantage, especially in the rapeseed flowering. The rape is dependent on cross-pollinators and you can then also increase the yield. The yield stabilizes or increases. But I also have to say that I have been a farmer for a few years now and I think that insects have really increased in recent years. If you go outside and really look, the number of insects, the species I do not know but the insects have become more."

"There has to be a plus. If I could promote biodiversity without having a disadvantage, I would also say that it is indirectly a plus for me. There are more beneficial insects and so on."

"And the other task that our catch crops actually over the ground over winter, that the ground is not bare. It's mostly about erosion, and other stories. There's a huge benefit from rooting the soil. The bees are also happy if they still have a sunflower there."

"But this flowering strip has been there 5 or 6 years now and is relatively free of sow thistle and nettle. For us, these are the core problems in a flowering strip. There you can see what nature can do and you can also see various different insects. And you can get pleasure from it. It doesn't look so beautiful visually, it's not a tulip field that shines super."

"Through the flowering strips and the intercrop mixtures, you can notice considerably that the insect population is in the stocks. And that is always something nice, I would say, when you notice that."

Farmers also noted a variety of other benefits that resulted from implementing biodiversity enhancing practices on their farms. However, no other single benefit was dominantly referenced across many of the farmers that were interviewed. A couple of farmers briefly noted that reducing the use of chemical inputs had the potential to save on costs.

"So every fertilizer not bought is a saving or a better distribution of fertilizer on the field is an optimization for us."

"The abandonment of chemical measures in the first place. Maybe a little cost savings overall."

A couple of farmers stated that biodiversity was beneficial to soil either in terms of improving fertility or reducing erosion.

"So for me, biodiversity is in any case soil fertility, also in connection with nature, to bring that into harmony, so that I also, for example, protect the beneficial insects in any case, that I create measures."

Other farmers referenced decreased pollution as an advantage of biodiversity.

"I would say that generally makes a lot of sense to protect against pollution of water or erosion-related issues."

"The environment is less polluted, i.e., groundwater, nitrate, things like that. Nitrate pollution is the buzzword everywhere at the moment."

A few farmers also expressed that biodiversity enhancing practices increased wildlife presence on their farms which they viewed as beneficial.

"Pest control, of course, is becoming more and more demanding, because many groups of active ingredients have been eliminated anyway. And then you actually have to concentrate on what is still available, and you can see it in the fields, for example in the wildlife. We have an incredible number of hares, we even have partridges again. So you can see that the living obstruction is getting better again through such measures."

"Yes, and the fact that wildlife lives there makes me happy. I also have children who go to a flowering strip in autumn and pick sunflowers as winter food for the birds on the farm. They come along and then the children also go with them to drill the flower strips. They get the rest from the seed drill in their hands and spread it by hand."

"I am always happy when I have more small game in my field again. Now also pheasants and so on settle again and increased, also field hares and rabbits. Also quails and so on we have a lot in the stock."

***Biodiversity Experience and Views of Methods' Effectiveness***

Farmers were also asked about their experience with biodiversity enhancing practices and explained throughout their interviews how these practices impacted their farms. Additionally, farmers were asked about the effectiveness of various farm management practices.

The two biodiversity enhancing practices that the highest number of interviewees said they used on their farms, was crop diversity and crop rotation. Each of these methods was referenced by 18 farmers. Many farmers use catch crops and intercropping to create diversity.

"Yes, so for summer crops I basically cultivate catch crops, so there is no fallow, there is always vegetation on it. I've been doing that for many years, for a couple of decades basically, well, we've been doing it forever actually."

"We don't have a field that stays as a fallow over the winter."

"We have greatly expanded our intercropping, winter intercropping. The areas that are harvested in June, for example as GPS cereals, i.e., rye for the biogas plant, are then cultivated with intercrops when corn or sugar beet is planted next year, so that they do not lie fallow."

"Intercrops are placed before grain, corn, sunflowers and before soybeans, yes."

"I have an intercrop in the fall, then organic fertilization in the fall with 60N or 30 NH4, that depends which one is suitable."

Flower strips were also used by a large number of interviewed farmers. 17 farmers noted that they had flower strips on their farms and several expressed that they viewed them as positive assets.

"Yes, in the case of biodiversity, which must be added, is that we have flowering strips in some corners, on just under 20, rather 16 hectares."

"I do have flowering strips and I would say they are a great measure."

"We have about 38 hectares of flower strips and 58 hectares of field margins."

"And our solution now is to try to produce beneficial insects via these flowering strips, so that we can perhaps contain an epidemic that is guaranteed to come. Because spraying and killing all the beneficial insects doesn't work."

Buffer strips was another biodiversity practice that a large number of farmers stated they had experience with.

“Yes, sure. I have a stream and I have had a buffer strip along the stream for 20 years.”

“We have buffer strips of 12 meters next to ditches and ponds, firstly to protect the biotope and secondly to avoid plant protection requirements and fertilizer requirements.”

“So is a quarry hole, which has been dry for five years now even with the big rain. But reeds grow inside is a water body, isn’t it? Yes, that's also a matter of dispute. That's why I do it generally. I put strips there and then it's good. Just for the conscience.”

Many farmers also noted that they reduced the use of chemical inputs on their farms and believed this was effective in supporting biodiversity.

“Yes, we are reducing the use of herbicides, and we also think it is important to do only what is necessary and to accept a few plant species that come up late. This is also a considerable commitment to biodiversity.”

“Originally, we bought a hoe because we were interested in the processing equipment, which was a rotary hoe, and the rotors were interesting for us. That is why we bought the hoe. In the meantime, we have been hoeing the corn for two years in order to reduce herbicides.”

“That is, so to speak, the creation of buffer strips along bodies of water. In order to simply create a natural area in this area as well. They have also been sown with a flower mixture to prevent the input of, let's say, operating resources, i.e., fertilizers and pesticides.”

Several interviewees also referenced the existence of permanent grassland on their farms.

“Yes, I have grassland here and there is little debate on this anyway. I think it is important. I think conservation is important anyway, there's nothing to be said against it.”

“Of these 178 or 180 hectares, 60 or 62 hectares are permanent grassland, not pasture.”

A couple of farmers expressed that permanent grassland needed to be thoughtfully managed in order to be beneficial for biodiversity.

“And of course, you can also preserve the insects for a really long time in comparison. If, of course, permanent grassland is maintained, but it is an intensive bull fattening farm or dairy cow farm, then it will mow five or six times. In that case, maintaining permanent grassland is also important, but that farmer needs fodder for the cows. Then the outcome for insects is not as great.”

“So with permanent grassland it still depends. If it is intensive permanent grassland, then in principle it is similar, perhaps a little better, to cereal fields. If it is not used so intensively but extensively, it is of course great for biodiversity. Then it is clearly a one.”

“Yes, we have permanent grassland, but you have to take care of it, and you can't leave it completely to itself to preserve certain species. Otherwise, strong species come through too much and then the diversity is lowered. So promote permanent grassland but just also maintained.”

Several farmers also stated that they were making efforts to decrease energy use on their farms and many believed this helped biodiversity.

“We have now optimized CO2 exchange in the storage of potatoes. We use a new technique. In the past, the CO2 was transported out of the storage building by active circulating air to the top. Since CO2 is heavy,

we now continuously extract it downward. This allows us to reduce our energy consumption. That is already a positive thing."

"Saving energy through energy-saving lamps, especially in the dairy plant. And then we also use the energy from our own photovoltaic and bio-power plant."

Another biodiversity enhancing practices that a few farmers stated they had experience with but was less popularly discussed than other methods, was reduced tillage or no-till.

"We've been trying for two years to do as little tillage as possible, to no tillage at all. I would say that we are trying to move into non-plough tillage."

"I do them no-till and I do them without total herbicides."

Although all farmers are required to conduct soil testing on their farms, many expressed that doing this was incredibly important and beneficial.

"It is a measure to know and to check yourself. This is important. We have to check ourselves, so this soil analysis is part of it. Especially in the other direction, to explain to the rest of the population: we are the professionals. The only way to do that is to always check ourselves. The only way to do that is to document it."

"We have to do that anyway. We also have to do this because we need to know what's going on or what we want to do."

"That is very important in any case. You always have to know what you have in the soil in terms of nutrients, and I also fertilize according to that. I don't do standard fertilization, but I do it really individually. But that's also due to the technology, because that's not a problem at all."

"Well, the soil life already plays a role and if the plants do not grow because of some deficiency or an overdose of some substance comes up. Then the plant also does not grow reasonably. So I see it as really meaningful. Only it is debatable in which way it is done, this soil test."

"Regular soil testing we do and find very effective for the environment."

During the interviews, farmers were given a list of biodiversity measures and asked to rate their effectiveness on a scale from 1 to 5, with 1 meaning "very effective" and 5 meaning "not effective at all". A table demonstrating the responses received is displayed below.

*Note: Although farmers were given an explanation of the 1 to 5 scale, many noted confusion or experienced difficulty in providing a score. Additionally, it is important to recognize that although a scale was provided, interpretations of the scale varied and therefore, scores given are subjective and may vary slightly in their meaning depending on the farmer.*

| Biodiversity Measure | Number of Farmers That Gave Score for Effectiveness of Measure | | | | |
|---|---|---|---|---|---|
| | Score 1 (very effective) | Score 2 | Score 3 (neutral) | Score 4 | Score 5 (not effective at all) |
| **Preservation or planting of agroforestry systems (ex. Hege strips & windbreaks)** | 4 Farmers | 8 Farmers | 2 Farmers | 1 Farmer | 2 Farmers |
| **Preservation or planting buffer strips** | 2 Farmers | 8 Farmers | 3 Farmers | No Farmers | 1 Farmer |
| **Conservation & planting of riparian buffers** | 3 Farmers | 6 Farmers | 3 Farmers | No Farmers | No Farmers |
| **Flower strips** | 10 Farmers | 4 Farmers | 2 Farmers | No Farmers | 1 Farmer |
| **Introduction of new habitats (ex. Scrubland, forest, or wetlands)** | 3 Farmers | 3 Farmers | 5 Farmers | 4 Farmers | 2 Farmers |
| **Management of field shrubs and kettle holes** | 6 Farmers | 4 Farmers | 1 Farmer | No Farmers | No Farmers |
| **Regular soil testing** | 10 Farmers | 5 Farmers | 1 Farmer | 1 Farmer | No Farmers |
| **Reduction of fertilizer use** | 5 Farmers | 8 Farmers | 1 Farmer | No Farmers | 1 Farmer |
| **Reduction of herbicides** | 5 Farmers | 3 Farmers | 1 Farmer | 3 Farmers | 1 Farmer |
| **Reduction of insecticides** | 2 Farmers | 3 Farmers | 6 Farmers | 1 Farmer | No Farmers |
| **Reduction of fungicides** | 2 Farmers | 6 Farmers | 3 Farmers | No Farmers | 2 Farmers |
| **Crop diversity** | 6 Farmers | No Farmers | 2 Farmers | No Farmers | No Farmers |
| **Permanent grassland** | 5 Farmers | 2 Farmers | 6 Farmers | No Farmers | 1 Farmer |
| **Organic farming** | 1 Farmer | 5 Farmers | 7 Farmers | 1 Farmer | 2 Farmers |
| **Engagement of local community (ex. school visits)** | 7 Farmers | 6 Farmers | 2 Farmers | No Farmers | No Farmers |
| **Energy saving** | 4 Farmers | 10 Farmers | 2 Farmers | No Farmers | No Farmers |

While being asked to measure the effectiveness of biodiversity enhancing practices. Farmers highlighted issues with specific measures and a lack of confidence that they are successful in improving biodiversity.

In reference to flower strips:

"For the farmer himself, I do not really see an advantage now. And I don't see any advantage for nature on the field either, because it's an artificial biotope. And if I create it once in the village for other people and it stays there for ten years or longer. Then a biocoenosis forms on it. But on the field, I have to break it up again anyway, and I don't really see an advantage for nature."

“So I had noted of it already briefly. So these wildflower strips must fit to the region, and I always have the feeling that these standard mixtures are not so good. I also have a few smaller areas, where today I can't even get there with a large combine harvester due to poor access roads. For a few years now, I've had them completely drilled in as a flowering area, so that's a 0.9 or 0.8 hectare plot or something like that. And when I see what's happening there on these areas, with the flowering mixtures, I have to say that's completely unsatisfactory. Nothing really fits. (Said in reference to flower strips as a method for increasing biodiversity)

In reference to soil testing:

“Yes, because I really can't imagine any influence of my fertilization on the biodiversity. At least on my farm. Looking further, yes, I can imagine. A catch crop that has been fertilized, there is more mass, more habitat. And it doesn't help us farmers if we carry out tests and the results are worthless. If I examine a soil and I have a deficiency of a nutrient and I am not allowed to fertilize it because it is a red fertilization area. So that doesn't get me anywhere. The upper meters at my red fertilization area, the soil is empty, there's no nitrogen there. That's what my research says. But I have a red fertilization area and I'm not allowed to fertilize there. The science and the law must not contradict each other.

In reference to reduced application of insecticides and fungicides:

“It's completely pointless to do that. The best example is canola. Six years ago, when we were still allowed to apply insecticides, we did nothing at all with insecticides in the field in autumn. We just dressed the rapeseed, sowed the rapeseed, did nothing. Once we did something against weeds in late fall and then canola was done for the fall. This year I've been in canola twice with an insecticide because I have to control the pests above ground now, otherwise they'll eat away at my roots below ground. That used to be done by the seed treatment. So insecticide use is increasing because neonicotinoid seed treatment has been banned. It's completely counterproductive. So that's an absolute disaster on the part of regulatory policy. Fungicides exactly the same.”

In reference to organic farming:

“Five. It's simple. We have a large arable farm next door that converted to organic 4 or 5 years ago. A 200 hectare organic wheat field is not more biodiverse than a 10 hectare conventional wheat field. There are also studies from the University of Göttingen, I believe. On field sizes and biodiversity and conventional versus organic farming and conventional land in XX country. They just happened to do it earlier on the inner-German border or on the former inner-German border. Conventional land in the old states was more or exactly as diverse as large organically grown land in the new states.

In reference to reduced fertilizer application”

“Well, that's the next problem. That's the reason why it's hardly fun in agriculture anymore. I can hardly be a farmer. I just have to make sure that I don't come into conflict with the law. For that, I need a university degree. Just ask the small farmers, who all need advisors because they can no longer manage it themselves, because otherwise they can't work in accordance with the law. Unfortunately, that's the way it is. You have to do fertilizer planning or fertilizer need analysis. What is then important for the farmer is what he can get out of it. Actually, we are limited by the regulations, you are not allowed to use more. One notices that immediately in the yields and the qualities that are declining. It doesn’t work. I have to say, I don't know to what extent you practice theoretical agriculture or are involved in it yourself.”

***Implementation Criteria, Limitations, and Disadvantages***

Farmers were also asked about the factors they consider when making the decision on whether to adopt biodiversity enhancing practices. Throughout their interviews, farmers also discussed the limitations that prevent them or others from implementing biodiversity practices as well as disadvantages that result from biodiversity.

The most common motivator farmers stated they consider while deciding to implement biodiversity practices are financial factors. This includes the economic efficiency of introducing a new practice and determining whether the necessary costs make sense, as well as any financial incentives that are available for choosing to adopt certain practices.

"So the ecological factor was definitely very important, but the economic one was definitely just as important."

"Yes, exactly. When I consider a measure, I first look at whether it makes sense for me. And then of course the cost-benefit effort the important one."

"As I said, profitability, feasibility, can I afford it? And then sensibility is certainly added, or perhaps also a bit of practicability. I couldn't start growing potatoes, for example, because I'd have to buy all the special technology separately. That wouldn't work either. So things like that. Practicability would sometimes still play a role."

"First and foremost, the focus for me is on economy. The economy. With regard to the flowering strips, for example, it must also pay off that you don't make too much of a loss, or any loss at all, when you plant them."

"How easy I can implement it plus a cost-benefit calculation. And then I said this makes sense and this doesn't make sense."

"I wouldn't do a flowering strip if I didn't get at least a black zero out of it. The costs for a flower strip are more than the seed."

"All these ecological measures must be better rewarded."

"Well, I have to say, I can't live on idealism alone. There must be an economic advantage in the meantime, and unfortunately I don't see that anymore due to the requirements of the legislator, which is becoming more and more difficult."

A couple of interviewees also noted the importance of a supportive market for farmers to incorporate biodiversity into their current practices.

"And what is very important is marketing. I would also love to grow soybeans or something like that, I've tried it before, but afterwards there was no one who would buy them. Then, of course, I can't grow them either. There has to be a market for everything. Someone has to buy it."

"Of course, one must also say the cost of the modules were much more expensive at the time. It always comes out the same. This is all regulated by the market. If there is a lower feed-in premium, then they must sell the modules at a lower price, for example."

A few other motivators were briefly mentioned by farmers, but no other motivators demonstrated a common priority amongst interviewed farmers. Other implementation motivations included disease control, soil health, authorization, crop yield, and the amount of required work.

"I don't do crop rotation because of biodiversity, I want to minimize two things with crop rotation. Once a pest occurrence and disease occurrence. I do not cultivate wheat every year in succession."

"If it has a positive effect for me, such as with catch crops, then I simply do it to improve the soil."

“Priority one is whether I'm allowed to. Priority two is economic efficiency, that is an issue.”

“Ultimately on the yield. If I do the measure, then I want that it works and I can do without the chemical. They are also a cost factor, although the hoe is also not free.”

“Definitely the amount of work. That you don’t have much to do. Honestly, that's why I only have the very simple marginal strips, you can also for all in Lower Saxony, there are these direct flowering strips or similar where you get extra money for or that is called in Brandenburg then the KULAP. But we don't do that, because the moment you apply for the extra money, you have one more inspector on the farm who comes to look once a year. Is that the way you have indicated it? And then I don't care about the 100 euros more for the hectare.”

For limitations that prevent farmers from implementing biodiversity enhancing practices, financial feasibility issues were most frequently brought up by interviewees. Farmers are concerned that the costs and work of biodiversity practices does not result in outcomes that they believe are worthwhile.

“Then I get the problem of less yield or poorer cereals quality and then I have a big problem, because who pays me the money I loose. These are the most stupid things we have been confronted with lately.”

“Then I get the problem of less yield or poorer cereals quality and then I have a big problem, because who pays me the money I loose. These are the most stupid things we have been confronted with lately.”

“So with the legumes the seed is very, very expensive and you harvest very, very little of these fruits here, because as I said we always have the pre-summer drought, where then everything always dries up. You wouldn't get that back in. And you also have to drill out the catch crop, the seed also costs money.”

“If possible, do even less with plant protection. In principle, you also have to earn money with it, so if you only do what's good for nature, you hardly earn any money at all. And that is the dichotomy somewhere. I would also spread less fertilizer. But then I also harvest less and earn nothing.”

“The last year has shown us that the fixed costs are getting higher and higher, and if I don't get something in return on the other side, then I inevitably end up in the negative. And then I no longer see any prospects for the future. And every business economist or business manager has to calculate economically, and if that no longer makes sense, then I just stop.”

“There has to be an incentive, because farms have to live on something. Soil is a scarce commodity, I would say. And if the biodiversity measures that we are currently implementing are not sufficient and more is to be done, it will eventually be at the expense of good soil or surface area and this must ultimately be rewarded somewhere”

“In principle, I am always in favour of mechanical weed control. So in our farm it's really only before sowing that comes into consideration. But it's always a cost-benefit consideration, and the weather is also a deciding factor.”

“If we should have for pastures for bees in 17 varieties, so that it is accepted for promotion and here in Brandenburg there are only 2, 3 mixtures that are registered by the state and then only annually, so annual. That is not advantageous. And when I look at the price per hectare, it is too tight for us economically.”

Farmers also commonly expressed that expensive costs associated with switching to biodiversity enhancing practices significantly impacted adoption decisions.

“It makes a lot of sense to do a flowering area in order to have a flowering area and you can afford that to a certain extent. But actually, the scope is quite small simply because it costs money.”

“But I think, in Germany if it becomes the means of choice one must consider that alternative soil loosening also costs fuel. Otherwise, there is an energy management from the office, so an energy comparison, if I want to call it that. We have now also registered, we will do that once, to simply look where exactly are there still potentials for us to save energy, but ultimately also as digital solutions to control the plants according to electricity demand or electricity generation.”

“We could do more here, and you could also do more in terms of intercropping. But it's always a question of money.”

“All these ecological measures must be better rewarded. Seed costs have risen extremely in recent years because demand is naturally also correspondingly high, and the multiplication areas cannot be expanded indefinitely.”

“The bottom line is that the business has to run, and the people have to get their money. That's why it's also a question of paying for many things. If I pay high rents, I can't afford it. If I pay 300 € rent, then I cannot afford to set aside 10 hectares, I will not say, where I actually only have work with the mulching and I get a premium of 240 from the EU. Everyone can calculate that is not so much. The recognition must come from somewhere or the community must also be willing to pay something. There are also people who do it only for money. If you then do something, if that is your strategy, that you are an environmental farmer or an energy farmer.”

“It's generally just a question of cost. If we didn't have that, then it would look a bit different. Then I would also, let's say on the larger areas, I would simply either divide the field or seed flowering strips and that would be good.”

“But you have to say only because they are funded by the country. I would not do it only voluntarily and only for the sake of biodiversity. Because the planting is quite a cost.”

Many farmers also criticized regulations that are designed to support biodiversity, noting that they are difficult to meet the requirements of, restrictive, and that subsidies and incentives given are not high enough. Seven farmers referenced these issues during their interviews.

“The issue is these flowering strip seed mixtures that we are currently using are not eligible for funding this year because the mix does not comply with regulations. I prefer to use the flowering mixture now where we are testing it.”

“Would be nice if it would be regulated differently. Because if the area is simply red, the culprit is difficult to track down, at least at the moment as long as there are only a few measuring points. But everyone in the red area suffers from it if you take away their prerequisites to obtain a good yield and then, if the price is also low, then, I don't know, how can a pure arable farmer survive then? That doesn't really work at all.”

“God, problems often arise with obtaining permits, it could all go faster. That could be called a problem. Let's see how it will be in the future, when the contract with the EEG expires and how one can then use one’s own energy best on site, because obviously little is paid for energy on the electricity market. But the costs are high for electricity. But when it comes to permits there is always a bit of back and forth. It all takes too long.”

“Also with this flowering strip thing, the question for us is, we will continue to do this, but whether we will actually continue to apply for it I am not sure. Because this mass of application, control, documentation, which results from it is no longer in proportion or ultimately the stress that arises there, so mentally in the head to expose oneself to these controls, I do not know if it is worth it.”

“The grass measure we do, with the mowing after the 15th of June. We don’t mention it anywhere. For the 10 hectares we say we can get €1,500 out of that. It is just not worth the stress. I think that is increasingly a problem.”

“And there the negative example is actually the change in regulations. I can't do more. All of a sudden there are backdrops (Kulissen) where I can do some and where I can't. If I don't have a backdrop, I can't make one even if I wanted to. Or if I'm in a field and say it would make sense here, if there's no backdrop there's no way to get there. So bureaucracy is an obstacle there.”

“At the moment, the only way is to use plant protection products that are already available and to allow them to be used. But things that have been developed directly for this purpose, things that have been researched for this purpose, do not exist, or hardly exist.”

“And then I have to turn it over after five years because otherwise it becomes permanent grassland and I have to watch out if I want to grow something else there, which I am not allowed to. Then I would have to create a compensation area or something. Such regulations are so counterproductive that no one does anything. You have to compare, on private land the trees are all cut down before they reach a diameter of 30 centimeters, because then I don't need a permit. Then you don't have to wonder why there is no big tree later on, because then I'm no longer allowed to cut it down.”

Another limitation that was discussed by several farmers is that the current market is not as supportive as it could be to farmers who use biodiversity enhancing practices.

“The problem is as a cash crop farm I need to be able to sell the crop I grow. We used to grow sugar beet, and I'd like to do it again. It's not possible, because cane sugar from Brazil is cheaper. The sugar factory in Anklam is too far away and the transport costs are so high. The middle Uckermark has stopped growing sugar beets.”

“So we need a marketing place in the market for other crops. I don't need to grow anything that I can't get rid of. And if you want to have other crops even on a small area, then there must be marketing cooperatives again. There was once a cooperative in the Uckermark region that marketed rapeseed as a renewable raw material. And there has to be something like that, because when we say we want to grow oats or spelt or whatever.”

“And seed treatment is the other example, in Poland and Ukraine this is all permitted but not here. How am I supposed to compete then? I'm supposed to fight against the world market price or something? Here it is becoming more and more difficult to produce. Well, well, you could find so many things. Yeah, I don't know, it seems to me like they're trying to make life difficult for us.”

“In agriculture, if we are honest, everything they always tell us is about a regional market, regional market from a certain size here in the East, generally here in the East, there is hardly a regional market. For scale, so I'm not talking here if you slaughter 20 pigs or grow a few vegetables. Organic farming or things like that. But I'm talking about our production structures and the quantities. You can hardly sell lupine like that, hardly anyone wants it.”

“If I don't have a dairy farm that accepts the lupine as a protein carrier for its feed and I have to sell it via the agricultural trade, it looks sad. Because the mixed feed companies are not interested at all, perhaps for special mixtures, but for the large market we have hardly a possibility, because certain products are not traded at all.”

“And the current issues in a market environment, which is very much oriented towards world market, is (...). Of cause we get subsidies, as European farmers, but nevertheless, our prices are world market-oriented and thus we compete with everyone, who so far do not in any way invest in something like that or pay attention to it. And it is not rewarded by the market if you do something like that.”

Farmers also discussed other factors that impact their ability to use biodiversity practices on such as limitations that occur from unideal weather conditions and lack of access to seeds.

“Unfortunately, there is the problem that many farmers have tried to plant flower strips in a dry spring, and then there was 90 percent white goosefoot growing in these strips, and that is the weed that remains in the soil for 40 years, where each plant that grows forms up to 6,000 or 10,000 seeds, and those farmers have ruined their field for the next generation. No turnip grows there anymore without 50 percent more crop protection than normal.”

“Of course, these are always weather-dependent. What I had last year, for example, in the last spring 2021, that was totally wet and then the requirements of the legislator, for example, for flowering programs, each state also has its own, of course, collided with the practice. The local participants all had to get a special permit, because no sowing was possible at the time specified there, because the areas were simply too wet, for example, to sow the flowering fields or strips. Some of these programs are really only based on

purely theoretical values, practice is always left out of the equation. And that, of course, is fatal. Politicians would have to think about whether something like this can be maintained at all."

"A second theme is that I break work peaks, a pea I drill in the spring when I just can't do crop protection or fertilizer because it's too windy and that's when I have time. So that's not in the main autumn sowing, like now September to October. So breaking labor peaks, seeding. Harvest coincides a little bit with wheat, but it doesn't matter. Risk spreading that's also a bit that's always an issue as well and that's where the whole flowering strip issue falls in. That's a super yield. This year it was extremely wet in the harvest. We got stuck several times with the combine. Those were scary expenses, especially in the barley crop."

"Intercrops or intercrop mixtures are also relatively rare here due to the low rainfall. You also have to be careful what survives here at all, whether it works in our region. If you take the 512 component mixtures, even if you would take the expensive ones, that is quite the same, there remain four plants and the rest, that does not survive the dryness. We actually always check it, whether it works, if I order a catch crop. Will it grow and develop or will it grow up once and die?"

"Flowering strips, yes, but we have a problem that in our region, there are hardly any flowering strips you can plant. There also are hardly any flowering strip seed mixtures for purchase. The issue in our region is that normally, nobody plants a flowering strip. That's why the demand for flower strip seed in our region is very low. Consequently, there are no seeds available."

"Seed is simply too expensive. And the provision of the seed. For the pastures for bees and something like that you can hardly get registered mixtures, because there is simply no seed for certain flowers or seeds. In the quantities we need."

"Seed costs have risen extremely in recent years because demand is naturally also correspondingly high and the multiplication areas cannot be expanded indefinitely."

## Policies and Programs

### *Experience with Programs and Regulations Designed to Support Biodiversity Enhancing Practices*

Another component of the interview was asking farmers about their experience, knowledge, and perceptions of company policies, guidelines, regulations, laws, support programs, and subsidies that are intended to encourage the use of biodiversity enhancing practices.

A majority of interviewed farmers have participated in some type of program that supports biodiversity enhancing practices. These include crop protection technology, water protection programs, HALM, organic farming subsidies, and watering programs.

"Which funding programs I participate in? Let's start with the new crop protection technology through the Rentenbank's agricultural subsidies. We participated in the first-come, first-served process and actually seem to be one of the few that got in. Otherwise, from an agricultural point of view, of course, we apply, as probably every agricultural business, at least the ones that only have a small area available, a so-called multiple application and then, of course, you have the EU money as well, so the basic premium and the greening premium. Of course, this we also applied for and as well as for the cultural landscape program. In fact, on my meadows I have explicitly participate in measure B30 (That means it is extensively oriented, renunciation of any fertilization and plant protection) And otherwise I also participate in KULAP measure B26. These are the inter-farm injection procedures for the fertilization technology. So we borrow such a vehicle."

"We will definitely take part in this. We had extensive grassland before. On the extensive grassland, I wanted to work more intensively, also with organic fertilization. Then we have made then rather still to the

ecological agriculture, so that we still can use the organic fertilization with on the fields. The extensive was actually only soil-consuming. That was not really something sustainable."

"We have participated in a project or funding program, which was from the county hunters (Kreisjägerschaft), we are on it, and we participate in it. I think that's very positive, but we are also monitored there. And I would say that this monitoring is a must. The point is that the people who spend the money have to make sure that the money is used in the right place."

"We have implemented measures and had positive experiences. It is then essentially what I have already said, then also an incentive to carry out the measures, because you then have a compensation for what you either omit or do not generate in terms of yield, etc. Yes, that's what I mean, that's the appreciation or the compensation for what I wouldn't do if I didn't take the corresponding measures, because then I would manage the area differently or, if necessary, also achieve a different yield."

"Currently, I participate in the water protection program through flowering fields or flowering strips. There are annual and perennial programs. So I take something from everything."

Farmers experience with different types of policies and programs varied. Only one farmer stated that they had experience with programs that required him to coordinate with other famers and expressed issues with coordination.

"In fact, it is sometimes even undesirable that you cooperate, and with regard to the agricultural subsidies from the Rentenbank, it even says that you are not allowed to use these machines off-farm for 5 years, so you are not allowed to cooperate if you want to get the 40 percent subsidy as a farmer. Secondly, contractors were also able to apply, but I think they only got 20 percent."

"Then, of course, the machine may be used on multiple farms, but then you only get half of the promised funding. That's where you say (...). But it is also partly the aim, the measure B26 in the cultural landscape program is actually oriented in a way that is the injection procedure for manure thinning is shared between farms. And this is already being done. For example, a farmer in the area has now procured such a slurry tank with injection distributor and then lends it out accordingly or drives it for others and then it is accounted for over multiple farms. So it is even encouraged to work together here."

Another farmer was aware of coordination programs but expressed that there needed to be increased buy-in to improve participation.

"Yes, for example here in our town an old arm is to be reconnected to the Lahn, i.e., temporarily. I would say that such measures can only be carried out together. And of course, this is ultimately also in the interest of the community here, because the Lahn embankment has to be relocated and things like that. Then the vegetation space is created. So different, not only the community, also different farms, which have to prove some compensation, are interested in it. Sure, these are community things. I believe that this hamster story only works if a certain number of companies participate, because if there are, let's say, two hamster strips in the district, it wouldn't make any sense. And well then it was necessary that several people say all right, I can imagine to participate and then this project has been brought to life."

No farmers have experience with programs that require landscape changes and only half of the interviewed farmers have heard of these types of programs.

"I have already heard, also rehydration of moors and so on, but I do not currently know what the status is, whether this must be done or not."

"Yes, I definitely heard or then. Heard or read about them in the media and from info sheets, but I not yet visited any or have seen any examples in the neighborhood of from people I know."

"Of course, I've heard about it, but I can see that here in our region, because it's so small (...), it actually has enough right from the start. I don't really see that as essential either. With such programs, you would

have to actually make a mapping in preparation, which you actually already have, and say: In these regions it is meaningful and in these regions, there it is not worthwhile to make there additionally something. Because on the one hand, I want to do business, and then I can't build in additional barriers everywhere. That's not possible."

"Yes, we've heard of it, but we haven't done it yet."

"Yes, I've heard it all before, but it's not current here."

Three farmers interviewed have experience with participating in programs with a spatial focus on specific areas, while all other farmers expressed that they do not have experience with this.

"Well, what I had told you about with the Zalf we have the amphibian project. Up there, that is already very valuable, I would already classify it that way. There it fits also to each other. And the cattle holes, now the last cattle hole also has no more water. That's a shame, of course, but it's not our fault. We can't do anything about it. That already has a high value."

"We have designated certain nature conservation areas, such as FFH areas (fauna flora habitat area). We also work with nature in these areas, so we have programs running there as well."

"We have a very small adjacent FFH area, which does not make up much area for us. This is a bit of the catchment area of the Black Elster and Elbe, but it is a huge area."

Four farmers have participated in flower strip programs.

"So we get subsidies for flowering areas that we create. We receive subsidies for harvest renunciation strips. These are the main subsidies that we receive, where we are also monitored."

"We participate in flowering strips, we also participate in the riparian buffer strip program. The guidelines are those of "good professional practice" in relation to the greening programs."

Farmers who had experience participating in programs were asked how they accessed information, training, and education for the programs they were in. A variety of responses were given.

"We have had great contacts from the Stiftung Rheinische Kulturlandschaft, who supported us by exchanging ideas. Also with advisors, let's say, agronomical advisors from Bayer. They have good people, with whom we have thought about how to get some things back again, so that it also works. But we also have an expert here who carries out a sampling, in other words, who determines what the situation is in regards to insect diversity. He is from NABU. He is a really great person who discussed with us very objectively where and what was particularly important. That was quite brilliant, and we then discussed with him how to do such things. We had a good exchange of experiences. That helped me a lot, to talk to other good people a lot about how we can make it work. And the important thing is that in the on-site or intimate conversation that you have with each other about the problem that you see and to find a joint solution, everyone has respect for the problem of the other."

"Yes, we actually have a very good connection with our agricultural office, which informed us there. Very regularly. And also the farmers' association, which has very good information and regularly issued information about the state of affairs. That's why we were always well informed."

"Well, I would say that it's quite easy for me since I'm at the source because of my work at the administrative office, and I've acquired the information through colleagues or e-mails or the like. Otherwise, there would certainly be other material. But through my work and also the training as a civil servant in the office, I am directly at the source and have also enough information there."

"Yes, well, that was the case during the training sessions on agricultural application funding. The State Office for Agriculture in Hesse informs farmers regularly, before the annual application, about the requirements that must be met and what support programs are available."

"We are always trained once a year, also by the office. What applications are available or what funding programs are available. You can also ask about that and get answers. And then you just pick out what is feasible or suitable for the company and then you do it. We don't have any consultants or training courses or anything like that here!"

"So information. I rely on the farmers' association or the LELF, there are always these information sheets from the farmers' association. I was informed about that and then I simply read up on the regulations myself. So I do that more often."

"Media, agricultural journals, information from the agricultural office, etc."

"No. Pretty much just from the Farmers Union, newspaper and an exchange with neighboring farms."

"There were actually no advanced training courses or training sessions. Mostly there was information about the farmers' association that something was decided again in the ministry. Or I look at the Lelf website from time to time to see what current measures are being promoted or what would be feasible again. There I actually look directly at the ministry again and again. But only the packages of measures themselves are not so exuberant now, I have to say."

Farmers were asked also about what factors were most important for them to participate in policies and programs. The most commonly received response was financial considerations. Farmers were focused on costs, financial feasibility, and incentives available.

"I would say that when I take part in a measure, I always decide whether it suits the farm. And then, of course, if you say okay, that's lucrative, you can do something. Of course, if I would now be offered even more money to create more flowering areas than usual, then you can say okay, I might think about this again. Here it's again all about the benefit, what is being funded so that I get the money I need."

"What was the decisive factor? Well, I would say that, on the one hand, there is the loss of income, which was not to be expected. The bottom line is that no monetary loss or no relevant monetary loss has occurred and at the same time it is good for the environment and to show the population something that is positively evaluated, also as an image cultivation for agriculture."

"So in any case the subsidies. So definitely the money, because that's the only reason you can afford it, I'd say. But money is not everything, we also consider it useful, I would say! Money and meaningful!"

"Oh well. The fact is, there must be something left for me in the end. If you know, I have generally always whether I do something or not between 500 and 600 euros costs. We first have to clear that hurdle per hectare and year."

"It is then essentially what I have already said, then also an incentive to carry out the measures, because you then have a compensation for what you either omit or do not generate in terms of yield, etc. Yes, that's what I mean, that's the appreciation or the compensation for what I wouldn't do if I didn't take the corresponding measures, because then I would manage the area differently or, if necessary, also achieve a different yield."

"The main problem or the only thing you have to pay attention to is basically the financial aspect. The extent to which the company is compensated, let's say in quotation marks, if I have to take some areas out of production or things like that, that is the decisive factor."

Four farmers also noted that it was important to them to see that there were benefits for their farm that resulted from program participation.

"When I notice that it also brings something to my areas, of course. That is the example with this intercropping, through which I have noticed that the areas, if I specifically mulch sow, they can better bind the water, they are better passable. Such effects, I also notice, for example, that I protect more beneficial insects."

“Because we have already experimented with flowering strips, I'll just call it that now, it was natural, we wanted to know how this mixture, which was put together or given, works. Because we were of course interested in expanding our flowering strips, in other words, expanding the area. Of course, this is more attractive through a funding program than if I had to pay for everything myself.”

Five farmers said that they considered the amount of effort it required to apply and participate in programs while deciding whether to take part in it.

“So I first weigh up whether it suits the business, because I am of the opinion that many subsidy programs have such rules that I would have to bend over backwards to comply with them. And unfortunately, it's always the case that when you have to bend, sooner or later mistakes happen.”

“At the end of the day, it's clearly a cost-benefit thing and I have to think that it makes sense, of course. If I think that this is totally off the mark, then the cost-benefit can be as good as it is, I think we would still not do it. And finally, what I said to you about the areas of grassland, that is, the permanent grassland on the oxbow lakes. As I said, if we were to get 1,500 euros out of it, but then we would also get some kind of controls on our entire farm, we just said, it's not worth the stress for us, let's just drop it. Yes well, that is ultimately also a weighing of cost-benefit.”

“I have already mentioned that sufficient compensation already plays a certain role. It always depends on whether the measures only have to be implemented ones and then serve their purpose for many years, so to speak. Or do the measures bring additional work with themselves throughout the year cause then there must be also a certain appreciation there or a compensation, if one obtains then no proceeds from it. So clearly, money also plays a role.”

“The additional effort and that is in the nature conservation programs actually the payment not ensured.”

“That is difficult. Well, so one thing is definitely what kind of effort I have to put in to be able to comply, no matter what kind of measures. Under certain circumstances, if I have a measure where I have to do a lot, for example with the tractor, then I also have costs incurred. That is the most important point, I would say, if you say you do something or you don't. And in second place it’s again about whether the pay-out is adequate. Because if I already have so much effort, I would like to have an invoice afterwards, where I don't end up with zero again, but at least have a benefit from it.”

Three farmers noted that impacts to soil were also a consideration for their participation decision.

“So the direct promotion and of course then how it positively affects nature. So more life in the soil, more flora, fauna and all.”

“That was already the cost-benefit consideration. That is like with the extensive grassland. I simply noticed that it is not good for the soil. If you couldn't really think about what you were taking out of the soil with the cuts, it wasn't really ecologically beneficial to leach out the soil like that.”

“No, certainly the cost played a bit of a role. Then also yield security and soil fertility. Then all the soil improvement measures. Maybe a little bit of landscape design. Things like that.” No, certainly the cost played a bit of a role. Then also yield security and soil fertility. Then all the soil improvement measures. Maybe a little bit of landscape design. Things like that.

One farmer explained that landowners can have an influence on participation in programs.

“I can't wet out leased land now. I lease an arable area and I have to give it back to the landlord (...) I don't get the area extended, for whatever reason. So now I give him back a swampland landscape. I say, yes, fine, I participated in the watering programme for your meadows and he tells me, no, I gave you meadows, I want to have meadows again. Also permanent grassland and things like that. The water protection strip that falls into my permanent grassland. Am I liable to the landlord. So I can't take part in it, if I commit myself not to do anything there, then after five years I have permanent grassland. So all this paperwork

has to be kept as slim as possible, so that someone is involved at all, because that's exactly the kind of thing that always happens. I can't plant hedges or trees on leased land. Agroforestry, I think it's great, others think it's great too. Then my landlord comes along, who lives far away and asks, wasn't there a field here? No, I'm doing agroforestry now. So it's only possible in a limited period of time that you can see over time."

Interviewed farmers were also asked what were the biggest costs for them to participate in biodiversity enhancing programs. Many farmers who answered this question expressed they were concerned about the cost of seeds.

"In the beginning, first of all the seeds, especially in the flowering meadows. This is quite expensive. Then the lease or even the imaginary lease depending on whether you are the owner, but that would be exactly the cost XX that you would need to communicate."

"I'd say investments, in this case mainly seeds."

Farmers were asked to share their views on the requirements to participate in biodiversity enhancing programs and legal guidelines. A majority of respondents expressed that they felt requirements were too strict.

"I think they are too specific. So the specification alone to use only this one mixture, which there is, I find not good, because even within Brandenburg, the soils are different. I don't think it's good either, I haven't had any bad experiences yet, but there are 37 species in this mixture and they all have to grow up. That's the requirement. If they are not emerged, we don't get the funding or we can even get penalties. So that's just not realistic."

"In general, everything in Germany is regulated. Freedoms are rather non-existent. For example, I have set up a nest for the kestrels here, which is an illegal construction. Nobody knows about it except you. Freedoms do not exist in Germany. Everything is regulated here."

"And the more requirements are imposed that don't make sense, the more frustration there is, of course. And then many farm managers no longer see any prospects for the future. And when I see all this documentation, what I have there in terms of requirements and I have to meet deadlines and so on. The workload in the office is becoming much higher or has already become much higher than the work outside. And that can't be it. Something has to be done."

"I think that is sometimes defined too specifically. For example, with the flower strips in the first year it was okay, but when I wanted to plant some again in the second year, there were considerably more regulations here, where you were allowed to plant some. And then it made no sense for the areas where I wanted to plant some, because they were then somewhere in the way of my arable farming. Since you would have to give also the farmers simply more free hand to decide to want to regulate everything by themselves."

A few farmers expressed that they did not feel like laws and program requirements were too restrictive.

"There is high flexibility. But I have to say that this high flexibility also lead to flowering strips being planted anywhere that made most sense in terms of cultivation or plots, in corners that are just not that good. On one side this was very useful for farmers. For biodiversity this is neither good nor bad. Nowadays they are tailored to the surroundings (Kulisse) meaning you can only have them next to a ditch, at least in our area."

"No, in principle it's okay. It's clear beforehand what's going to happen. And then I think about whether it fits or doesn't fit. If it didn't fit for us, we wouldn't have done it. And yes, in principle you know beforehand. It's similar to our organic farm, everything that is required is implemented, which is absolutely fine, but in the end I know beforehand what I'm getting into and then I have to implement it the way it is required. And if it bothers me then I just have to let it be, it's that simple."

"No, not really, I can't say anything negative about it. Besides, it's my personal decision, or a company decision, whether I do something or not. This voluntary part and what has been required up to now, we have not had any problems with this due to our soil equipment. That hasn't affected me economically yet. For example, I don't do any catch crops at all for GMO accounting or things like that, because we don't need that, because we have enough unproductive areas that we don't cultivate them anyway. In these highly productive areas where the rents are also a bit different and so on, it probably is differently than we do here in Brandenburg in our sandboxes."

"Well, I would say so. Although you have to look at the one or two measures since we have not yet participated in much more, but I must say that if something is done, things are seen quite narrowly and the room for maneuvering is very limited."

Farmers also shared any changes they would like to see to biodiversity-based programs, funding, guidelines, and laws. Many expressed less restrictive regulations.

"Just a bit broader. So it can be a guideline or a regulation, without question, it has to be, but it can also be formulated a bit more loosely. I mean, we are doing something good. Why does it have to be so strict and have so many conditions? You can also start with that."

"Certainly many. Ultimately, it often, simply depends on the people who then control this measure and how they approach any subject. Well, of course, they also have their professional experience and people will try to fool them, so maybe that is why they will be sharp with the controls or very narrow in the interpretation. The room for inspectors to say that it's okay the way it is gets smaller, because then again a follow-up control comes, so an audit, where the controller is controlled and he is simply afraid to then get one on the lid. That's why it's seen very sharply, even if farmers try to implement it well and it could still be seen within the framework. I think more and more attention is paid to that and there are fewer and fewer who say here, that's okay, I stand by it. That's why it's getting more and more difficult."

"Yes, this specificity, nowadays decisions are almost no longer made according to what is good for the company, but only according to what is still permitted."

"What would I wish for? That I could make more decisions for myself. That would be the most important thing. And that farming will still be worthwhile in 20 years, if our daughter really wants to continue. At the moment I'm a bit doubtful whether she's doing the right thing."

"That there will be more advertisement for it and the farmer is then given even more freedom for what is done and not predetermined. Only what must happen is predetermined, but what exactly he does, is left to him so that he can tailor it to his farm."

"And that's where I see the main problem. If this continues, with more and more requirements, requirements, requirements, requirements, then this will collapse. Then there will no longer be any sense. We no longer have any entrepreneurial freedom, and that's what we need."

"It could be easier, I wish it would be easier. It gives me gray hair. Yes, it's very time-consuming to do it all. So if you do it the way you want to do it, if you want it to be right, then it's very time-consuming. We are doing it now with the arable land index. It is eLMID. The fertilizers are different ones. Can't you do it all in one program? A reasonable program where everything is in it. No, there is an extra program for each thing. Everybody does their own thing. Such things are annoying. It would be much easier if the land use planning index and everything else were in one program."

"In part, not so much bureaucratic effort. One goes thereby also partly in the control mechanisms, if one accomplishes these things. There must be added value in all directions and it should definitely not be imposed. The decision should also still lie with the land managers. Everything that you have to do what you actually don't believe in, is not purposeful."

## Biodiversity Within a Larger Supporting Community

***Neighbors, Regional Adoption, and Growing Trends***

Throughout their interviews, farmers were asked questions about their willingness to share their experiences with neighbors, commonly held views, things that should be done in the region to increase biodiversity, and the trends they believed would grow in the area. The answers to these questions provide insight to the existing environment within farmers' regions.

Several farmers stated that they shared the practices they incorporate in their farming with other farmers.

"We actually exchange information on a regular basis, mostly when we meet at some field days or arrange to meet in this way. We have a good exchange there. I also swap machines back and forth with neighboring farms so that they can try out something that I do differently or I can try out what they do differently."

"Positive throughout. Of course, we try to present this in discussions with neighboring farms or at field days and also show the advantages and disadvantages, and we are also very open-minded about what the experiences are like."

"We do that all the time. So in general and everyone is just talking about what you're doing wrong. A sorrow shared is a sorrow halved."

A few farmers expressed that although they shared practices with other farmers, it didn't lead to any positive action.

"The reaction to this is very different. It is really very different, you cannot say it general. Many older farmers shake their heads. Younger ones, they have rather an ear for it, but sometimes it is the other way around. That's hard to answer. You get every kind of reaction."

"Yes, so we do exchange ideas, but everyone does their own thing, so to speak. So a strip over the land of five farmers, we would also still manage. But well, more would probably be difficult."

"No. I have to correct myself again. So I was in exchange with a distant neighbour at the time. What species and where to get the seed, because that was another problem. There were too few seeds to coordinate things well."

Only a couple of farmers stated that they had experience coordinating with neighboring farmers.

"We are also working together. We are part of the Bayer forward farm project, which means that the people from the Ifo Institute in Mannheim are also at our side. And they really do carry out studies in which they look for different insect species and then examine them. And once a year there is also a report on how the year has gone and which species have come and gone again or whatever. And we make that available. To anyone who is interested. And then there are also regular guided tours on the farm, so groups that register here or are invited. And then we also distribute the information."

"What I know people tried here once that didn't work was Greenland completely without fertilization, so also without organic fertilization. That didn't work. Afterwards, it was no longer usable for anyone. Coordination. Well. That's going to be difficult anyway, five farmers under one that is not possible at all."

When asked whether farmers felt like neighboring farmers shared similar views to them, a variety of responses were received. Several farmers expressed that their neighbors held similar views to them.

"I think every farmer will have about the same attitude. The capital that I have is the land that I can cultivate and if that is not top quality, or if I take away the conditions under which my yield can be a top yield, then it is of course not conducive. But otherwise I would say crop rotation is the magic word. Of course, all must fit together. And if you lay out the crops in such a way, in an order the crops so they best utilize resources, so that there is no leaching of nitrates or in a way where I have to do less plant protection, then that is of

course only advantageous. That would be the positive things about it. The negative owns would mostly be that it is regulated where one needs perhaps no regulations."

"I think that they share that, and some are perhaps even frustrated because of the constantly increased requirements and specifications that are imposed on conventional agriculture."

"I think they agree with most of what I have said so far or all of it."

Several interviewed farmers also stated that they did not believe that neighboring farmers held the same views as them.

"I'd say that's hard to assess. But certainly not all of them. Because we are on a terrain here, for example with our plant construction, where it is certainly not cheap. Or with the new crop protection technology. You could say, well you buy it or not, but they have already become extremely expensive, especially if you want to work with a lot of precision."

"Different. We are a smaller family business, and on the outside, there are a few large agricultural corporations, I would say. I don't think they're concerned about it at all. Nobody's gonna start with that."

"Well, I'd say they're all a bit conservative, of course, except for the fact that we once had an ecological company inside. But they have not made a concrete measure now."

"Well, the opinions also diverge to some extent. Due to the fact that a generation change is imminent everywhere, I think the attention is now directed more and more to the ecological. Above all also on the structure of humus and soil, you notice nevertheless already now. In the last few months and two or three years, more and more attention has been paid to this, especially among younger colleagues."

"I don't know. On farms it's really like that, everyone pays a little attention to it. So especially the farmers pay attention to the swallows. No villager or no house owner lets himself build more swallow nests to the house. I have also seen this with other farmers."

Many farmers expressed that it was mixed on whether their neighbors shared similar views to them.

"Well, that's mixed, of course. It always depends on the company structure. If I am a small farm that is not broadly positioned. We still have a little leeway."

"I'd say that's hard to assess. But certainly not all of them. Because we are on a terrain here, for example with our plant construction, where it is certainly not cheap. Or with the new crop protection technology. You could say, well you buy it or not, but they have already become extremely expensive, especially if you want to work with a lot of precision."

"Yes, in principle we are of the same opinion. However, everything has to be considered on a farm-by-farm basis. Take a flowering strip for example: if you have a very small area and you are dependent on the area or you are in an area where you have a rent level of 600 euros. It is certainly a different point of view than when you say, okay, the liquid manure that now accumulates on our farm is not an issue to accommodate and to accommodate sensibly. And the other farm, which simply has different circumstances, will of course also have different attitudes. And that is also the case. We are relatively open, which is why we participate in relatively many programs or say okay, to a certain extent that's good. Other colleagues are certainly more skeptical. But this skepticism is certainly also due to the fact that our own farm requires other things. And of course, there is an exchange about it, but of course every farm has to look at it for itself: what suits me? At the end of the day, it is also the case that the office has a say in the decision."

"From the farmers with whom I have talked, many have also developed good ideas and concepts themselves. But there is the demand so low as I have already explained, with everyone can lease for themselves."

"Some do it, but most of them don't do it. So, it's always, when the legislator prescribes it, then they become active. And as long as the legislator does not prescribe it, then they continue as before. So, in the end, not very much happens on a voluntary basis, let's put it that way."

"The reaction to this is very different. It is really very different; you cannot say it general. Many older farmers shake their heads. Younger ones, they have rather an ear for it, but sometimes it is the other way around. That's hard to answer. You get every kind of reaction."

"Yes, quite different. Some of them try it out on their own land. It depends on how the farm is set up, what else is involved, whether they still have dairy cattle or pig fattening and so on."

Some farmers also expressed that their neighbors were often open to adopting biodiversity enhancing practices but sometimes faced limitations.

"There are professional colleagues who see it a little differently, but they say: 'I think it's a good idea, try it out, tell me how it works. Maybe next year I can test something on a corner of my farm, or we can exchange ideas'."

"Many are also interested and if they weren't lacking this information then they would not come at all, for sure not. That's why I basically say that Bayer's forward farm is an important point. And yes, some things are received positively, but certainly at least just as much is perceived negatively, both from the farmer's point of view and the general public."

"As I said, everyone wants to do it, but not everyone gets it implemented. For cost reasons. I would see it that way now. So, catch crops were not so common in the past. Nowadays, almost everyone grows a catch crop in addition to corn or something like that. This was not really seen in the past. Something is already changing in agriculture. In the next few years, there will be many more changes that will benefit nature, I would say. But in which way, I can't really say."

"I believe, or rather I am of the opinion, that no farmer or no business is actually close-minded about biodiversity. It's all just a question of practicability."

Farmers were also asked about what they thought could be done throughout the region to improve biodiversity. Many mixed answers were received. A couple of farmers indicated they would like increased attention given on the financial aspect of incorporating biodiversity enhancing practices on their farms.

"There has to be an incentive, because farms have to live on something. Soil is a scarce commodity, I would say. And if the biodiversity measures that we are currently implementing are not sufficient and more is to be done, it will eventually be at the expense of good soil or surface area and this must ultimately be rewarded somewhere, to put it this way, what the farms then do even more than what we are already doing."

"Generally, a massive focus on profitability. Prices for farmland are rising, rents are rising. The focus is always on profitability. I can't run a business or do anything if I'm not profitable at the end of the year. Digitization is a big issue, but digitization in the sense of increasing profitability. In my company, all areas are now measured with GPS. All lanes are measured. When I get to the field with the seed drill, I load the track. Drive right in and start seeding right away. And not where do I start? Where do I stop? And things like that. So, economy in the field."

Several farmers expressed they would look to see changes to current bureaucratic structures that promote biodiversity enhancing practices.

"And I say, that's the way it has to be. You find out that it doesn't work optimally, you adjust it, and it works. And that's the crucial thing that scientists evaluate neutrally how it is. And then the laws are adjusted, and we are on the right track. It's not about the farmer always being right. That is totally bananas. The farmer also makes mistakes, he also has to be monitored. But we must have scientifically sound information and then decisions must be made for agriculture in the interest of all."

“I see the problem that we actually have two classes in Germany. The western part of Germany has a more small-scale structure, and there is also more biodiversity. But when I look at areas in the new federal states in the east, for example, there are areas that are as large as 200 hectares in one. Not a shrub, not a bush, nothing. Basically, these plots would have to be reduced in size again. And above all, one has always seen only this economic consideration, also from the business management, agricultural business management offices, which actually only look at the economy, but then at some points do not see the long-term consequences. This is the case, for example, with these field foxtail resistances that are now being recorded everywhere up and down the country in such farms. Yes, it was actually foreseeable that this would happen at some point, because they only focused on cheap crop protection products and said, "Guys, you can save on tillage, for example, just use glyphosate and that's the end of it.” But that was not thinking far enough.”

“NABU, BUND and all the others like them, when something comes up, they first have to object and then we have to come up with some expert opinions or some crap like that, it all takes way too long and it's all unproductive. So here in the area, the nature conservation associations don't play a good role. They play... how should I put it? They don't see the whole; they just see their self. And that's what annoys me immensely, because they have too much power. They have to give their opinion everywhere and so on. Unimaginable.”

“What many have to struggle with, if they still have animals, dairy cattle for example or pig fattening, is the feed supply and then also the manure that accumulates, it becomes too much somehow, with the fertilizer regulations that are becoming even stricter. Well. Somewhere they have to accommodate their organic fertilizer.”

“That's another thing. I apply for this measure in December and commit myself to doing it for five years. And then I don't get any seed in the spring. So, I took care of it here in Templin. I have now found a supplier who will do it for me, and I write him an email in the next few days and say, please provide seeds this year for a certain amount of hectares. So that has to be more flexible, less bureaucratic, more reliable in terms of planning.”

Other strategies for strengthening regional adoption of biodiversity enhancing practices that were mentioned by interviewed farmers include increased support for intercropping, flower strips, and bees.

“So, I had noted of it already briefly. So, these wildflower strips must fit to the region and I always have the feeling that these standard mixtures are not so good. I also have a few smaller areas, where today I can't even get there with a large combine harvester due to poor access roads. For a few years now, I've had them completely drilled in as a flowering area, so that's a 0.9 or 0.8 hectare plot or something like that. And when I see what's happening there on these areas, with the flowering mixtures, I have to say that's completely unsatisfactory. Nothing really fits.”

“So, intercropping and flower strips, but my colleagues only do that when it's less complicated, and uncomplicated means that I'm currently traipsing across the field with a tape measure in December and measuring the flower strips that I'll sow the following year in April, because I have to do that with the KULAP application in December.”

“A lot can still be done there. With flowering strips, I am almost the only one in the region who does that. Then the intercropping has become more, but it is not yet the mass and not the rule. Then agroforestry, but that may not be for everyone either.”

“Yes, intercropping. I now see large areas of corn that lie black over autumn. But I also understand every farmer who does not do that, because the plants might not freeze off in the winter.”

“Well, it's difficult to say, but I think there are very simple measures, such as a bee bank, which we have learned in recent years. In very simple terms, this is a pile of soil that is poured onto the edge of the field and built up. And it already does a lot to give wild bees a home there, I'll just say that now. It's not a big cost factor. It is actually said that everywhere on a farm a little bit of soil falls, so that's what you can do yourself without having a lot of effort and then already does a lot for the insects. So, such measures, about which you can inform yourself and implement it easily. But I would never say that everyone is able to create

a flowering strip, for example, because the reasons I mentioned earlier, the costs, the funding programs, are not yet available here so extensively. So, it's understandable that not everyone can do it, I would say."

"There are many offices. In the end, we are talking about the whole of Bavaria, which are of course also implementing, for example, these flowering areas. We have some ourselves where insects and bees and whatever can help themselves. That is already so. In my opinion, the task is actually in the hands of the administrative institutions, which are also responsible for it, because I believe that no one else can or wants to implement measures if there is no corresponding compensation."

Farmers were also asked what regional trends they believe will occur in the next 5 to 20 years that they will have to adapt to. Responses received for this question were also mixed. A few farmers believe organic farming will become bigger.

"I do see trends in the next few years, let's see if it works then, that's a completely different question, in organic farming."

"That's a very difficult question. It simply doesn't matter; in the end, a lot depends on some kind of economic viability. The trend will clearly be towards organic farming, towards animal husbandry that is more appropriate to the species."

"This trend, which is probably also going in the direction of using even less fertilizer and even less crop protection. We will not be able to avoid this. That will be the basic trend. In principle, organic and conventional agriculture are becoming more and more similar. That's probably how it will be. The trend will probably be unstoppable."

"And otherwise, I think with the synthetic pesticides, that will definitely be cut further, I can imagine. For some farms not unjustly, but the farms, also with me in the neighborhood, which really already reduce the spray effort with effort, not only because that is wanted by the legislator, but simply also because it is a big cost factor. They put obstacles in the path and not only those, who spray sweeping. But how you can work that out in a differentiated way is always such a thing."

Some farmers voiced that they believed that current markets would endure changes or that there is a need for them to be changed.

"In the region, I see a trend toward ever larger companies and ever larger investors. So, in principle, I see nothing good at the moment. So, what's going on here at the moment, because the soil here is relatively good. So, it is getting more and more expensive. Arable land prices, prices per hectare of 30,000 euros. Large investors, XX and what they are all called. It's getting more difficult. That is the trend that I see. I would like to see a different trend."

"The big trend is to more and more regionality. I don't think that's bad in itself, but then there should also be a slaughterhouse or a dairy in every smaller town, like it was the case 20 years ago, and also processing companies, so that I can leave the regional product here. Long ways like the one from Bavarian butter or so one would not be need. One could also take the local butter."

"The working goal is to increase the percentage of organic farms substantially. The marketing is unfortunately, let's say it casually; modest, because if too much of it is on the market and, for example, an organic dairy farm has problems to sell their products as organic. How should that work then? If there is too much organic product, you simply have the problem that the price drops."

"And what's in the marketing area? Availabilities or similar (...) For the selling, the prices will go first a little bit upward. Fortunately, the sales prices have also increased again. Before, it was always the other way around. In the last few years, everything has slowly become more expensive in terms of purchases. But the raw materials, the harvested goods have not yet followed, but they are now following. I think the prices will fluctuate depending on what's available. Which major region just has good harvests or if that has just failed in any regions, will then always have an even stronger impact here, I think. I'm pretty sure of that. These are the things that we have to be prepared for."

Other farmers believed changes would be seen in regulations.

"That's hard to say. I don't think we can really plan ahead. At the moment, we are also waiting for the new federal government to come up with guidelines. It's difficult to say. Overall, it would be nice if, how shall I put it, if everything was not formulated quite so sharply. So, I don't know that agriculture or that the farmers have practically learned what they are doing out there, that a little trust is brought towards them, that would be quite nice. I mean, there should be regulations and guidelines. There are always black sheep, which is probably the case in every industry, but sometimes you just want a little more trust. For example, the fertilizer regulations are pretty strict. We are now seeing the first effects in our company. It would be nice if it were formulated a bit more loosely or loosely again so that there is more room for maneuver."

"Further monitoring I'd say. From 23, we are somehow flown over once a week and then it is recorded what we actually do or do not do on the field or how it looks or does not look."

"The pressure is going a little bit towards, how do you say, transparent agriculture, to put it very cautiously, as a rough point, there is more and more observation, what are you doing, what is happening here. Who could know whether in 10 years there are only organic farms, I do not know, that would now perhaps be too daring to say. Yes, the pressure is there in any case, I would say or write, you can feel it a bit. (...) By pressure I mean that you think you have to move in a certain direction in order to meet the requirements."

"That will clearly be the weather conditions. The weather will fluctuate, if it's dry, it will be drier, and if it rains, it will rain more than usual. That will happen and it won't go away. We're going to have to adjust to that. My brother is sitting next to me right now and he says either no frost or real frost when winter comes."

A couple of farmers noted that adaptions would need to occur to respond to climate change.

"Definitely. We are still in the process of expanding diversified cultivation, so for one or two years now also step by step in sowing. Perhaps we will also adapt the crop rotations a bit more, provided that climate adaptation makes it possible for us to continue working on this. Perhaps we can also move back to more small-scale structures or something."

"I simply call that climate change. Here in the east, we have always been super extreme in everything anyway, and we have to get ahead somehow. But that is difficult, because we have hardly any alternatives, both soil-wise, soil fertility-wise and regionally climate-wise. So that's what worries me a little bit. We have always had the extremes here in the east, whether it is climate change or not, that will be proven in the next 50 years. Because here in the East, we have always had extremes."

When asked about existing obstacles that would prevent farmers from adopting regional trends, several responded saying legislation would be a barrier for them.

"These are the political framework conditions, I would add. So, if now everything and for every little thing there is a regulation and again an innovation and everything is pulled tighter, then we have at some point no more agriculture. Saying it a bit exaggerated."

"Yes, the legislation that always wants to have even more than it already is."

"Mainly through policy, legislation, that doesn't work."

## Ideal Farming

***Aspirations and Success Determinants***

Farmers expressed ideas on the ideal state of their farms. This was done through questions asked about the practices they would implement if costs did not play a factor. Farmers also provided factors and measurements of success.

The most common response received when interviewees were asked what biodiversity enhancing practices would they implement if cost wasn't an issue, was an increased presence of flower strips.

"Something we are working on, which I like, is that we're now trying to cultivate crops in the flower strips that promote beneficial insects within these flower strips. And that has a positive effect on my fields. That's because we currently have a huge problem with a dramatic decline in insecticides we are allowed to use, especially in sugar beet cultivation. The decline is so severe that we are close to the end."

"We are already doing some of this. For us, this topic of networking flowering strip structures is quite interesting. We would then probably expand this further."

"Also, flowering strips. They're much more around the fields and I would say that they definitely help, so there is definitely more going on, but it would also make more sense to have them appear more often in the field and then connect everything together."

"So massive expansion of flower strips. I easily get up to eight or ten percent of my farmland. From a business point of view, I would work every field in full width as a fillet piece and around it I would make flower strips, where I have corners, wedges and edges and distance requirements to water bodies with fertilization and plant protection. I would immediately sow 10 to 12 meters of flower strips everywhere. But I'm not allowed to."

"I would make more flower strips. Very simple."

A few farmers also expressed that they would like to implement new methods for plant protection or use less plant protection.

"Plant protection technology immediately comes to mind. With new crop protection technology such as a new sprayer where you can almost exclude an overlap, because it automatically switches on and off, then I also get a more accurate application. Or if the money would not play a role at all you could even think about a so-called Phytobac plant."

"If possible, do even less with plant protection. In principle, you also have to earn money with it, so if you only do what's good for nature, you hardly earn any money at all. And that is the dichotomy somewhere. I would also spread less fertilizer. But then I also harvest less and earn nothing."

"If cost were not an issue? Yes, mechanical weed control for sure. Maybe a little more reduced tillage. I wouldn't say no-till right now."

Some farmers noted that they would like to increase diversity of their crops if they had the ability to.

"If the costs are not so relevant, I can also say here, you divide the fields more. It is then less effective, but if you then have a greater diversity on the field, you could of course do that."

"Yes, as I said legumes would be good for the soil in any case. You would certainly do that even more if you could live from it. Intercrops certainly even more. I say times all-season ground cover is also always desirable."

"Maybe try a little more systems, different crop rotations depending on how they fit in."

At the end of the interviews, respondents were told to imagine that their farms were twice as successful in five or ten years. They were then asked how they would define this success. The most commonly received response was improved financial situations. This was referenced by 11 farmers.

"Also, financially. In most cases, it's what's left in the wallet that counts."

"Yes, you can measure it well in profit, no question. And how successful the company is depends to a large extent on the people who work there. So that's how I would see it. At the end of the day, there are always

some areas where you can earn money and where you can invest money. And at the end of the day, it's simply the skill of the people who do it to find the best possible way."

"Financially, of course, you can always measure success by that."

"I just saw a tax bill yesterday. I have to pay twice as much tax, that's twice as successful."

"How do I measure success? I first measure success by the economic situation that prevails."

Several farmers indicated they would define success as being able to focus on direct marketing or if market conditions were improved.

"The main factors, if you are twice as successful, is that you have managed to specialize in certain things and that you are very good at it and then also market them well or go in the direction of direct marketing. And always financially, I also admit that quite clearly."

"So twice as successful I could be if I found or set up massively different marketing channels. I'd start marketing my peas now (...) birdseed or I'd start marketing my peas now direct and build myself something great with that. Or I would start with oats now and I would make oatmeal now and sell oatmeal. Yeah, I could do that. Then I can make the financial return (...) To do something like that (...) Massive personnel input, personal and personnel input, direct marketing of special crops would be a possibility."

"We have attempts to get into direct marketing. But it is going very slowly. So, these are things that would be great in the next few years. Maybe."

"The agricultural products would actually cost money again. That is, goods would become expensive. Whether that is wanted or not."

"That the general conditions have improved, the market situation has improved."

Several farmers also stated that success would be achieving happiness and improving personal well-being, including for employees and families in some cases.

"On the other hand, I would also say that it is positive if you then say that you enjoy it. For example, we currently have more rabbits and that makes me happy, but it's hard to measure."

"I can say it like this, success in agriculture is satisfaction with what you do. And being satisfied that everything is going so that everyone is content. I can tell you, if the health of my loved ones around me is maintained, I'll give up a lot of money because it can't outweigh that. Yes, so that's the be-all and end-all for me. If the circle of people I have taken into my heart, if they are all doing well, their health is good and no misfortune or strokes of fate happen, no matter how, from that moment on I am successful, then I am a happy person. If there is something that is missing, if something unforeseen happens, no matter what they are, then although I sometimes can't do anything about it, then it is a twist of fate, then I may not be satisfied anymore. But I say quite simply, family happiness and friendship happiness is all you need. I don't need euros for that."

"Yes, success is of course economic success and that my men or employees are doing well. That we can pay them more than those in the surrounding area. I would measure it primarily by that. So, the economic success I would define through that."

"Twice as successful. Yes, certainly financially is a big criterion, employee satisfaction is a big criterion, if yields improve again would also be a big criterion, milk yield increases or animal health and things like that, if all these things improve, then the whole farm is better. It doesn't always have to do with money. It's a combination of everything."

Two farmers expressed that being able to maintain their farms for future generations was a factor of success and well-being.

“In the long term, it's more about the things that you do yourself and how the next generations will make a living.”
“I now have a daughter, whether she continues or whether there is someone else (...) In any case, you want to pass it on and therefore the interest is definitely that everything remains and can be continued. Yes, exactly.”

“The farm is now being managed in sideline by the second generation. I was the first generation in sideline farming, my father was a full-time farmer. I went into sideline farming and my son is in sideline farming, who has an exposed job in free enterprise and can actually farm with young children because I'm still in good health, thank God. But in ten years I'll be 75, then I don't know if the farm cannot expand, or in 15 years, when the grandson is almost 20. We will see if he will be interested in taking time in his spare time to continue the farm of his ancestors. For us, for me in particular and also for my son, this is still connected with a lot of idealism from the past. And interests, but if I would fail now as labor force. I would not know how long my son takes that on himself with his earnings situation besides his job if he still wants to cope that in his spare time. Or whether he says, my idealism has limits and for a few thousand euros, which remain in the year or not, I can also lease it to someone else.”

A couple of farmers indicated that they would consider success on their farm as improved efficiency of resources.

“We see this in the comparison of effort and return. And we think about what effort we are putting in and what effort is necessary to achieve an optimization of earnings in the end. Do I use a lot of energy, or is it in terms of labor, handling costs or operating resources, or do I optimize it to the necessary extent and then, at the end of the day, I have not used any unnecessary operating resources, including pesticides.”

“Everything that is needed is used. Not more and not less.”

“For the future it remains to be seen how the effort is regarding to the yield.”

“You could only be twice as successful if you either achieved twice the price with your products or only paid half the price for diesel or if everything only worked with very low-cost robots.”

“Oh! Twice as successful. How would one imagine that? Well, that's the thing, where do you put the success. If you say the company is twice as big, but then the question is, do I also have twice as much profit? Or have I increased the size of the company only a little bit? Or does everything remain as it is? I have the same profit. I have the same business. I also have only half the work.”

## Appendix: Survey method questionnaire

1. How were respondents identified? What criteria for identifying and selecting/screening respondents were used, if any?
    - Farmers from Brandenburg and personal contacts in other parts of Germany
    - Farmer contacts provided by Bayer AG
    - Main criteria: Arable farmers
    - Through ZALF networks
    - Through the local farmers associations
    - Through the online list of apprenticing farms

2. What were the steps for inviting farmers? (e.g., who, and through what channel, reached out to farmers)
    - Write and call farmers associations who included our invitation in their newsletter, this led to very limited responses
    - Contact ZALF departments that have direct contact to farmers for their contact information
    - Presentation at ZALF event to personally invite and introduce farmers to our research
    - Call farmers from the various contact lists obtained to see if they are interested in participating

3. Were any forms of incentives (both monetary and non-monetary; both positive and negative) used to encourage farmers to accept the invitation? (e.g., financial or in-kind compensation, prospect of advisory support or other services, opportunities to ask experts questions, peer pressure, network inclusion/exclusion, the chance of learning about survey results later, etc.)
    - No monetary incentives
    - Option to be invited at a later stage to participate in workshops was communicated so they could give feedback on our results
    - We told them we have the goal to communicate our finding to the public
    - Opportunity to speak their mind freely and get their opinions/frustrations shared with a broader audience

4. How many did you invite? How many declined?
    - Over 200 farmers were contacted, called using numbers from the apprenticing farms list available online
    - 35 farmers contacted through the ZALF networks
    - Out of those from the ZALF network 18 were either not reachable, did not respond, or declined our invitation

5. Are there any common characteristics of farmers who declined?
    - Not over all farmers
    - Organic farmers usually declined to cooperate with Bayer

6. How were the interviews conducted? For example, face to face interview or phone/zoom; one-on-one or as a group, etc.

- Over the phone
- One Zoom-Interview

**7.** How long did an average interview take?
- 60 min (45min –120 min)

**8.** How was the data recorded?
- Voice recording of the phone call/interview
- Followed by a transcription of the interview
- And a translation of the interviews to English

**9.** Profile of people who conducted the interviews (e.g., training/background, academic or extension or private consultant, etc)
- Academics, two PhD students
- No specific training

**10.** Did the same people who conducted interviews do the translation?
- Partly
- One master student- assistant helped with the translations who also worked on the transcriptions

**11.** Any issues or challenges or surprises worth highlighting? How did you attempt to resolve the problems? Did it work?
- we need to postpone a bit the survey because of the farming activities
- A big challenge related the equipment because of pandemic situation and the obligation of home-office: it was not possible to have a software to call farmers using softphones and no recording equipment. So, personal mobile phones and recording equipment were used

# Supplementary Information Item for WP1: Interview Finding Summaries, Part 2 – United States Interviews | Response Analysis Summary

Supporting: Enhancing Biodiversity and Resilience in Intensive Farming Systems

## Farmers' Perceptions and Attitudes

***Biodiversity Understanding and Knowledge***

To gauge farmers understanding of biodiversity enhancing practices, interviewees were asked to define it and share their perceived associated advantages and costs.

Overall, interviewees demonstrated an understanding of biodiversity. Several defined biodiversity as various forms of life existing together in an area.

"Biodiversity to me means all walks of life. Coexisting together on earth."

"All that is living within an area or environment."

"Historically, farms were diverse: animals and crop so you had oats, wheat, hay, etc. Things were more diverse. Now focused on soybeans and corn. Lack of diversity."

"Biodiversity is all the different kinds of life you'll find in one area- the variety of animals, plants, fungi, and even microorganisms like bacteria that make up our natural world. Each of these species and organisms work together in ecosystems, like an intricate web, to maintain balance and support."

Some interviewees explained biodiversity as effective and a means for achieving desirable outcomes.

"Biodiversity is use of the best practices on your farm in a way that balances out ecological, and economic benefits. This means using the tillage system, proper fertilization and application for each field in order to limit erosion and other ecological damage while enhancing soil and providing economic benefit."

"Biodiversity has allowed us to become better stewards of the land. We feel that we are improving not only soil health, but also improving water quality by reducing the amount of runoff, both soil and nutrients, that have the potential to leach and wash away."

"Biodiversity means improving soil, health and productivity through better conservation practices implemented on our farms."

The use of cover crops was the most discussed biodiversity enhancing practice amongst farmers; all respondents brought it up while speaking with the interviewer. No-till was also heavily mentioned by farmers, with 87.5% of respondents mentioning it in their interview. It is important to recognize that this does not mean these are the most favored biodiversity practices, but only the ones spoken of most. These results may provide insight on farmers awareness of biodiversity enhancing practices or levels of attention; however, further research must be conducted to determine reasoning for why some practices are referenced more than others.

"We have reduced tillage and tried to apply only the crop fertilizer and crop protection products need when needed. Plated cover crops in the time between when crops are produced to sale."

"Every acre would have a cover and there would be more experimenting with different cover crop species."

"I see cover crops and no-till practices on every acre. Improving both soil structure and life in general."

"A few options to enhance biodiversity on our farm include cover crops, no till, tile, and also use of non-GMO and untreated hybrids."

When asked about the potential benefits of biodiversity enhancing practices, improved soil health was the most frequently received responses. 9 interviewees referenced soil health as a positive outcome of biodiversity.

"Positive aspects of biodiversity: soil health is improved, and symbols of living organisms can be present."

"They improve soil structure, infiltration rates, lower weed pressure resulting in lower herbicide inputs."

Respondents also expressed the ability of biodiversity enhancing practices to reduce soil erosion.

"The benefits include less soil erosion, wildlife habitat, and cleaner water."

"This means using the tillage system, proper fertilization and application for each field in order to limit erosion and other ecological damage while enhancing soil and providing economic benefit."

Interviewees popularly noted that biodiversity enhancing practices were beneficial to water entry and sources. 8 respondents commented on outcomes resulting in improved water quality, protection, and infiltration.

"Use of buffer strips to protect rivers and streams."

"No-till and cover crops enhance water infiltration."

"The conservation practices by farmers within the watershed would help to reduce the siltation levels, the resulting phosphorus concentration in the lake and of course provide recreation, water, sports, bird, watching and fishing, on the lake to continue. This would reduce the finger pointing at the farmers as the sole entity responsible for degradation of the lake itself.

"Better soil health, less erosion, which could ultimately lead to better water."

A few farmers also acknowledged the economic benefits gained through biodiversity enhancing practices which are evident in decreased costs, increased profits, and reductions in labor and equipment. This contradicts many responses received about disadvantages of biodiversity practices.

"In 1981, we purchased our first no-till planter. Planting no-till soybeans was easy, without yield loss and more effective financially."

"Reduced erosion, improving water quality, leaving the farm, Reduced equipment and input cost, and reduced labor."

"Everything comes back to the farmer – circular economy will increase efficiency. This is what diversity did – kept the economy circular and supported the community."

Other less frequently noted benefits of biodiversity include increased crop resilience, nutrient stability, and weed management.

"Use of covers has provided better resilience for these farmers in this period of more rainfall and intensity of rainfall of the past 5 years."

"Healthier plants that are better able to cope with the changing environmental and cultural conditions that seem to change from year to year.

"Using cover crops to reduce soil erosion and hold nutrients in the soil."

"They improve soil structure, infiltration rates, lower weed pressure resulting in lower herbicide inputs."

Despite the wide recognition of the benefits of biodiversity, all farmers discussed how costs negatively impact the adoption or expansion of biodiversity practices. Many respondents expressed the costs outweighed the advantages gained.

"If we adopt a new biodiverse conservation practice and it fails (no matter the reason), it can have a significant impact for us financially for time invested, unanticipated rescue treatment costs, and sowing the seed of discontent in our minds to try this practice again, or to try other biodiverse conservation practices."

"There are many farmers in our area that use cover crops to enhance biodiversity. On the same hand, there are many farmers that have also tried to implement cover crops into their operation and have stopped doing so due to increased costs and lower yields."

"The cost doesn't pay for the benefits in some places and always in the near term."

Several respondents stated they desired certainty on the outcomes of implementing biodiversity practices. Farmers want to know that the costs of such practices are worthwhile.

"It's all about our bottom line. We need to know that adding more biodiversity to our operation will not cause a drastic reduction in our financial bottom line. If we adopt a new biodiverse conservation practice and it fails (no matter the reason), it can have a significant impact for us financially for time invested, unanticipated rescue treatment costs, and sowing the seed of discontent in our minds to try this practice again, or to try other biodiverse conservation practices."

"Cover crop can be solution- but it's not economical without viewing the long-term benefits that might or might not manifest as a result of cover crop (soil structure, reduced erosion, etc.)."

One respondent continuously emphasized the need for data on the beneficial results of biodiversity enhancing practices to be publicized and called for increased supporting research to be conducted.

"Viewed as an expense and not an investment. Need to get past that through the public research to show how these things work. Need the public research to show the benefits to the farmers and the public."

"If anything, would have adopted these things earlier. Cover crops only in 2010, should have started earlier. Again, more public research and data needed."

Many farmers discussed how limited resources influenced their use of biodiversity enhancing practices. Farmers explained how these practices required increased labor and necessitated additional costly equipment which they did not already own. 6 respondents noted this issue.

"Management is big cost – need whole other set of equipment. This is the big cost. Already short of labor at harvest time when cover crop is planted so timing is tight. Could hire out the work, but even then, you don't know if it will work or happen."

"Equipment cost right now is too much for individual farmers. Work within the neighborhood."

"Labor, inputs and management at the time you need it. If you can't afford the machinery, you have to hire someone, and they are booked up with the big farmers in the area. This limits access to smaller farmers."

The risks resulting from biodiversity enhancing practices related to weather was also frequently cited by farmers. The uncertainty of future weather conditions creates a limitation in farmers' confidence in practices. Weather concerns were brought up by 9 farmers.

"The costs are seating in termination. Risks are weather related if seating and termination aren't done at the right time, resulting in cash crop getting planted in less-than-ideal conditions."

"Only when weather would prohibit the on-ground planting of covers."

"The risks are reliance on weather at application time to be able to timely preform the practice."

"There is a lot of risk in this especially when factoring in the increasing variability in weather."

Other risks of biodiversity practices, such as decreased crop yields and increased pests and weeds, were discussed by a couple of farmers but overall were minimally mentioned. *Note: The interviewer believes that interviewed farmers were more inclined to practice conservation, however, other famers in general who prioritize conservation practices less may view these risks at a higher level of concern.*

"Some risks include lower yield, more pressure from weed and insects, and also less profit potential due to not being able to correct problems once they arise."

"Some risks include lower yield, more pressure from weed and insects, and also less profit potential due to not being able to correct problems once they arise."

One fourth of interviewees also discussed landowners' relation to the use of biodiversity enhancing practices on farms and express the need to provide them with incentives.

"Neither of these two types of managers is willing to adopt new practices for fear of reducing the income to their tenants/landowners or themselves."

"Landowners were used to seeing clean, black, barren fields after harvest and didn't seem concerned about soil and wind erosion, let alone building soil health. They were reluctant to pay more for herbicides, knowing that the tenant farmer was not investing in mechanical tillage of their land. In some cases yet today, landowners will not share in the expense of fertilizer and herbicide application if the fields are no-tilled."

"Need incentives for landlords. Most want to be conservationists, but only after income. Everything geared towards farmers; more needed to be geared towards landlords – especially as the amount of land rented is increasing."

"Some challenges include the need for better understanding and support for these practices from landowners and general public."

However, one interview demonstrated how achieving landowner support for biodiversity enhancing practices is possible in some cases if risk concerns are mitigated and aesthetics are evident.

"Had a land-owner that started to adopt the practices that this farmer put in his own land. Would have never thought this landowner would pay for those on their land, but they did. Started with pollinator strips and riparian buffers. If you can show it doesn't impact yield, they are more open to it because the aesthetics are obvious."

When interviewees were asked about what they thought should be done across the region to achieve support for biodiversity, 6 expressed a need to educate farmers about biodiversity. Several noted that informing farmers of the benefits specifically would be helpful.

"Educating our farmers and producers about the benefits of enhanced biodiversity practices."

"What do you think should be done across the whole region to support biodiversity? Cover crops. But it's not going to happen without support. Every year it's not going to be a financial possibility. It's tough to start – need to get in front of public about benefits so public supports this with dollars."

5 interviewees also responded stating that paying farmers or covering necessary costs could increase biodiversity support.

"To encourage the use of biodiversity, there may be a requirement set forth by the government in order to receive government support/payment."

"Also, grants to help with the cost of buffer strips, waterway improvement, and cover crops are always popular."

## Farmers' Experience

***Experience with Biodiversity Enhancing and Conservation Practices***

Interviewees were also asked about which biodiversity practices they previously or currently use and related motivations, outcomes, and interactions with neighbors. The questions that were asked on this topic provide insight on whether farmers have a positive or negative perception of biodiversity practices and factors that influence their willingness to adopt.

Cover crops was the most stated biodiversity enhancing practice that farmers said they had experience with. 87.5% of interviewees referenced their experience with cover crops during the interview.

"We have reduced tillage and tried to apply only the crop fertilizer and crop protection products need when needed. Plated cover crops in the time between when crops are produced to sale."

Experience with no-till was also popular and 75% of farmers referenced their experience with this practice.

"Yes. I use reduced tillage or no till on fields that are higher risk of erosion, use VRT fertilization and bi-annual soil testing to apply the appropriate amount of fertilizer where it is needed."

"We have switched some of our acres to non-GMO seed, and also tried no-till practices on some acres as well."

Practicing crop rotation was also frequently noted during interviews. 68.75% stated their experience with using crop rotation on their farm. We note that the rotation practice here refers mostly to just corn-soybean rotation (the standard) with a cover crop.

*"During the past 10 years, my crop diversity has moved from corn and soybeans to include cover crops of cereal rye prior to soybean production, and spring oats and radish prior to corn production to a barley, radish and rape prior to corn with cereal rye continuing to be prior to soybeans."*

Additionally, 50% of farmers referenced their used buffer strips during their interview.

"Use buffer strips around rivers and streams."

Farmers were also asked about their motivation for adopting biodiversity enhancing practices and many answers focused on soil benefits. Reducing soil erosion was noted by 9 farmers and a desire to improve soil health was expressed by 4 farmers.

"We have switched some of our acres to non-GMO seed, and also tried no-till practices on some acres as well. Our main motivation for doing so was cheaper seed costs and less soil erosion."

"I was losing my soil, that was the motivation – reduced erosion."

"The use of cover crops first were used as a soil health improvement factor, not necessarily for erosion control because my farm is fairly level with 0-2% slope."

"I value the importance of soil health."

Another commonly expressed motivation for adopting biodiversity enhancing practices were financial factors that resulted in beneficial outcomes. Answers on this topic included references to reduced costs and government assistance with associated costs for implementing practices.

"Two very wet fields (95 acres total), some compaction and weed pressure. Financial assistance was available for crop insurance premiums ($5/acre discount) from IL Dept of Ag."

"Cover crops – main motivation initially was the financial cost share incentive."

"Soil savings and labors savings – so it was economics. Eliminated a lot of equipment (no-till reduces equipment need)."

"First was profits and labor savings, second was water quality third was pollinators and last is soil biology."

Interviewees were then asked about performance indicators that influenced their decision to adopt or dis-adopt the biodiversity practices they have used on their farm. Many expressed they were influenced by return on investments. Several noted the costs of practices influenced their decision. A couple of interviewees noted crop yield explicitly, which is assumed to directly link to costs and profit.

"Most decision-making revolves around cost and profit."

"It's all about profit and I was able to make it work by using space. Don't do this everywhere on the farm, but their places where it is profitable. Finding those is the key."

"Has to be profitable. In the long run, it is on our operation."

"Money. When prices are low, this farmer plants fewer acres of his farm to cover crops. Some acres always have them, but less sensitive don't get them."

"Side-by-side trials when first starting. Keeping track of input costs. Easy to see the resilience to big rains, especially as they have become more common."

"Every improvement has helped. Crop yields are the number one priority for any project. Conservation practices and costs are short-term and long-term investments. Return on investment is always a priority with me because our land has been purchased over the last 50 years. We survived various cycles of interest rates and commodity prices."

"I have been happy with my practices. Practices are judge on their effectiveness and whether or not they are yield limiting."

Several interviewees also brought up soil benefits again when asked about performance indicators' impact on their decision to use or not use biodiversity enhancing practices.

"Was able to reduce the amount of soil loss in vulnerable areas during late fall winter and early spring months when cash crop isn't growing."

"However, we feel that our yields in the end are competitive with those farmers doing conventional tillage, and the amount of soil loss has been reduced dramatically."

"One indication of the soil health is the reduction of compacted layers in the field so that more rain is captured by the soil and less runs off."

Farmers also varied on their responses about their willingness to share their experiences with biodiversity enhancing practices with neighbors. Most expressed some extent of willingness to share.

"We would like to do more trials with each practice before sharing the information with the surrounding farmers."

"Yes. When I have shared this information, I have received mostly positive reactions and interest."

"Yes, helps other farmers with implementation. Some farmers are scared to share information, but it's important to share and this does help implementation. A lot of help setting equipment, but again some farmers hesitant to do this (competition)."

"I share my farm data which is rare among farmers. Everyone seems very positive to my presentations."

"Absolutely. No farmer tries something without seeing it work and visiting with other farmers about how it works."

A couple of farmers expressed that they are willing to share but other farmers are not receptive.

"We often get questions regarding practices that we have implemented. It's something others will try for a season, get frustrated because of not understanding the different management style and go back to what they were comfortable with."

"Shared but have seen little movement to adopt the practices. Some have tried reducing the tillage but expect that miracles will happen and soon get tired of the process before they have really given it enough time of looked critically why things are the way they are."

## Policies and Programs

***Experience and Knowledge of Government Regulations and Programs Promoting Conservation Practices***

Interviewed farmers were also asked questions about their understanding, views, and experience with government regulations or programs that supported conservation practices. These questions were specifically focused on policies and programs that are designed to create or restore habitats, improve soil health, and nature conservation. Answers to these questions shine light on factors that encourage farmers to participate in environmentally friendly practices through government policies and programs. Additionally, asking questions on this subject allows us to better understand whether experiences with policies and programs based on promoting conservation practices went well or demonstrate areas for improvement.

15 out of 16 farmers stated that they were currently participating or had previously participated in government policies or programs designed to support conservation practices.

"Yes, I have used state and federal cost-share programs. Experience is OK."

"State and federal. Currently enrolled in a crop insurance discount for planting cover crops, but that's it. Otherwise, I am doing this on my own."

1 farmer noted that they were prohibited from enrolling in certain programs due to existing conflicts of interests. This farmer shared their efforts to spread awareness of programs to neighboring farms and their willingness to share practices that they have had success with. A different farmer indicated that they were frustrated they were locked out of certain programs, including Bayer C, because they had been doing it for a long time. However, this farmer indicated there were some other programs that they were still participating it. Only 1 farmer indicated they had no experience with policies and programs.

When interviewees were asked about how they accessed information on policies and programs, 3 farmers noted from the USDA Farm Service Agencies, 3 responded with the NRCS Office, and 2 referenced the Soil and Water Conservation District.

"How did you access information? What kind of training you received? Who helped convincing you to adopt? Most information is usually obtained from local Soil and Water Conservation Districts or Farm Service Agencies."

"We accessed all our information from the FSA."

"The information and motivation to begin came from my local NRCS. There was little explanation except seed rate and mix to use."

Of those who indicated the programs that they participated in, 7 name CRP, 3 referenced Conservation Reserve Enhancement Program (CREP), and 2 said CSP. 3 farmers also indicated they were part of a cost share program and 2 said they participated in an insurance discount program.

Some farmers who participated in programs expressed their experience was positive. A couple of farmers noted that although parts of their experience was positive, inefficiencies were also present.

"We are currently enrolled into CRP programs and consider to be serving the correct purpose."

"I have farms enrolled I CRP, CREP, and Farm programs. I believe these are valuable programs to provide habitat, soil stability, and cleaner water."

"I feel these targeted programs provide better results by focusing and applying your resources at one goal."

"Some have been helpful i.e., allowing waterways and filter strips to be enrolled in CRP program. Many times, the programs serve as a means to an end (money) not correcting the problems when the money flow ends the practices do to."

"CREP was a good decision for this acreage. This land was highly productive, but due to flooding issues primarily caused by opening of the Lake Decatur during peak capacity most years, a full crop was seldom harvested."

43.75% of interviewees expressed economic factors were one of the most important reasons for them to adopt policies and programs. These factors included financial benefits and costs of practices. This was the most commonly visible theme in answers to this question.

"It would have to be something that we could manage in our operation and have some sort of financial benefit to our cash crop or long-term benefit to our land."

"I would have to consider payments, yield stability, and personal costs before adopting."

"If we could better predict the years and places where conservation would pay, farmers would do it."

Farmers were also asked about the most important benefits and costs to them while adopting policies and programs. Again, financial influences were the most popular response. 5 farmers answered that some type of financial benefit was most important to them and 4 farmers noted costs held the highest importance.

"In the end it was the totality of it all. Profits, environmental, social, aesthetical."

"It's all financial – is the payment worth the time for the paperwork, etc."

"These programs generally take more fragile ground out of intensive cropping and put it into a crop which enhances habitat, soil and water, while still providing some income."

"Dollars to offset the cost."

"They have to help me significantly lower the cost of the practice."

One farmer ranked additional adoption factors that were important to them weighed against the benefit of profit.

"Improve farm profitability first, environmental outcomes second, aesthetical improvement third."

However, this farmer also noted that it was a combination of all these factors that produced a benefit that was important to him while considering whether to adopt available policies and programs.

"Totality of it all. They all fit together, profits, environment, aesthetics. It's all a package."

Interviewed farmers were also asked whether they felt like they had freedom in deciding what practices to implement and how to do it while participating in conservation practices programs. 9 farmers indicated they felt like they had freedom while 4 noted they felt like did not.

"Yes, as long as it is a voluntary program. Usually there are more than one option for the land to select (e.g., grasses, trees, a combination)."

"Yes, because you don't have to do it or take the money. It's your choice."

"Yes, plenty of freedom."

"No, locked out of a lot of programs because we're already doing it. Not good."

"No, we do not have the freedom to decide what practices to implement because the programs are so strict and precise on what has to be done to qualify."

2 farmers expressed that they felt like they did not have freedom due to decisions on requirements not being made with the full information needed.

"Decisions made in Washington by the USDA i.e., seating rates leave me skeptical. On the ground. Decisions should be made at the local level, i.e., a midterm management of a filter strip approved practice is disking up portions of the strip."

"Policies are limited because there is not sufficient public research. As a result, farmers sit back and watch others. This is a big drag on implementation."

1 farmer noted that they typically felt as if they had freedom with conservation practices programs but had been experience some difficulty recently.

"For most part yes however lately couldn't requalify for CSP."

A different farmer stated that they felt like they had freedom, however, even if at times requirements felt restrictive, flexibility was possible.

"Generally, requirements are put into these programs in order to achieve the goal of the program, however I have found that if you run into problems and have a legitimate reason to go outside the requirements if you communicate with the supervising agency, they will generally help you work through or around the problem."

Interviewees were also asked whether they had experience with policies or programs that required coordination with other farmers or required spatial targeting. 6 expressed that they did have experience and 3 noted that although they did not have experience, they were aware of such policies and programs. 4 farmers indicated that they had no experience or awareness of these policies and programs.

"Yes. With CREP, we targeted landowners with 100-yr floodplain cropland with CREP program information, the program's economic benefits, details on the restoration back to its original habitat prior to conversion to farming."

"Yes, the CREP program is targeted at river bottoms within certain watersheds."

"We are familiar with programs that target certain problem areas such as low bottom areas and hillsides."

"Spatial targeting to specific watersheds in the state. Also, spatial targeting to fields that haven't had practice. I am ineligible for a lot of things, especially the C stuff, because I am already doing it."

Farmers were also asked about desired changes that they would like to see on conservation practices policies and programs. The most common response received was financial reasons. This was referenced by 9 farmers. Several noted a need to increase incentives for adopting. One of these farmers stated that incentives should be increased for landowners instead of farmers. A couple of farmers said that more cost share was needed.

"$5-10 incentives are not enough. Society has a role to play here to help."

"Adequate compensation for loss of income in our farming operation."

"Need incentives for landlords. Most want to be conservationists, but only after income. Everything geared towards farmers; more needed to be geared towards landlords – especially as the amount of land rented is increasing."

"More cost share with (sub)urban Iowans who benefit from these practices (water quality), but don't bear the cost."

"Higher percentage of cost share paid by the government."

4 interviewees said farmers needed more information was needed on the outcomes of policies and programs.

"Availability of data that proves adopting these policies or programs is meeting the goal of the program, while improving the biodiversity of our land."

"Need data; can help people stay involved. Has a feeling that younger farmers are more interested in data. Want to compare data anonymously with other farmers – a benchmarking system."

A couple of farmers expressed that they would like to see policies and programs designed at the local level.

"I think that these program rules should be finalized at the local level. A lot of the time at the state or federal level may have a good general grasp of a problem but the local agencies have the boots on the ground and know what will or will not work in their area."

"More conservation programs approved at the local level (County FSA officials), like continuous CRP that don't have to compete Statewide or nationwide for approval."

Farmers also said that they would like to see a reduction in the work necessary to enroll in programs or in restrictive requirements.

"Too much paperwork with government programs (EQUIP). Other ones are handled by a county employee "watershed coordinator" who helps file the paperwork and this helps with adoption a lot. Most farmers don't want to do paperwork – big deterrent."

"We would like to see less strict rules. For example, we were not able to re-enroll filter strips because of the wrong species of grass growing in them. We felt they were securing their purpose regardless of the species of grass."

## Aspirations and Visions

***Hopes for Future State of Farm, Challenges, and Success Measurements***

The last section of interview questions focused on visions and aspirations for interviewees' farms. Asking farmers about this allows us to understand farmers hopes for the future of their farms. Farmers were asked to describe their ideal farm system, potential constraints and challenges that would limit their ability to get their farm to their desired state, and factors of success to assess their farm if it were twice as successful 5 to 10 years in the future.

Note: 9 farmers did not answer these questions. Many who did answer did not answer all questions on the topic.

31.25% of farmers said they would like the future state of their farm to increase cover crops. This was one of the most popular answers received.

"Our farmland would be 100% no-till/strip-till, with annual cover crops, structural."

"Ideal system includes 2,000 acres of cattle and row crops with cover crops, buffer strips on the entire acreage."

"Utilize cover crops through grazing and allowing more summer crops."

4 farmers noted that they hope to see financial improvements in their future farm. 2 said they would like better markets for biodiversity practices and improved costs of practices. 1 farmer stated that they hoped their future farm was profitable.

"A continuation of the present conservation and other practices which will enhance the farms value as an economic asset."

"Market prices and input costs for growing and selling our crops would remain stable so that we can always sustain a reasonable level of financial stability during our lifetime."

"It also includes improved/good commodity prices and government subsidies for cover crop users only."

"My vision is a continual profitable farm to hand down to the next generation with good structures to control water flow and erosion."

3 farmers also noted that they would like their future farm to be environmentally friendly or emphasize conservation.

"Weeds would be controlled with more environmentally-safe herbicides."

"The ideal farm will be environmentally friendly with a very high respect for biodiversity practices."

"I would like to see the family farm remain intact with the next generation, appreciating the conservation presently on the farm."

Of the farmers who noted challenges for achieving their ideal farm in the future, 3 noted financial limitations. This was the most commonly received response.

"As a landowner and father of four, I foresee a state taxes to be a challenge in growing of our farm."

"Has to be economically compelling."

"Challenges are generally financial; with the ups and downs of the ag economy you don't always have the extra funds to do land improvement work you would like to."

2 farmers also indicated measurements of success would be financial outcomes and 2 expressed that the ability to pass down their farm would demonstrate success.

"I see success as decreased input costs and increase ROI."

"Success for me would be measured and yield, ROI, a successful transition to a new tenant for the family farm."

"For me at age 70 looking down the road 5-10 years at the success of our farm will be dependent on who we chose to be the next farmer on our land. Currently there are several young farmers in our area that are adopting great conservation practices on their farms and will be the candidates we will look at."

## General Themes

***Themes Evident Throughout Interviews***

The information below highlights general and important themes visible throughout and across the responses received in the interviews.

Farmers were asked what biodiversity enhancing practices they would incorporate on their farm if costs and practicality were not a factor. The most common response received to this question was to increase cover crops. This was referenced by 62.5% of interviewees.

"Starting to incorporate more cover crop into my crop rotation."

"Using cover crops and further spreading out N applications."

4 farmers expressed they would like to expand the diversity of cover crops.

"Every acre would have a cover and there would be more experimenting with different cover crop species."

"Diversify cover crop with more species."

Throughout the questions that were asked, costs of biodiversity enhancing practices were most consistently brought up.

"Cover crops. Many stop however when funding stops or grain prices low. A lot of still comes down to money."

"Biodiversity means improving soil, health and productivity through better conservation practices implemented on our farms. These practices must be cost-effective and stay within the scope of diminishing returns."

"Most decision-making revolves around cost and profit."

"I think we need to assess what biodiversity we have now, and for how long, what is our farm lacking, and how or can we afford adding more biodiversity."

Ability to maintain or increase profit was also often referenced throughout interview responses.

"ROI is extremely important to the producer."

"It's all about profit and I was able to make it work by using space. Don't do this everywhere on the farm, but their places where it is profitable. Finding those is the key."

"We need to know that adding more biodiversity to our operation will not cause a drastic reduction in our financial bottom line."

"Has to be profitable. In the long run, it is on our operation."

Neighbors' willingness or unwillingness to adopt biodiversity enhancing practices was also noted often throughout interviews. Several farmers noted that although neighbors seem willing to adopt, they experienced challenges that influenced their adoption.

"Most of them are open-minded about incorporating biodiverse conservation practices, are concerned about protecting the environment, but also are equally concerned about the risk to their bottom line."

"There are many farmers in our area that use cover crops to enhance biodiversity. On the same hand, there are many farmers that have also tried to implement cover crops into their operation and have stopped doing so due to increased costs and lower yields."

A couple of farmers noted that neighbors understand biodiversity enhancing practices are beneficial but do not take the time to implement them on their farm.

"We often get questions regarding practices that we have implemented. It's something others will try for a season, get frustrated because of not understanding the different management style and go back to what they were comfortable with."

"Most see the benefits but don't take the time to do it."

"Shared but have seen little movement to adopt the practices. Some have tried reducing the tillage but expect that miracles will happen and soon get tired of the process before they have really given it enough time of looked critically why things are the way they are."

"The problem may be that the producer is not patient enough to allow the transitions necessary when adopting no-till and cover crops to occur. Professional farm managers vary in abilities! Ag economics majors from universities with little knowledge of agronomics and soils on a practical basis or years of experience in traditional tillage and bare fields make up the vast majority of these professional farm managers. Neither of these two types of managers is willing to adopt new practices for fear of reducing the income to their tenants/landowners or themselves. It is difficult to facilitate change when risk is involved, especially with individuals whose personalities are not geared to change."

However, many farmers expressed that their neighbors were unwilling to adopt biodiversity enhancing practices.

"No. They're pretty much set in their ways. Maybe dangling the financial carrot in front of them might help."

"Unfortunately, many large cash rent farmers dominate our area. Many of which are unwilling to commit to long-term conservation practices while having short-term cash rent leases."

"Farmers worry about what they are doing and what people will say about their operations. Potential negative of trying something new from neighbors' perspectives."

"Most farmers are skeptical of the process let alone not understanding how complex many of these processes are. So, most would just kick the can down the road."

"Approaching 90% no-till in this farmer's area, but they started in late 70s. Cover crops much more slow. 10% or less on cover crops. Viewed as an expense and not an investment. Need to get past that through the public research to show how these things work. Need the public research to show the benefits to the farmers and the public."

Several farmers also noted that although government support exists to encourage the adoption of biodiversity enhancing practices, it is limited and needs to be increased.

"I wish I hadn't counted on the $5/acre premium discount. Wish more acres had been available for the discount."

"We have a problem of governmental programs throwing money at producers on short-term practices where the producer leaves the practice. As soon as payments stop. We need commitment towards long-term adoption."

Overall, a majority of farmers expressed the positive outcomes that could potentially result from biodiversity enhancing practices during some point of their interview.

"In 1981, we purchased our first no-till planter. Planting no-till soybeans was easy, without yield loss and more effective financially. Over time, planters have improved to the point that every farmer with a decent planter can plant no-till to build soil health today."

"We are constantly improving drainage via tile, improved waterways and buffer strips. This prevents string bank erosion."

"If anything, would have adopted these things earlier. Cover crops only in 2010, should have started earlier."

"Use of buffer strips to protect rivers and streams. Using cover crops to reduce soil erosion and hold nutrients in the soil."

"Biodiversity has allowed us to become better stewards of the land. We feel that we are improving not only soil health, but also improving water quality by reducing the amount of runoff, both soil and nutrients, that have the potential to leach and wash away."

"Wish I had done it sooner."

## Appendix: Survey method questionnaire (filled in by Michael Castellano)

1. How were respondents identified? What criteria for identifying and selecting/screening respondents were used, if any?

Half were identified through an Illinois Soil & Water Conservation District. The remaining half were identified through personal connections.

2. What were the steps for inviting farmers? (e.g., who, and through what channel, reached out to farmers)

For the Illinois Soil & Water Conservation District, a representative from the district contacted the farmers. For the other half, I contacted the farmers.

3. Were any forms of incentives (both monetary and non-monetary; both positive and negative) used to encourage farmers to accept the invitation? (e.g., financial or in-kind compensation, prospect of advisory support or other services, opportunities to ask experts questions, peer pressure, network inclusion/exclusion, the chance of learning about survey results later, etc.)

For the Illinois group, I have done speaking engagements for them in the past at no cost. So, I asked for a favor in return. For the Iowa group, I offered $100/farmer for their time. Not all took the money.

4. How many did you invite? How many declined?

None declined.

5. Are there any common characteristics of farmers who declined?

N/A

6. How were the interviews conducted? For example, face to face interview or phone/zoom; one-on-one or as a group, etc.

In person, face-to-face.

7. How long did an average interview take?

1:15, ranging 45 mins to 1:45 mins

8. How was the data recorded?

Typing on a laptop as the farmer spoke.

9. Profile of people who conducted the interviews (e.g., training/background, academic or extension or private consultant, etc)

I conducted half, and an extension agent conducted half.

10. Did the same people who conducted interviews do the translation?

N/A

11. Any issues or challenges or surprises worth highlighting? How did you attempt to resolve the problems? Did it work?

The process was quite smooth. I doubt farmers would have been open to recording, so I did not ask. Note the farmers we reached are likely to be on the leading edge of conservation adopters. That said, they are also leading technology adopters (genetically engineered seeds, herbicides, etc.). They are all very high-functioning farmers.

# Part 3. Follow up interactions with farmers (France and Brazil)

## Supplementary Information Item for WP1: Follow Up Interactions with Farmers

Supporting: Enhancing Biodiversity and Resilience in Intensive Farming Systems

## France| Second Round Analysis

For the second round of interviews with farmers, we conducted semi-structured interviews lasting from 30 minutes to 1 hour. In total, we interviewed 17 farmers, 12 new farmers and 5 farmers who were previously interviewed in round 1. We invited them to comment on the results of round one, and more specifically about the limitations of adoption for practices in favor of biodiversity which were not adopted by 100% of participants. We further asked about the impact of the current war in Ukraine, rise of wheat prices and chemical inputs prices, on their decisions. Results of the second round of interviews are displayed within the next 3 sections.

### 1. What are the most important constraints to the adoption of practice in favor of biodiversity? A Sankey Diagram.

The objective of the first phase of interview was to create a better understanding of the main factors limiting the adoption of certain practices enhancing biodiversity in crop field systems. Based on results obtained in round 1 of interviews (Fig. 1), we asked participants to comment on the main limitations to the adoption of practices which were not adopted at a 100%, i.e., all the practices from reduce or no-till to organic agriculture in Fig.1

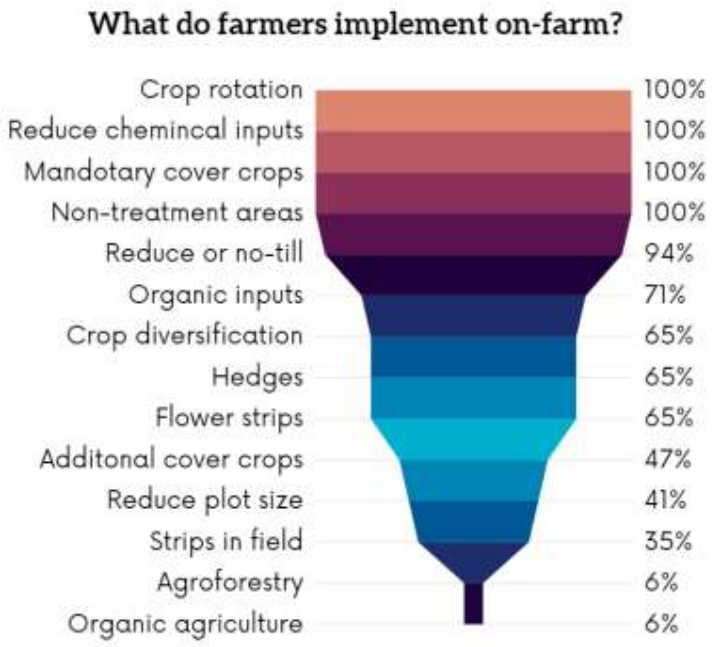



*Figure 1: Results of round 1 interview depicting the most common practices implemented in favor of biodiversity in northern*

In total, we interviewed 17 farmers, 12 new farmers and 5 farmers who were previously interviewed in round 1. During the interviews, participants were allowed to answer as many limiting factors as they could think of for each practice. We present the results of the main limiting factors in a Sankey diagram (Fig.2). For visualization purposes, Fig. 2 only depicts the 3 main limitations to each practice. We further listed all the explanations given, as well as their explanation in Section 2.

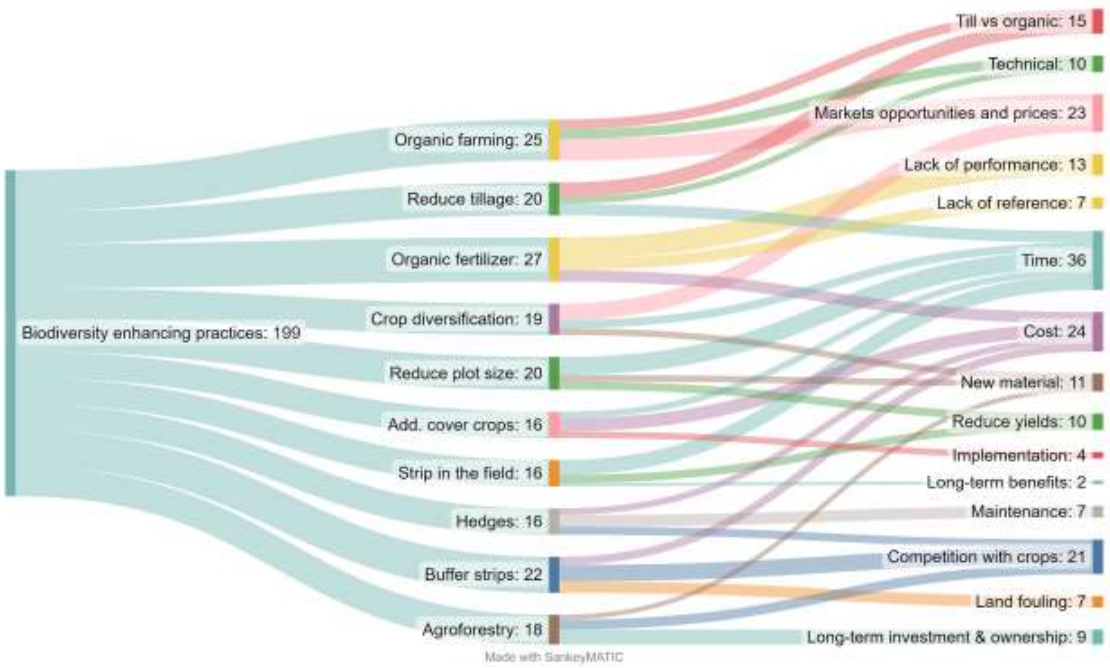



*Figure 2: Sankey diagram of the 3 main limiting factors of adoption for each practice in favor of biodiversity.*

Most important constraints identified by farmers across all practices are:

- Time mentioned 36 times.
- Cost mentioned 24 times.
- Market opportunities and prices mentioned 23 times.
- Competition with crops mentioned 21 times.

## 2. Detailed reasons to the non-adoption of practices enhancing biodiversity

In this section, we detail every constraint mentioned during the interviews and their meaning. As farmers were allowed to mention as many constraints as they wanted per practice, the total percentage of each practice does not equal to 0. Unlike, you should read for every constraint that, for instance, out of 17 participants, 53% mentioned that the major issue with reducing till was that till comes along with the use of chemical inputs.

### REDUCE TILLAGE OR NO-TILL

**53% . Till vs organic**

Strict no-till is a practice that requires from time to time the use of chemical inputs, whereas organic agriculture requires till. Choices are made based on personal preference, and a large majority of respondents try to find a compromise between reduction of till and reduction of chemical inputs use.

**41% . Industrial crops**

Strict no-till is not always compatible with every type of crop. In northern France, the main crop rotation consists of wheat, potatoes, and beets. In the case of beets and potatoes, farmers mention that a strict no-till is almost impossible.

**24% . Generational change**

The use of till is ingrained into older generations' practices. Respondents mention that a change of generation as the head of the farm could lead to further adoption of no-till practices.

**24% . Technical**

No-till practices require more observation, more time on the field and more agronomic knowledge.

**18% . Time consuming**

It is more time consuming to reduce till as it requires more observation in the field.

**12% . Grass resistance**

Resisting grasses are hindering the long-term adoption of no-till practices.

**12% . Weather constraints**

If weather conditions favored the development of weed or do not allow direct seeding, participants will use till.

**6% . Market constraints**

Specifications imposed by agrobusiness do not allow farmers to provide product issued from direct seeding.

**6% . New material**

Strict no-till practices require investment into new types of machinery.

## ORGANIC INPUTS

Refer to biocontrol and bio stimulant products as well as animal manure.

**76% . Lack of performance**

Organic inputs have not been used long enough to have proven their efficacy and tend to be perceived as not effective enough.

**41% . Lack of reference**

There is not enough literature and essays at their scale that have been made, proving the efficiency of the product.

**41% . Cost**

Organic inputs are perceived to be more expensive than chemical inputs, especially as their efficiency has not been proven.

**35% . Mistrust**

Some participants refer to the lack of trust they have developed against these products which have not proven their efficacy yet.

**12% . Lack of cattle**

The lack of livestock in the region does not allow every farmer to cover their need for organic nitrogen.

**12% . Product availability**

Available organic inputs are not sufficient to cover the range of problems encountered by farmers.

**12% . Risk taking is too high**

In comparison to the price of the seeds, the risk of using organic inputs compared to chemical inputs is perceived as too high by participants.

**6% . Time**

Organic inputs require more time of observation in the field.

## CROP DIVERSIFICATION

We consider crop diversification over 5 crops, which was the average crop rotation across participants in the 1rst round of interviews.

**59% . Market opportunities and prices**

Diversification of crops requires the market to propose sale channels for these products. It also requires the market to propose “attractive” enough prices for these products in comparison to other main sold crops: wheat, flax, beets.

**29% . Time consuming**

More crops require more work on the field.

**24% . New material**

New crops can require investment for new material.

**18% . Technical**

Further diversification in crops requires more knowledge about different crops and their combination.

**12% . Extra weeding**

Additional crops in the system require more weeding between crop rotation.

**12% . Generational change**

Historically farmers of northern France are used to producing on a 4 crops rotation system, contracts with traders and cooperatives are designed based on these systems.

**6% . Not interesting agronomically wise**

Some participants would prefer to install a flower or a biodiverse strip in their field, to attract more diversity than further diversifying their production.

**6% . Lack of labor**

Some participants refer to the lack of labor to match the increase of time spent in the field with an increase of crops.

**6% . Soil type**

Depending on your soil structure and type, it is not always an option to diversify your crop rotation.

## HEDGES

**41% . Maintenance**

Hedges require maintenance every year which require material and time from farmers.

**29% . Competition with crops**

Hedges take up space, nutrients and water resources competing with cash crops needs.

**24% . Cost**

In this case, farmers refer to the initial costs of investment for species and the implementation costs.

**24% . Contradictory regulations**

In the case of northern France, farmers were forced to cut down their hedges 20 years ago. It sounds contradictory to replant them today. Moreover, once hedges are planted, farmers are not legally allowed to cut them down whenever they want to, as they are legally protected. Perceived as a long term obligation, farmers tend to avoid having to deal with further constraints.

**18% . Land fouling**

Hedges are habitat favoring the development of additional weeds.

**18% . Long-term investment & ownership**

If a farmer rents his land and does not know if his family will take over, he will not be incentivized to plant trees and invest on long term on land he is not sure to secure.

**12% . No financial return**

Hedges require maintenance, care, and take up space whereas they do not provide any financial return.

**12% . Pest nuisance:** hedges create habitat for biodiversity but also for pests which can lead to problems for production.

**12% . Lack of understanding**

Farmers lack the understanding of the benefits hedges can create for their system.

**6% . Time**

Time of implementation and maintenance required by hedges.

## BUFFER AND FLOWER STRIPS

**59% . Competition with crop**

In this case, farmers referred to land competition with cash crops. Land dedicated for strips is not dedicated to production.

**41% . Land fouling**

Strips bring weeds problems along.

**29% . Cost**

Investment costs in flower seeds can be expensive.

**29% . Maintenance**

Buffer and flower strips require maintenance which means more time being spent for farmers on non-productive lands.

**29% . Regulation and control**

Original mix of grass and flower strips, such as the on design for the reintroduction of the grey partridge in the landscape:

*"So we made 15m wide strips that don't fit in the CAP declarations because we did things that are very complicated and we simplified them to declare them. We have 5 different mixtures 3m wide. So there's a grass mixture with perennial crops that serve as windbreaks. Then there's a nesting site, with a floral mixture of 15 species of wildflowers, a mixture of about 15 species with cabbage, flax, alfalfa, a whole bunch of different species. And then a final mix that we reseed every year, made up of sunflowers, sorghum and buckwheat."*

Some participants report that they would rather avoid additional administrative problems, others mention the fear of control and losing their CAP subsidies due to the un-flexibility of the CAP declaration.

**18% . Time consuming**

For seeding, growing and destruction if necessary.

## ADDITIONAL COVER CROPS

We refer to additional cover crops when farmers integrate more than the 2 mandatory cover crops, usually mustard and clover, imposed by CAP regulations.

**47% . Cost**

Seeds for additional cover crops are expensive.

**24% . Time**

Additional cover crops require more time for seed and for destroying them afterwards. additional cover crops also reduce workflow.

**24% . Implementation**

It requires time and good weather conditions for implementation, otherwise cover crops won't match their purpose, which is to enhance soil health.

**18% . Weather constraints**

It can be a high risk to a farmer to invest a lot of money into a lot of cover crops, while they might have difficult weather conditions, and cover crops could not grow well. If weather conditions do not allow a well growth of cover crops, farmers won't even get the environmental benefit of these crops.

**18% . Problem for destruction**

Some cover crops can be difficult to get rid of when seeding time comes and may also require the use of chemical inputs, which goes against farmer's desire to reduce their use of inputs.

**12% . Lack of understanding**

Farmers lack the understanding of the benefits additional cover crops can generate for their crops.

**12% . New material**

It may require new material for seeding or destruction.

**6% . Regulation and control**

Original cover crop mixes which require a higher investment, e.g. higher than 100€/ha such as sorghum, faba bean, phacelia etc, can require more flexibility in seeding date for optimal growth, than the date imposed by the CAP declaration. As participants fear CAP controls, they would rather follow CAP's rules (compulsory cover crops and seeding date) than take the risk to invest more and lose it all.

**6% . No financial return**

Additional cover crops require more initial investment and care, but do not provide any direct financial return to farmers.

## REDUCE PLOT SIZE

For every participant, reducing plot size differs according to the size of each farm. However, they overall refer to a reduced plot size lower than 10 - 15 ha.

**65% . Time**

Reducing plot size reduces the workflow of farmers.

**29% . Reduce yield**

Reducing plot size usually includes space between fields to be dedicated to other activities, which reduces the total yield.

**24% . New material**

It can require the use of new material adapted to the new size of the field.

**18% . Plot size**

By the structure of the landscape, plot sizes are already small.

## STRIPS IN THE CROPPING FIELD

**53% . Time**

Integrating strips on the cropping field reduces the workflow of farmers.

**29% . Reduce yield**

Land use for strips is considered as lost land for productive purposes, which reduces the total yield of the farm.

**12% . Long term benefits**

Adding strips within the cropping field only brings soil and biodiversity benefits in the long-term.

**12 % . Regulation and control**

CAP declarations are strict and not easy to fill. Some participants refer to the lack of flexibility of the CAP system as a major constraint to change their practices and implement a flower or grass strip in their field.

**6% . Maintenance**

Farmers need to spend time and energy weeding and checking at the strips.

**6% . Cost**

Initial investment for seeds or shrubs can be expensive.

## AGROFORESTRY

**53% . Long-term investment and ownership**

If a farmer rents his land and does not know if his family will take over, he will not be incentivized to plant trees and invest on long term on land he is not sure to secure.

**35% . Competition with crops**

The implementation of trees in the middle of cropping fields compete in terms of resources and space with other crops.

**18% . New material**

Agroforestry requires investment into special material adapted to this system.

**12% . Maintenance**

According to participants, agroforestry requires more maintenance than more conventional cultivation systems.

**12% . Lack of understanding**

Farmers are not aware of the benefits of agroforestry systems, mainly due to a lack of literature in this field, especially related to grain systems.

**6% . Not interesting agronomically wise**

Some participants mention that agroforestry does not provide as many agronomic advantages as all the above practices implemented on a more conventional system.

**76% . Market opportunities and prices**

Many farmers mentioned that organic farming has reached a plateau where the supply is higher than the demand. As organic farming requires more labor and time spent in the field, sales prices for organic products should be higher than conventional. However, it is not always the case that the gap in price between organic and conventional allows farmers to convert all their production into organic.

**35% . Till vs organic**

Strict no-till is a practice that requires from time to time the use of chemical inputs, whereas organic agriculture requires till. Thus, organic farmers decide to go for tilling.

**35% . Technical**

Organic agriculture requires more knowledge, it's more technical. It relies a lot on observation, agronomic principles, and a deep understanding of the ecosystem's dynamics.

**29% . Time**

Organic agriculture requires much more time spent in the field than so-called conventional agriculture.

**24% . Lower yield**

Organic farming produces on average less yield compared to conventional farming.

18% . Lack of labor

Organic farming requires more time spent in the field, the lack of labor is a major constraint too.

**18% . Not compatible with industrial crops**

Some participants mention the incompatibility between certain crops produced at an industrial level and organic agriculture such as sugar beets.

**12% . New material**

Organic farming relies on a different set of machines and material which requires an important initial investment.

## 3. What are the impacts of Russia's war on farmers' decisions?

Russia's war on Ukraine risks causing a global food shortage. To avoid this, should the European agricultural strategy be reversed to rapidly increase production and yields? Should we, in other words, sacrifice the ecological transition in the name of stability? Raising prices of wheat, grains,

fuel and nitrogen, few months after the outbreak of the war, what strategies are being adopted by farmers in Northern France?

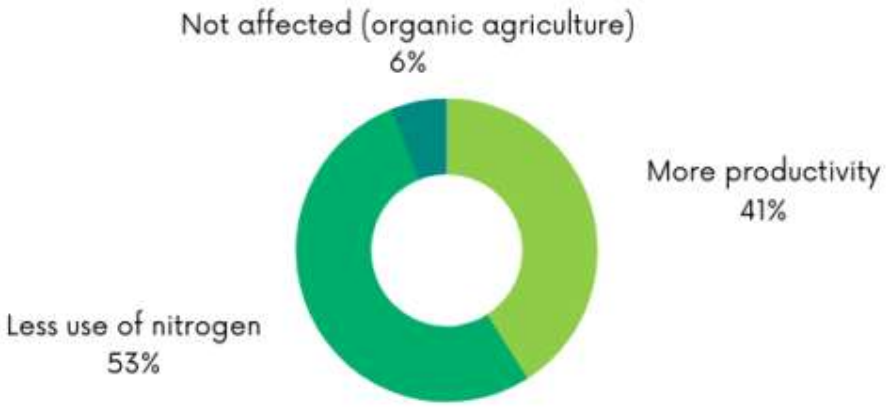



*Figure 3: Farmers' decision between productivity and agroecological transition*

Fig. 3 shows that decisions in reaction to Russia's war are not so clear. A light majority (53%) perceive the increasing prices of nitrogen as a major obstacle and tend to modify their practices accordingly: using as little as possible nitrogen, change crop rotations for next season in favor of legumes. 41% of respondents decided to secure their harvest in wheat, even if it means to use more chemical inputs. Finally, 6% of respondents were not so affected by these changes as they are in organic agriculture.

Overall, participants agree that it is too soon to affect long-term decisions. Most of them can balance off high inputs' prices with high wheat prices. Some respondents also mention that:

- Organic farmers were not benefiting of the rise in wheat prices
- Farmers also fear the lack of seed availability
- High prices in fuel could lead to reduce till practices
- Lack of nitrogen availability could lead to further conversion to organic farming
- High prices in nitrogen could lead to modification of crop rotation in favor of legumes.

# Supplementary Information Item for WP1: Follow Up Interactions with Farmers, Part 3 – Brazil | Brief Synthesis of Interview Notes

Supporting: Enhancing Biodiversity and Resilience in Intensive Farming Systems

# Brazil | Brief Synthesis of Interview Notes

In order to understand farmers perceptions about biodiversity and biodiversity enhancing practices, 18 farmers from Mato Grosso (Brazil) were interviewed about the source of the information they receive about the topic, their current management, biodiversity understanding and views, experience, adoption, policies and programs, ideal farm, aspirations and challenges. The main results are written in this paper.

At the moment, most farmers' biodiversity enhancing practices are related to soil fertility and soil control, as no-tillage systems, coverage cultures and rotation cultures, few farmers also practice waste control or use organic fertilizers.

Interviewees were asked about the meaning of biodiversity and how it relates to their farm. They emphasized biodiversity impacts on soil, they also believe no-tillage systems, minimal use of chemical inputs, maintenance and restoration of preservation areas were practices that enhance biodiversity. Leaving cost and practicality issues aside, farmers believe reducing chemical inputs and increasing organic and natural products, crop rotation, biologicals, maintenance of preservation areas and Integrated Crop-Livestock-Forestry Systems would improve biodiversity on their farm. The most popular advantages noted by farmers were less costs from reducing chemical inputs and increased productivity as well as soil conservation, and existence of microorganisms.

Farmers stated that they believed there were no or minimal risks involved with biodiversity practices. Some farmers believed neighboring properties shared similar perceptions with them related to biodiversity enhancing practices, others said the perceptions were mixed or completely different. They have been adopting practices that benefit biodiversity in order to preserve natural resources (water/soil), economic reasons and environmental considerations. The most used criteria in their decision-making were financial factors.

Producers were asked about experience with policies and programs that are designed to support biodiversity. Most farmers had experience, although one third had no experience. Among the programs the mentioned the Round Table on Responsible Soy (RTRS), Soja Plus and financing from the Brazil's Low Carbon in Agriculture Plan (ABC). The reason they took part of the programs were mostly capital demand. Most farmers had no experience with programs that either require coordination with other farmers, include high-value territories for conservation, or are designed to reduce habitat fragmentation.

Of farmers who shared their opinion on policies and programs' requirements, a few stated that they believed the requirements were reasonable and fair. Many of them felt like they had the no freedom to decide on which preservation practices to adopt and how to implement them, they said it was the law or required regulation and that they were restrictive.

Farmers noted that the benefits received from those policies and programs are marginal, payments for environmental services are not yet a reality, and that resources from the government programs often arrive late. Farmers also had critics about the efficiency of the programs, they suggested that a stronger political will and more university research on biodiversity would be helpful. They would like to see several changes in the implementation of biodiversity enhancing policies and programs, such as more financial incentives, attractive interest rates, and market rewards; greater disclosure, articulation, and publicizing of biodiversity enhancing policies and programs; changes in governance.

Their desired property template is diverse. Many farmers want more profitable properties, others want more technology, improved biological factories and soil quality. Meanwhile, some farmers believe their current farm is close to their ideal state. Those who haven't reached the ideal farm yet mentioned economic obstacles and governance issues.

Farmers then shared the main factors of their envisioned success and how they measured success, they cited economic factors, ability to maintain or improve their current levels of productivity, the incorporation of new technology and improved management. Only two farmers mentioned they view success as increased biodiversity and other two see as improved soil quality.

# Supplementary Information Item for WP1: Follow Up Interactions with Farmers, Part 3 – Brazil | Second Round Analysis

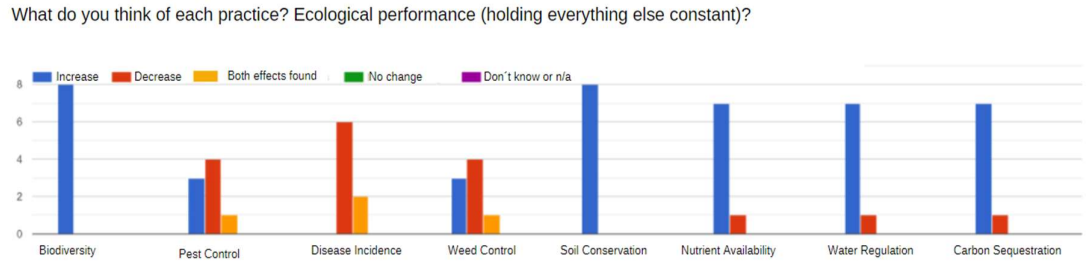
Supporting: Enhancing Biodiversity and Resilience in Intensive Farming Systems

# Brazil | Second Round Analysis

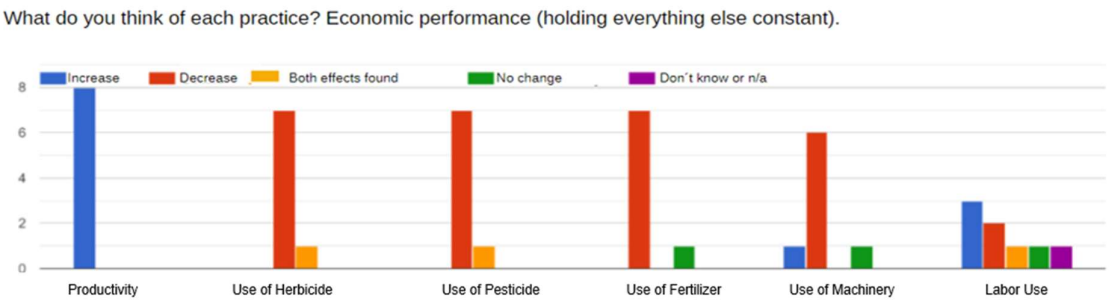
For the second round of interviews with farmers, we conducted an online survey in order to better understand farmers perceptions about biodiversity enhancing practices in crop field systems. In total, 8 people were consulted, with 5 farmers who were previously interviewed in round 1, 2 more representatives from relevant organizations among the agricultural sector in the state of Mato Grosso and 1 private consulting rural technician. We invited them to comment on the results of round 1, as well as explain the limitations of adoption for practices in favor of biodiversity. Results of the survey are shared in this paper.

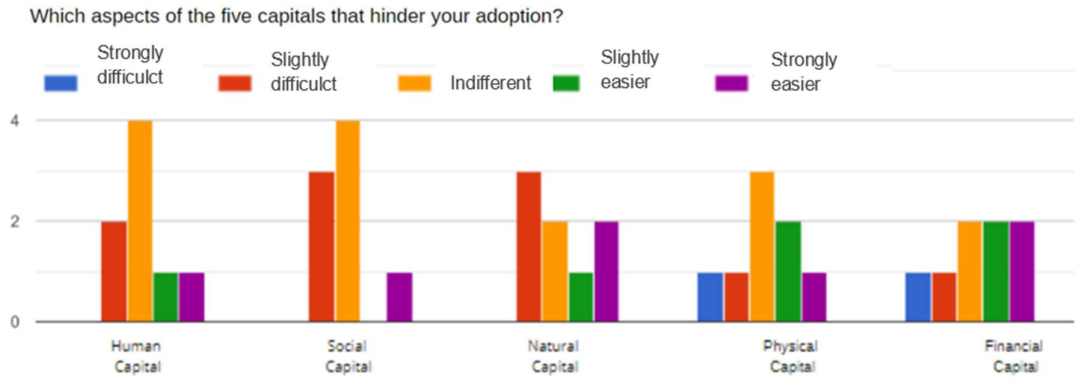
**Cover crop**

Considering cover crop, all 8 farmers currently adopt (voluntary) the practice. All of them believe it increases the biodiversity. 4 farmers believe it decrease the pest control and 3 believe it increases. Of the interviewees, 6 consider that cover crop decreases the disease incidence and 2 stated that both effects were found. About weed control, 4 farmers believe it increases, 3 decreases and 1 found both effects. All farmers chose that it increases soil conservation and 7 farmers said it increases nutrient availability, water regulation and carbon sequestration.



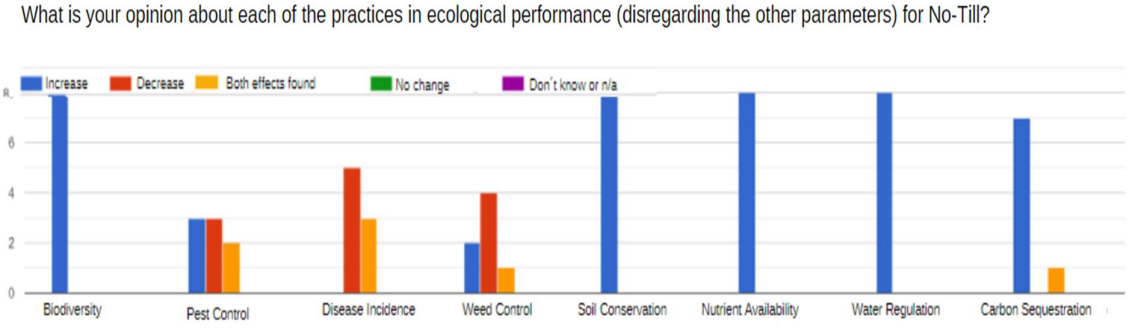

Regarding the economic performance, despite everything else, 8 farmers said cover crop increases productivity, 7 chose it decreases herbicides, fertilizer and pesticide use, 6 said it decreases machinery use and 3 said it increases labor use while 2 said it decreases and others said it could cause both effects, no change or they didn't know. About the capitals that hinder or foster their adoption, 4 believe human capital is indifferent, 2 that it makes slightly difficult and 2 that it makes easier. Considering social capital, 4 believe it is indifferent, 3 that it makes slightly difficult and 1 that makes strongly easier. Nature capital makes it slightly difficult for 3 farmers, indifferent for 2, slightly easier for 1 and strongly easier for 2. Physical capital is indifferent for 3 farmers, difficult for 2 and facilitate for 3. Meanwhile the financial capital facilitates for 4 farmers, indifferent for 2 and difficult for other 2.



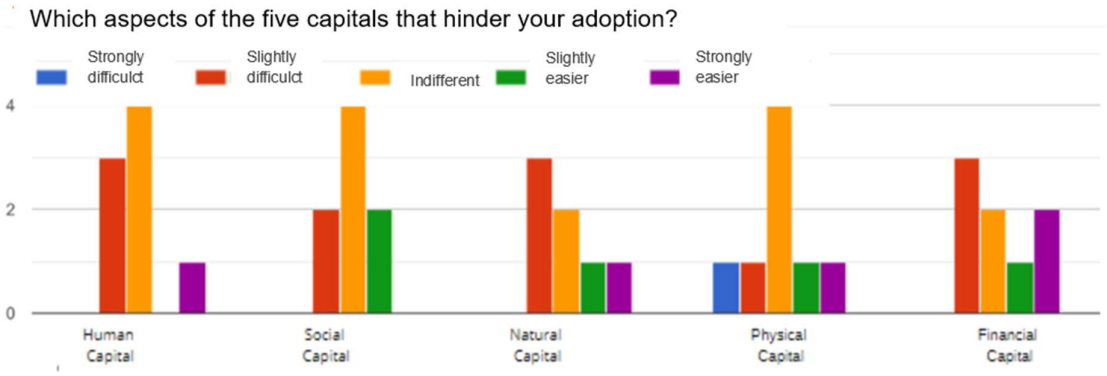



**No till**

Considering no till, all 8 farmers currently adopt (voluntary) the practice. All of them believe it increases the biodiversity. 3 farmers believe it decrease the pest control, 3 believe it increases and 2 believe it could cause both effects. Of the interviewees, 5 consider that no till decreases the disease incidence and 3 stated that both effects were found. About weed control, 4 farmers believe it decreases, 2 increases and 1 found both effects. All farmers chose that it increases soil conservation, nutrient availability and water regulation. 7 finds that no till practice increases carbon sequestration.

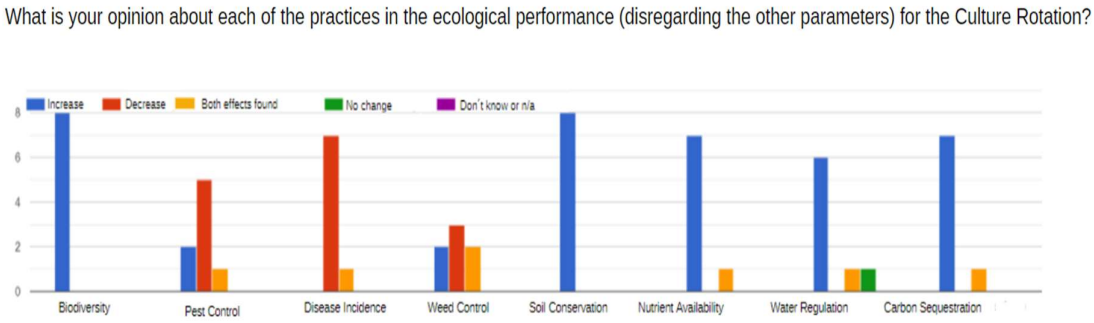


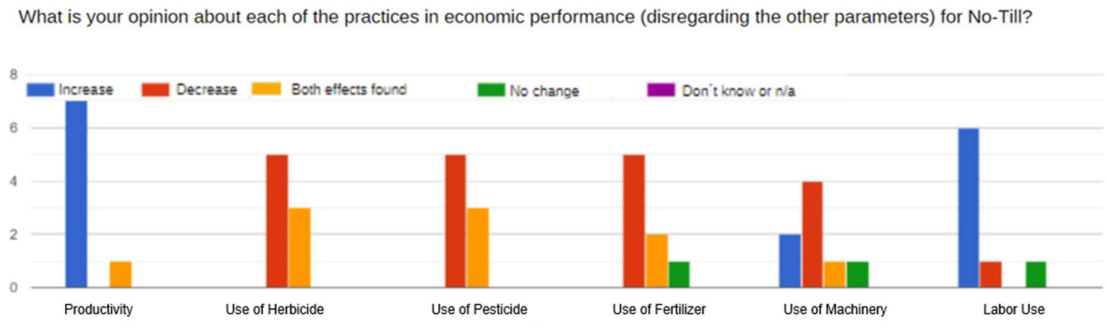

If the economic performance is considered despite everything else, 8 farmers said no till increases productivity, 6 chose it decreases herbicides and pesticides, while 7 chose it decreases fertilizer use, 7 said it decreases machinery use and 5 said it increases labor use while 2 said it decreases. About the capitals that hinder or foster their adoption, 4 believe human capital is indifferent, 3 that it makes slightly difficult and 1 that it makes strongly easier. Considering social capital, 4 believe it is indifferent, 2 that it makes slightly difficult and 2 that makes slightly easier. Nature capital makes it slightly difficult for 3 farmers, indifferent for 2, slightly easier for 1 and strongly easier for 1. Physical capital is indifferent for 4 farmers, difficult for 2 and facilitate for 3. Meanwhile the financial capital facilitates for 3 farmers, difficult for 3 and indifferent for 2.

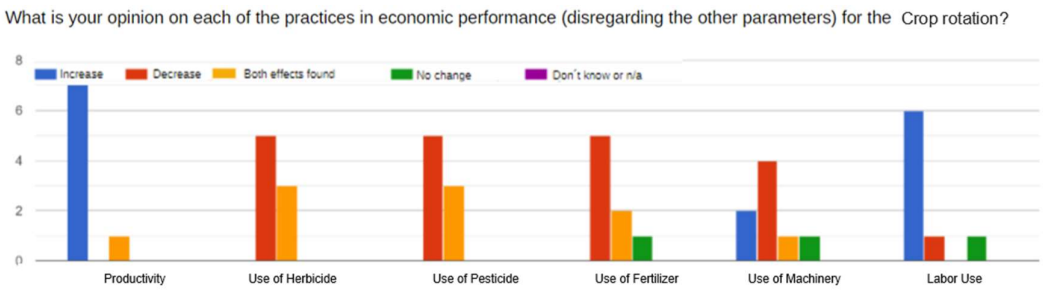



**Crop rotation**

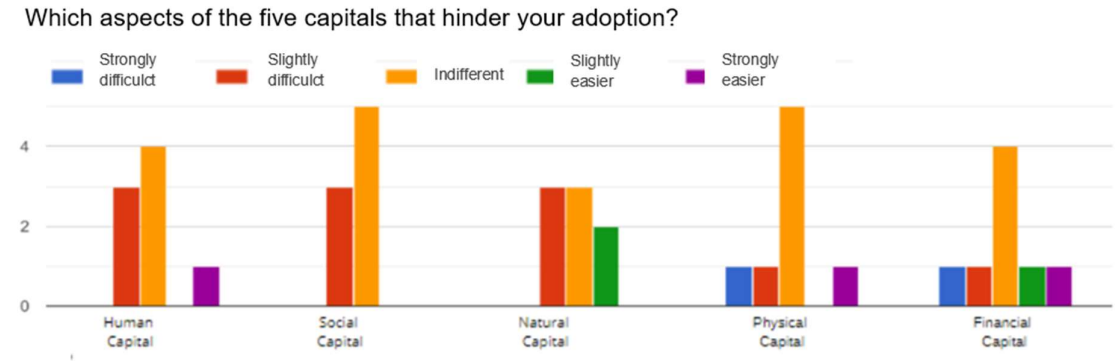
Regarding crop rotation, 6 out of 8 farmers willingly adopt the practice and 2 never adopted but are interested. They all believe this practice increase biodiversity, most of them are convinced that it decreases pest control but 2 are convinced that it increases, 7 out of 8 chose that it decreases disease incidence while 1 of them said it could cause both effects. Of the interviewees, 3 consider that crop rotation decreases the weed control, 2 stated that increases and 2 stated that both effects were found. All farmers agree it increases soil conservation and most farmers believe it increases nutrient availability, water regulation and carbon sequestration. For the interviewed farmers, crop rotation can increase productivity. 5 out of 8 farmers said it decreases herbicide, pesticide and fertilizer use, while 3 said it could cause both effects. Four producers think crop rotation reduces machinery use, while 2 say it increases, 1 believe it can cause both effects and another one that it doesn't change anything. 6 farmers agree it increases labor use, one chose that it decreases labor use and another no change.





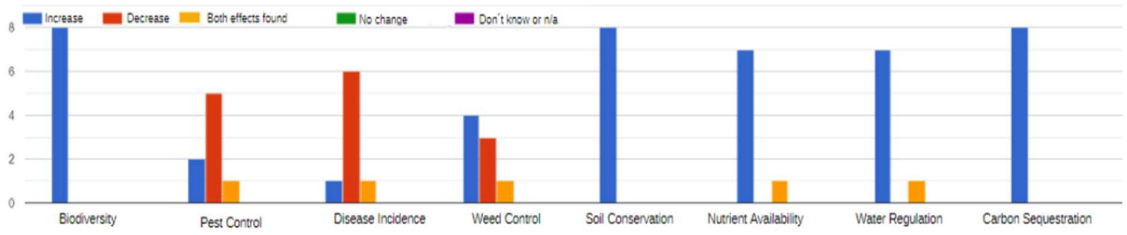

Considering the capitals that hinder or foster their adoption, 4 believe human capital is indifferent, 3 that it makes slightly difficult and 1 that it makes strongly easier. Social capital is indifferent for 5 interviewees and slightly difficult for 3. Nature capital makes it slightly difficult for 3 farmers, indifferent for 3 and slightly easier for 2 farmers. Physical capital is indifferent for 5 farmers, difficult for 2 and slightly easier for 1. Financial capital is indifferent for 4, difficult for 2 and easy for 2.



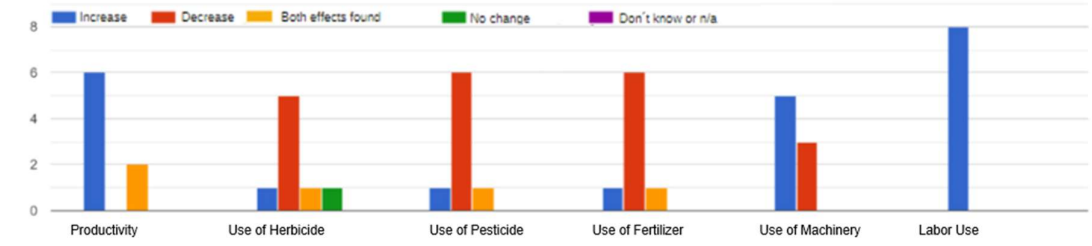

**Integrated Crop-Livestock-Forestry (ICLF)**

4 out of 7 farmers never adopted the practice but are interested, while 3 currently adopt voluntarily. 8 farmers believe it increases biodiversity, soil conservation and carbon sequestration. About pest control, 5 are certain that it decreases pest control, 2 chose that it increases and 1 chose it could cause both effects. For 6 farmers the practice decreases disease incidence, for one it increases and for another it could cause both effects. Furthermore, 4 farmers believe it increases weed control meanwhile 3 farmers believe it decreases, one farmer chose it could cause both effects. 7 interviewees said it increases nutrient availability and water regulation. 6 of the 8 farmers consider that ICLF can increase biodiversity, but 2 consider it can cause both effects, 5 out of 8 believe it decreases herbicide use while 1 thinks it increases the use of herbicide, 1 says it can cause both effects and another one that it makes no change. Pesticides and fertilizers' use follow the same pattern where 6 thinks it decreases, 1 that increases and another 1 that it can cause both effects. For 5 producers ICLF increases the use of machinery but 3 chose that it decreases. All the interviewees agree it increases labor use.

What is your opinion about each of the practices in ecological performance (disregarding the other parameters) for the Crop-Livestock-Forest integration?

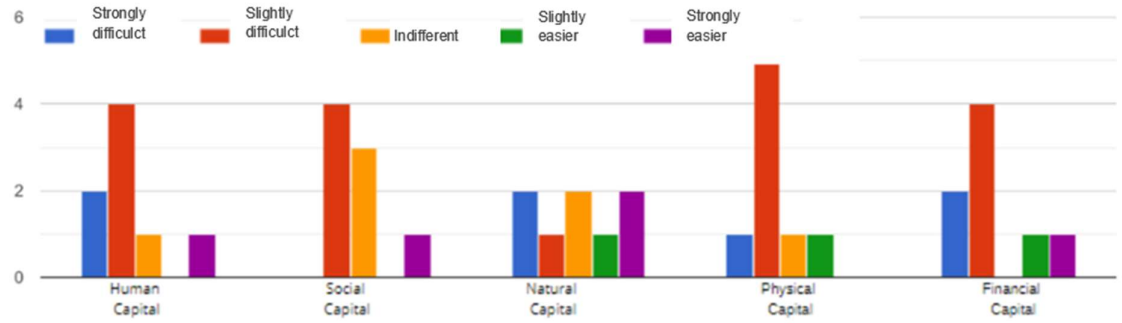



What is your opinion about each of the practices in economic performance (disregarding the other parameters) for the Crop-Livestock-Forest integration?




Among these farmers, human capital makes it slightly difficult for 4 of them, strongly difficult for 2, indifferent for one and strongly easier for one. Social capital makes it slightly difficult for 4 farmers, indifferent for 3 and strongly easier for one. Nature capital share opinions, for 2 it's strongly difficult, other 2 it's indifferent and for 2 others it is strongly easier, while for one it's slightly difficult and another one it's slightly easier. Physical capital is slightly difficult for 5 farmers, strongly difficult for 1, indifferent for 1 and slightly easier for 1. Financial capital is slightly difficult for 4 interviewees, strongly difficult for 2, slightly easy for 1 and strongly easy for 1.

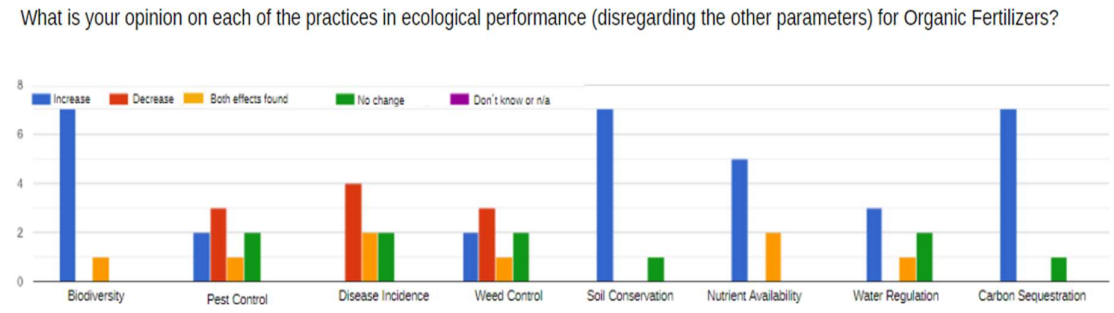
Which aspects of the five capitals that hinder your adoption?



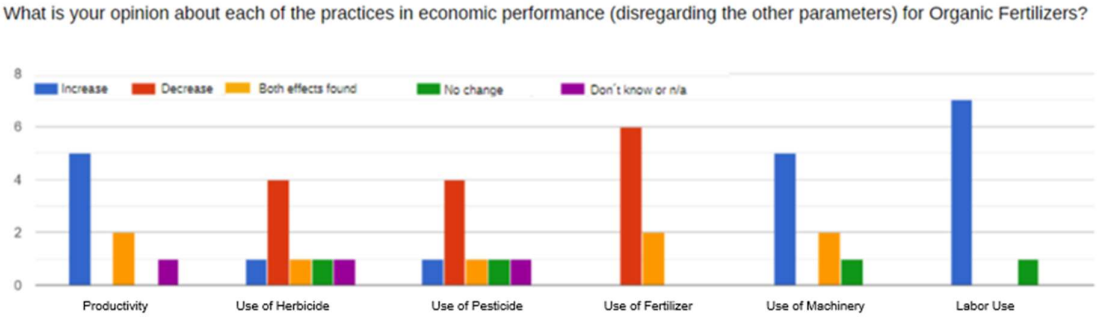

**Organic fertilizers**

Nowadays, 4 farmers out of 8 willingly adopt the practice, 3 never adopted but have interest and 1 used adopt but don't adopt anymore. 7 of them believe it increases biodiversity and one that it can cause both effects. Meanwhile, 3 think it decreases pest control, 2 think it increases, 2 think it makes no change and one thinks it can cause both effects. Disease incidence increases with organic fertilizers

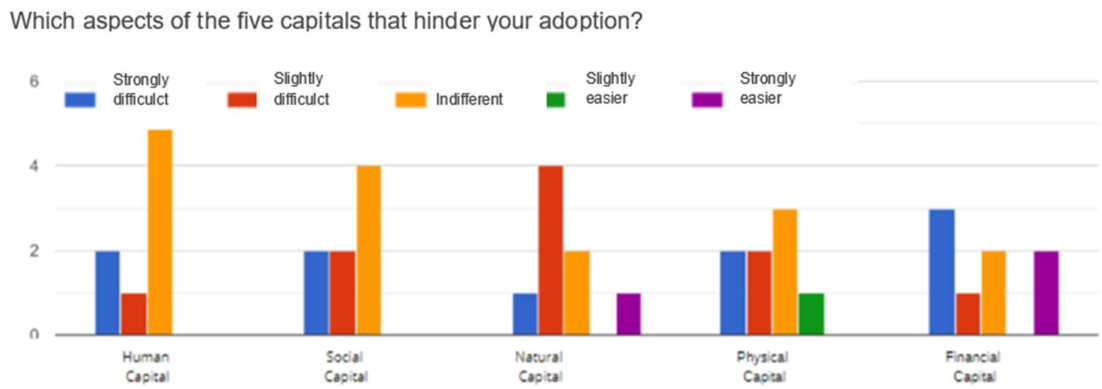
for 4 farmers, for 3 it can cause both effects and for other 3 it makes no difference. Weed control decreases for 3 of them, increases for 2, no change for 2 and causes both effects for one. In the opinion of 7 interviewees, it increases soil conservation while for one it makes no change. Considering nutrient availability, it increases for 5 farmers and cause both effects for 2. Water regulation increases for 3 farmers, makes no difference for 2 and causes both effects for 1. Carbon sequestration increases for 7 farmers and makes no difference for 1.




For 5 of the interviewed farmers, organic fertilizers can increase productivity, 2 think it can cause both effects and 1 doesn't know. 4 out of 8 farmers said it decreases herbicide and pesticide use, while 4 said it could cause both effects, increase, no change or doesn't know. 6 believe it decreases fertilizers use and 2 that it can cause both effects. 5 producers think organic fertilizers increases machinery use, while 2 say it causes both effects and 1 no change. 7 farmers agree it increases labor use, one chose that it makes no change.



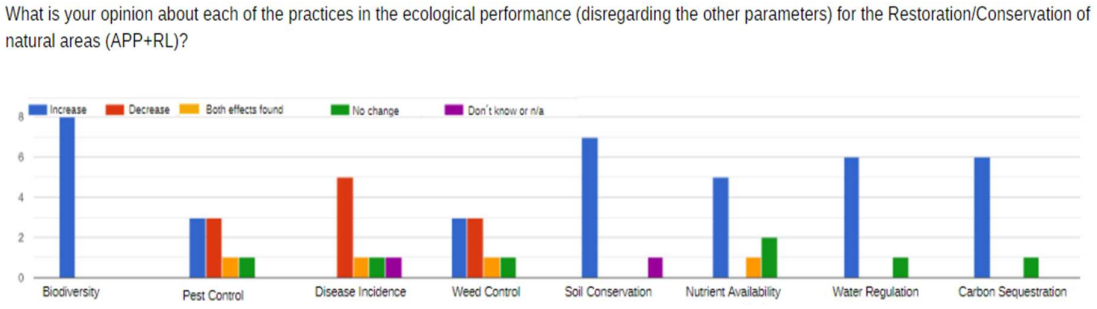

Regarding the capitals that hinder or foster their adoption, human capital is indifferent for 5 farmers, strongly difficult for 2 and slightly difficult for 1. Social capital is indifferent for 4, strongly difficult for 2 and slightly difficult for 2. Natural capital is slightly difficult for 4, indifferent for 2, strongly difficult for 1 and strongly easier for another 1. Physical capital is indifferent for 3, strongly difficult for 2,



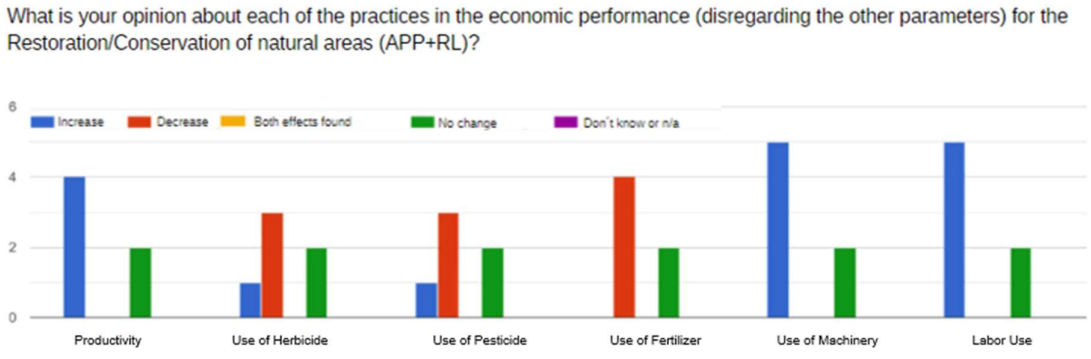
slightly difficult for 2 and slightly easier for 1. Financial capital is strongly difficult for 3, indifferent for 2, strongly easier for 2 and slightly difficult for 1.

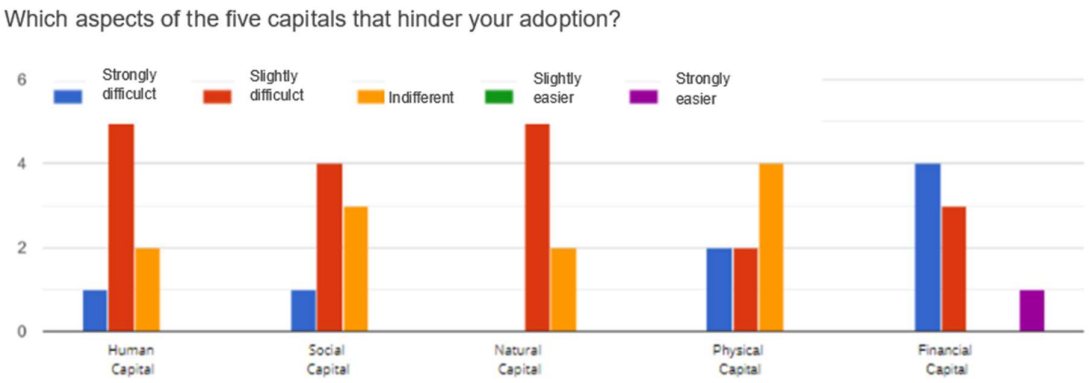
**Habitat restoration and conservation**

7 farmers currently adopt (voluntary) the practice of habitat restoration and conservation and 1 currently adopt (compulsory). All the 8 farmers agree it increases biodiversity. Meanwhile, 3 farmers believe it increases pest control and other 3 that it decreases pest control, 1 farmer thinks it can cause both effects and other 1 that makes no change. Disease incidence decreases for 5 interviewees, other 3 chose both effects found, no change or don't know. For 3 farmers, weed control is increased but for other 3 it's decreased, while 1 farmer found both effects and other saw no change. Soil conservation increases for 7 farmers and 1 doesn't know. Nutrient availability increases for 5 farmers, 2 chose no change and 1 both effects found. Water regulation and carbon sequestration increases for 6 farmers and 1 thinks they don't change.



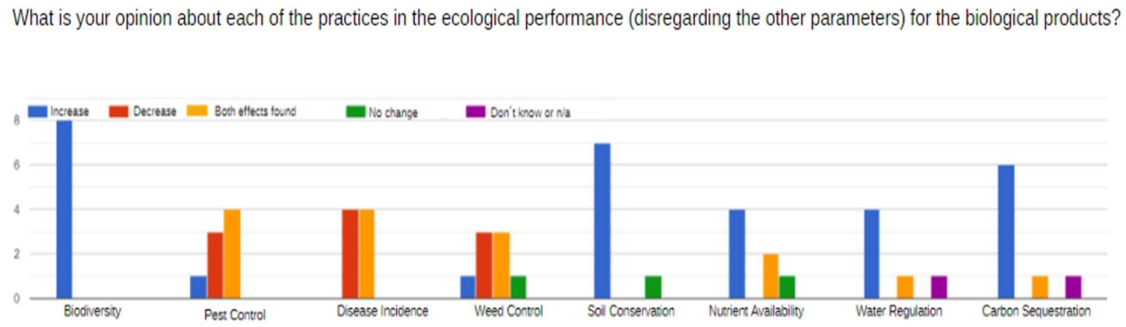

Regarding economic aspects, 4 farmers believe productivity increases with restoration and conservation of natural areas, 2 think it makes no change. Herbicide and pesticide use decreases for 3 farmers, don't change for 2 and increases for 1. For 4 farmers fertilizer use decreases and for other 2 it makes no change. Machinery and labor use increase for 5 producers and make no change for 2. The aspects that hinder or foster the adoption are human capital which makes slightly difficult for 5 farmers, indifferent for 2 and strongly difficult for 1. While social capital is slightly difficult for 4, indifferent for 3 and strongly difficult for 1. Natural capital is slightly difficult for 5 and indifferent for 2. Physical capital is indifferent for 4, strongly difficult for 2 and slightly difficult for 2. For farmers financial capital is strongly difficult in 4 out of 8 cases, slightly difficult for 3 and strongly easier for 1.



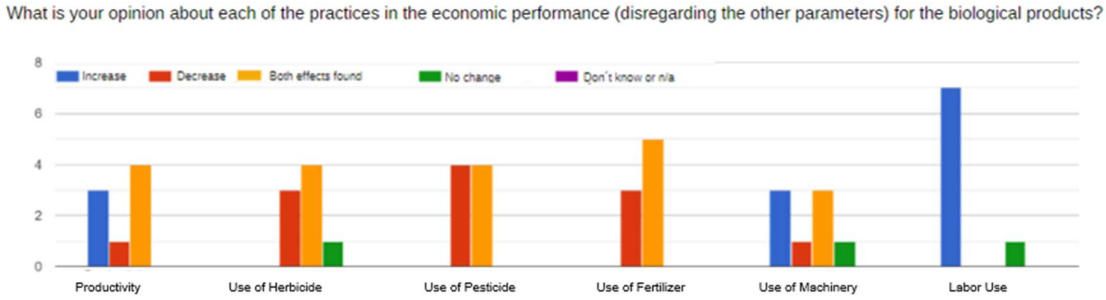



**Biological products**

Currently 7 farmers adopt the practice and 1 never adopted but is interested. All of them agree it increases biodiversity. Among them, 4 think it can cause both effects in pest control, 3 think it decreases and 1 thinks it increases. Half of the interviewees said it decreases disease incidence while the other half think it can cause both effects. 3 farmers believe it decreases weed control, 3 others think it can cause both effects, 1 believe it increases and 1 sees no change. For 7 of them biologicals increase soil conservation, while 1 sees no change. Nutrients availability increases for 4 farmers, 2 found both effects and 1 chose no change. Water regulation is increased for 4 out of 6, 1 thinks it causes both effects and another 1 doesn't know. Carbon sequestration is increased in 6 of the farmers' opinion, while 1 doesn't know and 1 reported both effects.

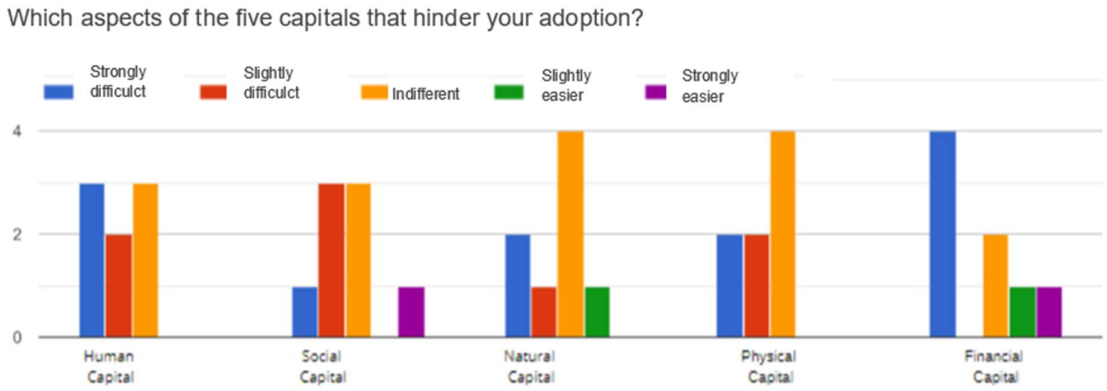



Biological products can cause both effects on productivity according to 4 interviewees, for 3 it increases and for 1 farmer decreases. 4 farmers think it can cause both effects in herbicide use, while 3 think it decreases the use and 1 that makes no change. Half of the interviewees think it decreases pesticide use and the other half that it can cause both effects. Considering fertilizer use 5 farmers have found both effects and 3 decreased the use. Machinery use increases for 3 farmers, have both effects



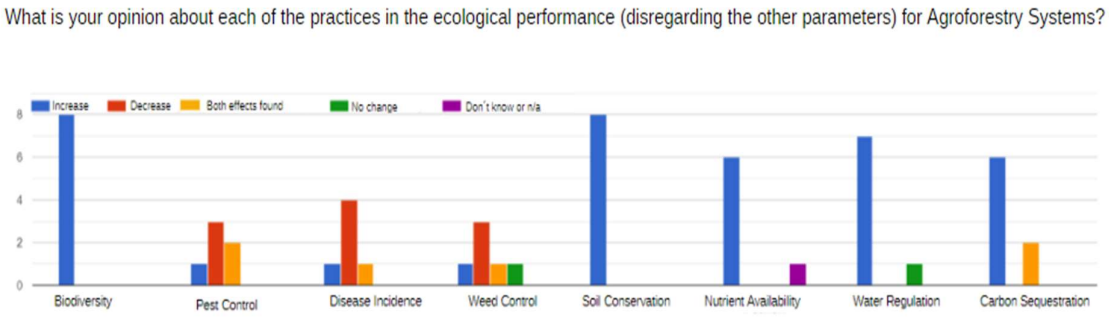
for 3 farmers, decreases for 1 and has no change for another 1. Labor use increases for 7 out of 8 farmers and 1 noticed no change.

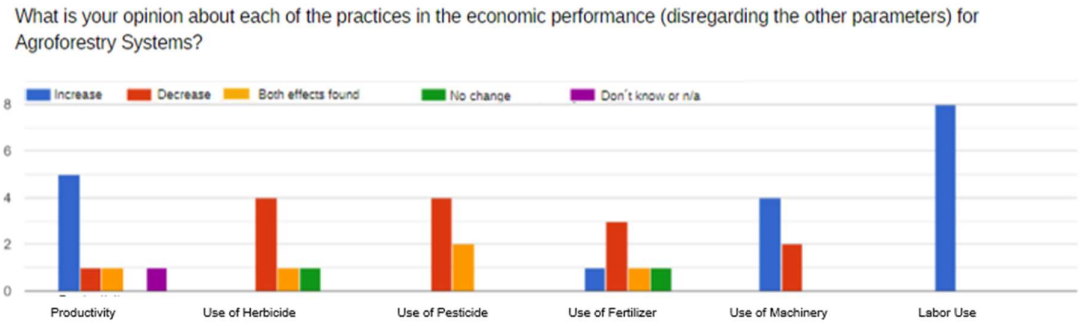
Regarding the five capitals which hinder or foster the adoption of biological products, 3 farmers feel like human capital in strongly difficult, 3 that it's indifferent and 2 that it's slightly difficult. Social capital is slightly difficult for 3, indifferent for 3, strongly difficult for 1 and strongly easier for another 1. Natural capital is indifferent for 4 interviewees, strongly difficult for 2, slightly difficult for 1 and slightly easier for another 1. Financial capital is strongly difficult for 4, indifferent for 2 and easier for other 2.



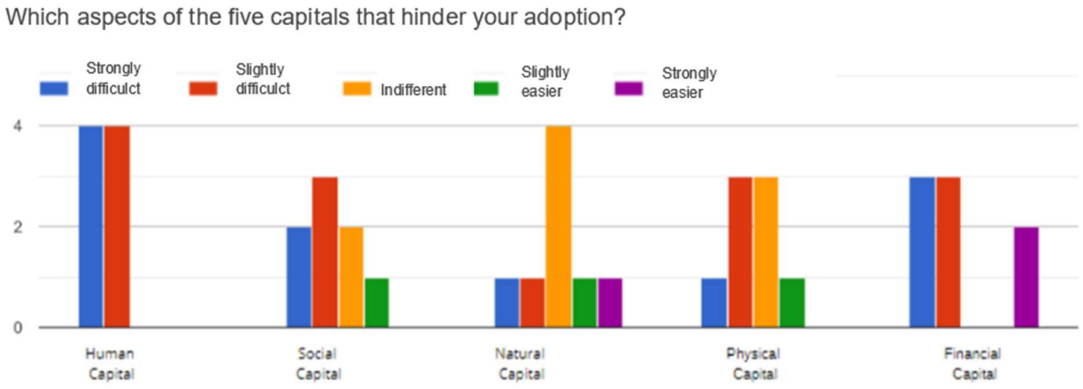

**Agroforestry systems**

The agroforestry systems are currently adopted willingly by 4 farmers, 3 others are interested but never adopted and 1 never adopted and has no interest. Although, all of them agree that the practice increases biodiversity and soil conservation. Regarding pest control, 3 farmers believe the practice decreases, 2 said it could cause both effects and 1 that it increases. 4 out of 6 believe agroforestry systems decreases disease incidence, 1 that it causes both effects and another 1 that it increases. Weed control is also believed by 3 farmers to decrease with the systems, other 3 chose increase, both effects found and no change. Nutrient availability in 6 of the farmers' opinion increases with the practice, while 1 doesn't know. Water regulation increases for 7 farmers and 1 believes it makes no change. Carbon sequestration, for 6 farmers it increases and for 2 it can cause both effects. Productivity also increases for 5 farmers, for 3 it decreases, both effects and no change. Herbicide use decreases for 4, causes both effects for 1 and causes no change for another 1. Pesticide use decreases for 4 and causes no changes for 2. Fertilizers use decreases for 3, increases for 1, causes both effects for another 1 and causes no change for other 1. For 4 farmers machinery use increases and for 2 others it decreases. They all agree the practice increases labor use.



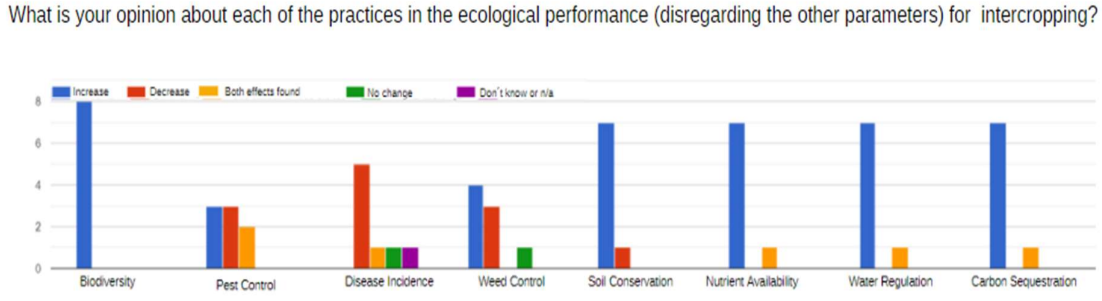



Human capital makes it strongly difficult for half of the interviewees and slightly difficult for the other half. Social capital is slightly difficult for 3, strongly difficult for 2, indifferent for 2 and slightly easier for 1. Natural capital is indifferent for 4 farmers and each one of the other 4 chose each other category. Meanwhile, physical capital is slightly difficult for 3 interviewees, indifferent for 3, strongly difficult for 1 and slightly difficult for another 1. Financial capital is strongly difficult for 3, slightly difficult for 3 and strongly easier for 2.

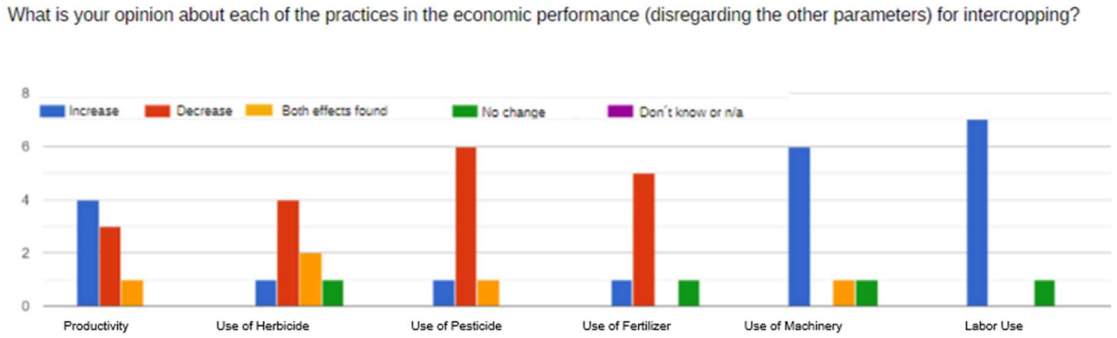



**Intercropping**

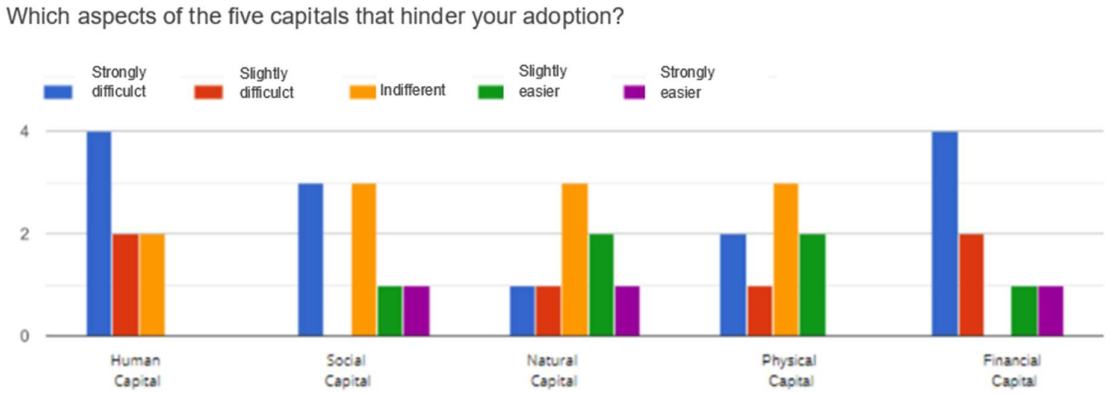
Intercropping is currently adopted willingly by 6 farmers, 1 other used to adopt but stopped and 1 never adopted and has no interest. They all agree it increases biodiversity. Pest control is increased in the opinion of 3 farmers while other 3 believe it decreases, 2 said it could cause both effects, Disease incidence is decreased according to 5 farmers, other 3 chose both effects, no change and don't know. For 4 farmers weed control is increased, while 3 think it's decreased, 1 farmer said it makes no change. Soil conservation is increased according to 7 farmers and decreased according to one. Nutrient availability, water regulation and carbon sequestration share the same answers, 7 farmers believe they are increased and 1 that both effects can be found.



When farmers were asked about financial aspects 4 notified intercropping increases productivity, 3 that it decreases and 1 that both effects are found. In the opinion of 4 farmers, the practice decreases herbicide use, 2 think it's indifferent, 1 that it increases and another 1 that it makes no change. 6 interviewees believe it decreases pesticide use, only 1 that it increases and another 1 it causes both effects. For 5 it decreases fertilizer use, 1 said it increases and 1 that makes no change. Meanwhile, 6 believe it increases machinery use, 1 that both effects are found and another 1 that makes no change. For 7 of them the practice increases labor use and 1 believe it makes no difference.




Considering the capitals that hinder or foster their adoption, 4 believe human capital is strongly difficult, 2 that it is slightly difficult and 2 that it is indifferent. Social capital is strongly difficult for 3 interviewees, indifferent for 3, slightly easier for 1 and strongly easier for another 1. Natural capital is indifferent for 3, slightly easier for 2 farmers, difficult for 2 and strongly easier for 1. Physical capital is indifferent for 3 farmers, strongly difficult for 2, slightly easier for 2 and slightly difficult for 1. Financial capital is strongly difficult for 4 farmers, slightly difficult for 2 and easier for other 2.




Interviewees felt substantially confident about their performance adopting biodiversity enhancing practices. Most of them agree that the practices listed in above increase biodiversity and are willing to adopt.

# Supplementary information for WP3

## Glossary

In this report cover crops refers to the plant sown in addition to the main crop for agronomic or environmental purposes while plant could be harvested or not (adapted from Beillouin et al, 2019).

Intercropping based on the definition provided by Beillouin et al (2019) refers to "the simultaneous cultivation in the same field of two or more crop species, varieties, or cultivars, for all or part of their growth cycle. All crops are harvested".

## Part 1

### Systematic review method

The method of this review was followed by Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA[5]). Data acquisition and processing is the first step of this systematic review. In order to search for published results of cover crop effects, we prepared a search strategy. A search strategy is an organized structure of key terms used to identify and define search strings and collect relevant documents. The literature search was conducted on the Web of Science Core Collection (WoSCC) and Scopus in March 2022. The scope of the search was journal and conference articles published in English and whose access was fully available and not limited to a specific geographical area and publish date. The resulting search instruction for the database was as follows:

"living mulch" OR "cover crop*" OR "green manure" OR "catch crop" AND "meta-analysis" OR review

The appraisal phase evaluated and screened the selected literature to identify relevant papers for the review.

According to the pre-defined inclusion and exclusion criteria, studies that fulfil the inclusion criteria were selected for the next phase and further investigation. Articles were selected if the two criteria were satisfied: (1) the paper compared cover crop treatments versus no cover crop controls, and (2) the paper provides a clear result of the effect of cover crops on soil properties and other ecosystem services.

The search yielded 1360 publications. The titles and abstracts of these publications were screened to select those reviews and meta-analyses that compared cover cropping practice with no cover cropping as a control comparison group. A total of 148 publications were retained based on the title and the abstract screening. The full texts of these articles were read in detail and a total of 44 articles were included in the synthesis. Paper screening and selection procedure is presented in a PRISMA diagram (Fig. 1S).

[5] https://prisma-statement.org/

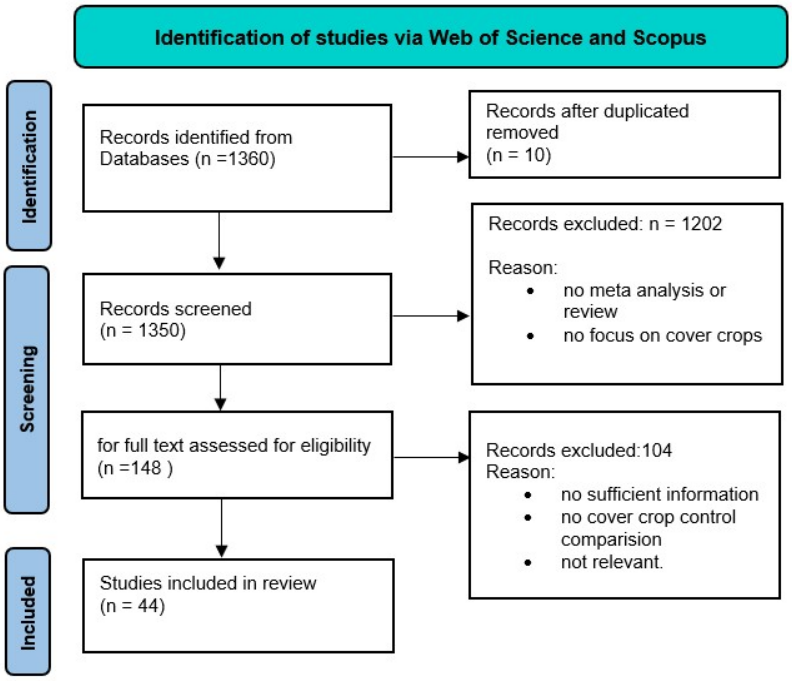



Fig 1S: The procedure of paper screening and selection in a PRISMA diagram

Finally, a ranking method based on Rosa-Schleich et al, (2019) was applied for each indicator. We coded the positive output as 1 and a negative output as −1; if both effects or no effect were reported in the literature, we coded this result as zero. We then summed the numbers for each outcome, divided them by the number of papers for each outcome, and ranked cover crop performance accordingly.

Soil health parameters and other ecosystem services measured in the study are presented in Tables 1S and 2S.

Table 1S: Soil health indicators and parameters

| Indicators | Parameters |
|---|---|
| **Soil biodiversity status** | Total bacteria |
| | Total fungi |
| | Soil microbial abundance and activity |
| | Microbial biomass |
| **Soil water content** | Water-use efficiency |
| | Soil available water |
| | Water regulation |
| | Soil water content |
| **Soil nutrient status** | Soil organic matter |
| | Nutrient balance |
| **N leaching** | Nitrate leaching rate |

| | |
|---|---|
| **Runoff prevention** | Runoff<br>Sediment production<br>Infiltration rates |
| **Soil physical properties** | Precipitation storage efficiency<br>Total porosity<br>Soil compaction<br>Macropores<br>PH |
| **Soil organic carbon** | Organic carbon content<br>Soil organic matter |

Table 2S: other ecosystem services Indicators and Parameters

| Indicators | Parameters |
|---|---|
| **Weed suppression** | Weed biomass<br>Weed suppression |
| **Crop yield** | Yield |
| **Pest biocontrol** | Biocontrol services<br>Abundance of omnivore-predators |
| **Climate regulation** | $N_2O$ emission |

## Grey literature

Grey literature in this systematic review consisted of working papers, technical bulletins, theses and dissertations, conference proceedings, and government reports. As we focused on existing meta-analyses of the effect of cover cropping on soil health and biodiversity, we decided not to include grey literature. However, below, some examples of grey literature in the context of cover cropping are provided.

**Thesis**

Fenton, M. C. (2017). The Profitability of Cover Crops: Investigating the Effect of Additional Soil Organic Carbon (Doctoral dissertation, Purdue University).

St Aime, Ricardo, "Cover Crop Biomass Production and Effects on Soil Moisture in the Upstate of South Carolina" (2019). All Theses. 3630.

West, Brionna Lee, "Impacts of Cover Crop Mixtures on Productivity of Cropping Systems" (2018). MSU Graduate Theses. 3334.

Hodgdon, Elisabeth Ann, "Use of cover crops for weed suppression and nutrient capture" (2013). Master's Theses and Capstones. 836.

**Reports**

Smit, B., Janssens, B., Haagsma, W., Hennen, W. H. G. J., Adrados, J. L., Kathage, J., & Domínguez, I. P. (2019). Adoption of cover crops for climate change mitigation in the EU. *Publications Office of the European Union, Luxembourg*.

Wallander, S., Smith, D., Bowman, M., & Claassen, R. (2021). *Cover crop trends, programs, and practices in the United States* (No. 1476-2021-709).

Lugato, E., Cescatti, A., Jones, A., Ceccherini, G., & Duveiller, G. (2020). Maximizing climate mitigation potential by carbon and radiative agricultural land management with cover crops. *Environmental Research Letters*, *15*(9), 094075.

Kathage, J., Smit, B., Janssens, B., Haagsma, W., & Adrados, J. L. (2022). How much is policy driving the adoption of cover crops? Evidence from four EU regions. *Land Use Policy*, *116*, 106016.

Morrison, C.L., and Y. Lawley. 2021. 2020 Prairie Cover Crop Survey Report. Department of Plant Science, University of Manitoba. https://umanitoba.ca/agricultural-food-sciences/make/make-ag-foodresources#crops

**Conference papers**

Alonso-Ayuso, M., Quemada, M., Vanclooster, M., Ruiz, M., Rodriguez, A., & Gabriel, J. L. (2018). Implications of the cover crop termination date on N and water cycles. In *20th Nitrogen workshop" Coupling CNPS cycles"*.

Vidotto, F., Fogliatto, S., De Palo, F., Milan, M., & Ferrero, A. (2018). Cover crops as mulching to manage weeds in organic rice cultivation. In *18th European Weed Research Society Symposium" New approaches for smarter weed management"* (pp. 135-135). Kmetijski inštitut Slovenije.

Morton, T. A., Bergtold, J. S., & Price, A. J. (2006, June). The economics of cover crop biomass for corn and cotton. In *Proceedings of the Annual Southern Conservation Tillage Systems Conference*.

Jaya, I. K. D., & Sudika, I. W. (2021). Mung bean cover crop improved soil organic carbon and maize yield in a semiarid area. In *IOP Conference Series: Earth and Environmental Science* (Vol. 637, No. 1, p. 012006). IOP Publishing.

# Part 2

## Country-specific cover cropping outcomes

To find field experiment articles for each country, the search was done on the Web of Science and Scopus in June 2022, with the same search strategy for both databases as below:

**Search term (topic):**

"cover crop*" and wheat OR maize OR soybean and France OR Brazil OR Germany OR "united state" OR America

Then the first 30 articles for each country were considered to extract their results regarding the effect of cover cropping on soil, biodiversity and other ecosystem services (table 3S).

Table 3S: Published cover crop field experimental studies in the US, Brazil, Germany and France

| 1 | Country | Cover crop type | Main crop type | effects | Paper |
|---|---|---|---|---|---|
| 2 | United States | oats, rye | Corn | **Soil**: increasing mycorrhizal colonization<br>with oats, potentially less herbicide is needed | Kabir at al (2002) |
| 3 | United States | Oat, pea, flax, rapeseed, lentil, vetch, clover, barley, safflower | Wheat | **Soil:** cover crops had a short-lived effect on soil microbial communities in semiarid wheat-based rotations and irrigation could enhance soil enzyme activity.<br>The total fatty acid methyl ester concentration was correlated with cover crop biomass<br>In the semiarid environment, longer time spans may have been needed to see beneficial effects of cover crops on soil microbial community structure, soil enzyme activities, and soil C sequestration. | Calderon et al (2016) |
| 4 | United States | oats, rye and a combination of oats and rye | Corn | **Microbe**: oats was as effective as rye in increasing mycorrhizal colonization of sweet corn, density of mycorrhizal hyphae, and soil aggregate stability<br>The combination of cover crops (rye and oats), however, was significantly better than single species. | Kabir & Koide (2002) |
| 5 | United States | cereal rye, oilseed radish, crimson clover | Maize and soybean | **Soil**: Cover crops and no-tillage did not significantly increase soil organic matter in the short term (3 years).<br>**Yield**: lack of consistent improvement in soil properties such as soil organic matter increase or crop yield in the conservation system over the three-year period. | Jacobs et al (2022) |
| 6 | United States | cowpea | Wheat | **Soil** The winter cash crop season was the prime opportunity for introducing legume-based N fixation to the system | Hinson et al (2022) |

| | | | | | |
|---|---|---|---|---|---|
| | | | | **Yield**: Organic wheat yield was 20% lower than conventional in the first season of organic transition, but there was no yield difference by the third year (because of N fixation by a legume-based cash crop the previous winter season) | |
| | United States | cereal rye | Corn–Soybean | **Weed**: no-till management with a cover crop reduced weed density by 31% and reduced weed biomass by 61% compared with no-till without a cover crop | Grint et al (2022) |
| **7** | | | | the use of a cereal rye cover crop in the Upper Midwest has potential to reduce the exclusive reliance on spring burndown herbicides in no-till, | |
| | United States | cereal rye, cereal rye–crimson clover | Wheat-soybean | **Yield**: winter crop did not affect soybean yield despite differences in soybean stand, soil moisture, soil temperature, and soybean chlorophyll content following various winter crops | Gross, et al (2022) |
| **8** | | | | soybean yield response is relatively insensitive to previous crops | |
| | United States | forage oat, hairy vetch, winter canola | Corn, Soybean | **Soil:** For site-years 1 and 2, some cover crop treatments resulted in modest, but significant increases in soil N during spring. | Chim et al (2022) |
| | | | | Cover crop treatments had little effect on plant-available soil P. | |
| | | | | **Yield**: corn yield was significantly higher with oat, vetch, and a combination of all three cover crops compared to the no cover crop treatment | |
| | | | | At site-year 3, corn yields in the canola and oat treatments were equivalent to no cover crop, while corn yields with vetch and the combination treatments were lower. | |
| **9** | | | | soybean yields two years following cover crop treatments were higher for all three site years | |

| | | | | | |
|---|---|---|---|---|---|
| 10 | United States | medium red clover, cereal rye, forage radish, Austrian winter pea | Maize | **Yield**: Cereal rye, reduced yield relative to cover crop treatments that contained legumes by up to 43 %.<br><br>There were no other yield differences among cover crop treatments, including the fallow control. | Hunter et al (2021) |
| 11 | United States | cereal rye, hairy vetch, | Soybean | **Weeds**: Biomass of weeds surviving management within a soybean crop following either a vetch or rye cover crop was reduced by 26 and 56 percent, respectively,<br><br>**Yield**: variation in soybean yield among cover crops and cover-crop termination treatments was due largely to differences in soybean establishment, rather than differences in the soil environment | Davis (2010) |
| 12 | United States | multispecies mixture of legumes, grasses, and Brassica spp | Corn, soybean | **Soil**: However, after 3-year, cover cropping did not increase soil organic carbon<br><br>Significantly increased soil inorganic nitrogen as compared to the less-diverse treatments and a no-cover control<br><br>**Yield:** significantly increased soybean yield<br><br>**Water**: significantly increased gravimetric soil water content, and soil inorganic nitrogen as compared to the less-diverse treatments and a no-cover control | Chu et al (2017) |
| 13 | United States | Oat, rye | Corn and soybean | **Soil**: Neither cover crop significantly reduced cumulative drainage or nitrate loads because of variability in cumulative annual drainage among plots.<br><br>The rye winter cover crop significantly reduced drainage water $NO_3$ concentrations by 48% over five years, but this was less than the 58% reduction observed in its first four years of use | Kaspar et al (2012) |

| | | | | | |
|---|---|---|---|---|---|
| | | | | The oat fall cover crop reduced $NO_3$ concentrations by 26% or about half of the reduction of the rye cover crop. | |
| 14 | United States | Pea, oat, canola, hairy vetch, forage radish | Wheat | **Yield**: Cover crops showed little effect on wheat yield, yield components<br>**Water:** Cover crops showed little effect on water use efficiency<br>**Weed**: weed biomass in the oat and oat mixtures with legumes and brassicas were 73 to 85% less than in fallow during 2018. | Mesbah et al (2019) |
| 15 | United States | rye cover crop | Corn and soybean | Beneficial Arthropods: Most taxa did not significantly respond to the presence of the rye cover crop when analyzed individually, with the exceptions of Carabidae and Gryllidae sampled from soybean pitfall traps. Activity density of Carabidae was significantly greater in soybean plots that included a rye cover crop, while activity density of Gryllidae was significantly reduced in plots with the rye cover crop<br>Although a rye cover crop may be agronomically beneficial, there may be only limited effects on beneficial arthropods when added within an annual rotation of corn and soybean. | Dunbar et al (2017) |
| 16 | Brazil | forage turnip, linseed, triticale, rye, canola, crambe, oats | Soybean | **Yield**: grain yield was not influenced by cover crops | de Oliveira Gomes et al (2022) |
| 17 | Brazil | black oats, lupine | Soybean | **Yield**: Black oats are the best option to increase soybean yield. In the absence of cover crops, nitrogen fertilization in soybean is necessary. | Cordeiro et al (2021) |
| 18 | Brazil | hairy vetch | Maize | **Yield**: maize yield increased by 8.3% with vetch presence relative to the control, without vetch<br>N coming from the legume cover crop in addition to the N fertilization was critical for supplying N to maize | Pott et al (2021) |

| | | | | | |
|---|---|---|---|---|---|
| 19 | Brazil | oats, black oats, ryegrass, canola, vetch, fodder radish and red clover | Maize | **Yield**: Vetch showed greater contribution to the development of maize promoting an increase in stem diameter in all crop season and directly reflecting in higher grain yield. | Piva et al (2021) |
| 20 | Brazil | triticale, sunflower, pearl millet, sunn hemp, forage sorghum | Soybean | **Soil**: Winter crop treatments had no effect on soil aggregation<br><br>but total organic C and N concentrations were greater ($p < 0.05$) with triticale than with sunflower | Rigon et al (2020) |
| 21 | Brazil | Crotalaria juncea(CJ), Stylosanthes humilis, Pennisetum glaucum ,Triticum aestivum, Mucuna aterrima | Soybean | **Pest:** Crotalaria juncea , Pennisetum glaucum and Mucuna aterrima were effective in controlling M. javanica and M. incognita. | Ferreira et al (2020) |
| 22 | Brazil | white-oats, black-oats, annual-ryegrass, canola, vetch, fodder-radish and red-clover | Maize | **Soil**: The establishment of a high-quality and high C input cover crops in the winter, as vetch or black-oats in succession to maize, are able to increase SOC stocks, even in the short term. | Locatelli et al (2020) |
| 23 | Brazil | Urochloa brizantha and Urochloa ruziziensis | Soybean | **Nutrient**: Nutrient accumulation in cover crop straw was enhanced due to greater biomass production in treatments with N applied 20 and 10 D ays before desiccation<br><br>**Yield**: Soybean grain yield was 17% greater following U. brizantha than following U. ruziziensis. Nitrogen application at different times did not affect soybean grain yield. | Tanaka et al (2019) |

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| 24 | Brazil | blue lupin, hairy vetch, black oat, oilseed radish | Wheat | **Nutrient**: Nutrient cycling by winter cover crops reduced P and K losses, especially when the soil is not plowed.<br><br>black oat stood out by its greater production of biomass, resulting in higher P and K availability in the soil surface.<br><br>Lupine resulted in a greater cycling of P possibly due to its ability to absorb P from less labile forms in the soil. | Tiecher et al (2017) |
| 25 | Brazil | pearl millet, forage sorghum and sunn hemp | Soybean | **Soil**: In the long-term, cover crops improve soil structure, with equal or better results than those obtained by occasional chiseling, as an increase in soil macro porosity by Sunn hemp up to 0.20 m depth and a decrease in soil bulk density by Sunn hemp and pearl millet in the 0.40-0.60 m layer.<br><br>**Yield**: in two years the use of cover crops resulted in higher yields. Sunn hemp increases the soybean yield | Calonego et al (2017) |
| 26 | Brazil | Millet, cober crop, Sorghum, sunn hemp | Soybean | **Soil**: Generally, cover crops increased soil carbon contents, but soil N was only increased by sunn hemp in the particulate organic C fraction<br><br>Labile-fractioned soil organic carbon and total carbon levels are more efficiently increased by grasses than by legumes in the short term, and grasses cropped in spring increase soil C/N ratio | Rosolem et al (2016) |
| 27 | Brazil | oat/corn; vetch/corn; oat + vetch/corn; oat + vetch/corn + cowpea; and lablab/corn | Corn | **Soil**: The inclusion of legume intercropped or in succession to cover crops promoted the occurrence of edaphic fauna and increased microbial biomass C and N, which favored cycling potential and nutrient availability | Almeida et al (2016) |

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| 28 | Brazil | pigeon pea (Cajanus cajan) and Brachiaria | Maize | **Yield**: Maize grain yield was not reduced by the presence of the relay cover crops in comparison with maize as the sole crop, even when the cover crop was sown soon after maize emergence. | Baldé et al (2011) |
| 29 | Brazil | black oat, vetch, cowpea , pigeon pea, lablab | Maize | **$N_2O$**: Greater soil $N_2O$ emissions were observed in the first 45 days after the cover crop residue management in all crop rotations<br>Legume-based crop rotations had the largest cumulative emissions in this period | Gomes et al (2009) |
| 30 | Brazil | black oat, wheat, radish, blue lupin, and hairy vetch | soybean/ Maize rotation | **Nutrient:** Including legumes in the crop rotation was important for N balance in the soil-plant system, increasing soil organic C content, and enhancing soil quality parameters to a greater extent than grasses or radish.<br>**Microbe**: Winter crops increased soil microbial quality parameters compared to fallow in both tillage systems | Balota et al (2014) |
| 31 | Germany | Mustard, phacelia and buckwheat | Soybean | **Nutrient**: concentration of enzyme-labile P- organic was higher than that in the control<br>few changes in the bulk soil and only a limited carryover effect to soybean, except for fungi.<br>little differences among cover crop species | Hallama et al (2022) |
| 32 | Germany | winter cover crop | Soybean | **Microbial status:** Microbial phosphorus, phosphatase, and fatty acids increased under cover crops, indicating an enhanced potential for organic P cycling. | Hallama et al (2021) |
| 33 | Germany | cover crop mixture | Wheat | **Weed:** the great ability for weed control and highlight that soil conservation systems do not have to rely on chemical weed control practices. | Schappert et al (2018) |
| 34 | Germany | rye and barley | soybean | **Weed**: No difference in weed suppression was found between the two cover crops. The highest cover crop soil coverage was measured in the NT treatment. | Weber et al (2017) |
| 35 | France | ---- | Wheat | **Nutrient**: N use efficiency related traits were increased in the presence of CC both under NT and CT. | Habbib et al (2017) |
| 36 | France | crucifer, Ethiopan mustard, crimson clover | Wheat | **Water**:cover crops always reduce water drainage by 20-60 mm | Meyer et al (2020) |

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| | | | | | significantly reduce soil water content (0-120 cm deep) for the next cash crop by a mean of 20-50 mm, and up to 80 mm in dry spring conditions<br><br>No difference in soil water content was observed between the three cover crop treatments | |
| **37** | France | Oats, phacelia, flax , vetch, faba bean, Egyptian clover. | Wheat | | **Soil**: without N fertilization, conventional tillage plus standard cover crops strongly decreased the soil CN content and markedly increased potential soil polymer degradation<br><br>**Microbe**: Cover crops without N fertilization under no-till led to higher microbial functional activity | Nivelle et al (2016) |
| **38** | France | Mustard, vetch, vetch – oat | Wheat | | **Soil:** crops in grain-legume rotations mitigated the loss of soil organic carbon and nitrogen.<br><br>The use of cover crops was efficient to mitigate SOC and nitrogen losses and then increase N use efficiency at the cropping system level without reducing productivity | Plaza-Bonilla et al (2016) |
| **39** | South-East France | black medic,<br>alfalfa, red clover<br>and white clove | Maize or wheat | | **Nutrient**: None of the relay intercropped legumes affected the N uptake of the associated winter wheat but all significantly increased the N uptake of the succeeding spring crop, either maize or spring wheat.<br><br>**Yield**: The improvement of the N nutrition of the subsequent maize crop induced a 30 % increase in grain yield. | Amossé et al (2014) |
| **40** | Grignon, France | red fescue (Festuca rubra L.; Fr), bird's-foot-trefoil (Lotus | Wheat | | **Soil**: Compared with NT, total porosity and pore morphology changed little when a cover crop was grown in no-till except that, in the 0–10 cm layer, total porosity was consistently greater than in the absence of cover crop. | Carof, et al (2007) |

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| | | corniculatus L.; Lc) and alfalfa | | | |
| | southwestern France | legumes | Wheat | **Yield**: The insertion of cover crops in the cropping systems did not change wheat grain yield,<br><br>**Soil**: The insertion of cover crops in the cropping systems did not change uptake, or grain protein concentration<br><br>Cover crop reduced N fertilizer requirements without compromising subsequent cereal crop yield and grain quality. | Plaza-Bonilla et al (2017) |
| **41** | | | | | |
| | France | red fescue turf grass. | Wheat | **Yield**: The undersown red fescue decreased wheat yield by about 12% for Isengrain and 7% for Scipion | Picard et al (2010) |
| **42** | | | | | |

# Part 3

## Meta analysis Methods

Literature search

We performed a systematic search in December 2021 and updated it in April 2022, following the guidelines of PRISM. We used the Web of Science Core Collection and Scopus search engines to find studies using the following terms (table 4S)

Table 1: search syntax

| Crop diversification scheme | Search syntax |
|---|---|
| Field-scale | **"intercrop*" OR "crop diversification*" OR "polyculture" OR "crop mixture" OR "mixed crop*" OR "crop divers*" OR "crop* strip"** |
| local scale | **OR agri-environment* OR "flower strip" OR "riparian buffer" OR "riparian zone" OR "set aside" OR "hedgerow" OR "field margin" OR "buffer strip."** |
| Biodiversity | **arthropod* OR insect* OR beetle* OR carabid* OR spider* OR hoverfl* OR syrphid* OR parasitoid* OR wasp OR pollinat* OR bee OR bumble* OR syrph* OR butterfl* OR** "predat*" OR "biological control*" OR "pest control*" OR "natural en*" OR "pest manag*" |
| Main crops | **wheat OR maize OR soybean OR corn** |

The literature search resulted in 1'257 publications, which were narrowed down to 41 for both field and local scales based on inclusion and exclusion criteria. The following criteria were used to identify studies for the analysis:

Only data from the primary agricultural field experimental studies were included. We excluded primary studies conducted in laboratories or greenhouses, single observations, or missing an appropriate control. The articles described the crop diversification systems at the farm or/and local scale and reported a quantitative comparison of crop diversification outcomes compared to a relatively simplified farming system or natural habitat. The studies that would not provide enough information to differentiate the intervention were excluded. Other farm practices such as fertilizer, crop irrigation, crop rotation, and crop residue management had to be similar between plots, ensuring that the treatments were affected only by intervention. The papers published before 1999 and written in languages other than English and those lacking experimental data such as reviews or book chapters were excluded. If the study reported the results in multiple years, we extracted data in the last year of experience. Wheat, maize and soybean had to be included in the intercropping, and companion crops had to be harvestable and consumable (human consumption, animal feeding) at local scale. Besides following criteria were considered:

- If the study was conducted in multiple geographical areas, multiple companion crops, multiple AES species types, and multiple arthropod sampling dates after main crop cultivation, we extracted each area as a separate record.
- If the article didn't specify the sampling date or in the case of replicating the sampling procedure, we considered the mean of the first and last sampling date.
- If the study examined transgenic and non-transgenic crop species, we extracted data from non-transgenic species.
- The papers that examined intercropping between different cultivars were excluded.
- We included studies that reported the mean, the number of replicates and a measure of variability around the mean.

The manuscript was not included in the review when the abstract was unavailable. The entire paper was evaluated when the information in the abstract was insufficiently precise to fulfil the study criteria. If the publication was not available, it was not included in the analysis. Data were extracted from tables or graphs using WebPlotDigitizer (https://automeris.io/WebPlotDigitizer/).

The log response ratio as a measure of effect size was used to estimate the outcome of an experiment as the log-proportional change between the treatment means and control group. Publication bias test, Subgroup analysis and meta-regression were done. The Metafor package in R was used to conduct two separate meta-analyses for field and local scales.

## Reference:

Beillouin, D., Ben-Ari, T., & Makowski, D. (2019). A dataset of meta-analyses on crop diversification at the global scale. *Data in brief*, *24*, 103898.