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Toward climate-resilient and biodiverse agriculture in the Mediterranean region: experiences and perceptions of farmers engaged in sustainable food production

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Abstract The abandonment of smallholder agriculture and the expansion of conventional intensive agriculture pose a potential threat to the multifunctionality of agriculture. The adoption of intensive conventional practices generates negative outcomes, such as increased greenhouse gas emissions, biodiversity loss, and degradation of land, water, and ecosystems. An ecological transition in agriculture is urgently needed. This paper collects and systematizes the opinion of farmers in Spain, engaged in different food production systems (e.g., organic agriculture, biodynamic agriculture, regenerative agriculture, and conservation agriculture), as alternatives to intensive conventional agriculture. In collaboration with agricultural associations and networks in Spain, we co-created an exploratory online survey including qualitative and quantitative questions. Based on 60 in-depth questionnaires, we assess (1) the practices used by the consulted farmers, (2) the perceived effects following the introduction of sustainable practices, and (3) the challenges and opportunities for farm profitability. Our preliminary results show that farmers apply nine out of 14 sustainable practices, on average, and 65% of our sample consciously adapt their practices to climate change. Farmers perceived positive changes in soil properties, biodiversity, and pests after using these practices. They mentioned the low income as the most significant challenge. Finally, we conducted an online discussion with representatives of the associations. Farmers' perceptions of positive changes presented in this paper are not intended to be representative of farmer communities across Spain, but provide a first overview of those engaged in the ecological transition.

Keywords Biodiversity · Climate change · Multifunctional agriculture · Organic agriculture · Spain

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Introduction

The concept of multifunctionality is applied to agriculture to evaluate and emphasize its diverse functions for individuals and society (International Assessment of Agricultural Knowledge, Science and Technology for Development IAASTD 2009). The statement that "agriculture is multifunctional" (IAASTD 2009:2) is the first key message of the

IAASTD, an international collaborative project including more than 400 experts representing all continents and disciplines. Multifunctionality means that, in addition to food, agriculture can contribute to the protection of regional flora, fauna, water, air, and soil, as well as the offsetting of emissions and adaptation to climate change, depending on the management practices used in an agroecosystem. In addition, agriculture can provide multiple aesthetical landscape values connected to regional histories and traditions. These landscapes serve as spaces for recreation, facilitating physical activities with positive health effects and attracting tourism. Agriculture in all its dimensions remains a fundamental source of income and employment, sustaining local livelihoods (Cairol et al. 2009; IAASTD 2009; Jose 2009; OECD 2001; Ruiz Pulpón and Cañizares Ruiz 2022; Zagaria et al. 2018). The multiple functions of agriculture can be grouped under ecological, economic, and social dimensions, revealing the close relationship between multifunctionality and sustainability. Here, we define sustainable food production as "[production] that meets the needs of the present without compromising the ability of future generations to meet their own needs," based on the Brundtland report (Brundtland 1987), while also stressing the importance of considering those ecological, social, and economic dimensions.

Moreover, multifunctional agriculture can help to comply with the United Nation's Sustainable Development Goals (SDGs) and maintain the Earth system within identified planetary boundaries. Indeed, the four main transgressions of planetary boundaries are strongly connected to the negative impacts caused by the expansion of intensive conventional agriculture: loss of genetic diversity, pollution from high nitrogen and phosphorus inputs, land system changes, and the high inputs of fresh water that increase water scarcity worldwide, particularly in the Mediterranean area (Campbell et al. 2017; Cramer et al. 2018; IAASTD 2009; Persson et al. 2020; Rockström et al. 2009; Steffen et al. 2015). Traditional landscapes still exist among conventional western Mediterranean agriculture, but agricultural intensification and land abandonment are increasingly threatening them (Heider et al. 2021; Lomba et al. 2019; Plieninger et al. 2006).

Agroecology may provide solutions, preserving the multiple functions of agriculture. It describes a scientific discipline, set of practices, and social movement. In this study, we define agroecology as land management practices that aim for a sustainable farming system. These practices aim to stabilize and optimize yields while also providing a wide range of agroecosystem services. These services include the use of diversified crop systems, the replacement of external inputs (e.g., nitrogen and phosphorus) with natural processes, and efficient water use in heterogenous landscapes (Altieri and Nicholls 2012; Bernard and Lux 2017; Duru et al. 2015; Eyhorn et al. 2019; Hathaway 2016; IAASTD 2009; IPES-FOOD 2016; Martin et al. 2019; Pretty 2018; Reganold and Wachter 2016; Scarlato et al. 2021; Seufert et al. 2012; Via Campesina, 2010). A diversified crop system may imply additional costs at the beginning, but it can reduce the market risk for farmers, and brings positive economic impacts in the longer term (Martin-Górriz et al. 2022).

Agroecosystem services are strongly connected to ecosystem services and describe the positive services for the environment, economy, and society that an anthropized ecosystem such as agriculture can provide (Duru et al. 2015; Zabala et al. 2021a). Ecosystem services are usually divided into the areas of provisioning (e.g., food and fiber), regulating (e.g., climate regulation), and cultural services (e.g., nonmaterial services like recreation) since the Millennium Ecosystem Assessment (MEA) report (Balzan et al. 2020; Eliasson et al. 2022; MEA 2005). Notably, irrigation in agriculture can contribute to increase several agroecosystem services and social well-being (Alcón et al. 2022). Nevertheless, agriculture not only provides but also receives ecosystem services, sometimes contributing to their depletion (Campbell et al. 2017; Zhang et al. 2007), and to the generation of so-called ecosystem disservices, such as groundwater pollution or water scarcity from intensive irrigation (Zabala et al. 2021a; Zabala et al. 2021b).

In this study, we give a voice to the perceptions and experiences of farmers engaged in the ecological transition in Spain regarding challenges and opportunities for farm profitability, climate change, and the effects of implementing sustainable practices. Moreover, we assess the agricultural practices used by farmers engaged in different agricultural associations and networks. An assessment of the sustainability of practices can be helpful to (1) redirect public investment, (2) for farmers' self-assessment, and (3) for consumers to buy food with a positive impact on

Table 1 Agroecological practices in three categories and agroecosystem services associated with each principle

Agroecological practices	Services associated with each principle
Principle: increasing (agro)biodiversity	
Diversification of crops Integration of trees and bushes Crop rotation Integration of livestock Integration of natural zone	Biodiversity (Jose 2009; Kassam et al. 2012; IPBES 2019; Martin et al. 2019), soil maintenance (Altieri and Nicholls 2012; Sinclair et al. 2019), crop yield stability (Foley et al. 2011; Altieri and Nicholls 2012; Pretty 2018), pest control (Altieri and Nicholls 2012), water (Sinclair et al. 2019), water purification (Jose 2009; Sinclair et al. 2019), resilience (Jose 2009; Sinclair et al. 2019), climate regulation and carbon stocks (Gattinger et al. 2012; IPBES 2019), air quality regulation (Altieri and Nicholls 2012)
Principle: maintaining soil health	
Minimization of external inputs (e.g., pesticides, mineral fertilizer) Reduction of tillage Use of natural fertilizer (e.g., compost, green manure, legume cultivation)	Minimizing emissions of contaminants (Reganold and Wachter 2016), biodiversity (Reganold and Wachter 2016; Kassam et al. 2012; DeLeijster et al. 2019), soil maintenance (Kassam et al. 2012), water (Kassam et al. 2012; Foley et al. 2011; Montemurro et al. 2020), resilience (Kassam et al. 2012), carbon stocks (Gattinger et al. 2012; Kassam et al. 2012; DeLeijster et al. 2019; Martin-Gorriz et al. 2021), crop yield stability (DeLeijster et al. 2019), energy balance (Montemurro et al. 2020)
Principle: efficient water use	
Cover crops Contour farming and terraces Water harvesting Locally adapted crops	Biodiversity (Martin et al. 2019; Wagg et al. 2021), water (Altieri and Nicholls 2012; Foley et al. 2011; Elevitch et al. 2018, Montemurro et al. 2020), soil maintenance (Altieri and Nicholls 2012), pest control (Altieri and Nicholls 2012), resilience (Kassam et al. 2012), energy balance (Montemurro et al. 2020)

the environment. This led to the research questions explored in this paper:

- What are the perceptions and experiences of farmers engaged in sustainable food production?

The main research question above is further divided into the following sub-questions:

- Which sustainable management practices do the consulted farmers use?
- How do farmers adapt agricultural land and water management to climate change?
- What are the perceived effects on soil, biodiversity, and pests after the use of sustainable management practices?
- Which opportunities and challenges do farmers identify for farm profitability?

We co-created an exploratory online survey in cooperation with Spanish agricultural associations and networks engaged in sustainable food production. We applied a less divisive approach of sustainable food production by including also non-organic agriculture (e.g., conservation agriculture), therefore promoting the transition of conventional systems to organic systems and recognizing the existence of a system in between both (Debuschewitz and Sanders 2022; Rahmann et al. 2017). The online survey was answered by members of these associations and networks. Based on their answers, we explored (1) the sustainable practices used by the consulted farmers, (2) the ways in which the farmers adapted to climate change, (3) the perceived effects following their introduction of sustainable practices, and (4) the challenges and opportunities for farm profitability. Finally, we aimed to explain biodiversity improvements using a regression model.

Sustainable agricultural practices

Sustainable agricultural practices explored in this study were selected based on a literature review of agroecological practices and principles (Altieri and Nicholls 2012; Bernard and Lux 2017; Elevitch et al. 2018), based on a combination of local traditional (ecological) knowledge and innovations (FAO 2018, 2019). In this study, we focus on the ecological dimension of agroecology. Table 1 shows the three selected agroecological principles: (1) increasing (agro)biodiversity, (2) maintaining soil health, and (3) efficient water use. For each principle, we listed below a set of associated agroecological practices (left column), and the services associated with each principle (right column).

Micro-habitats storing water were not included; resilience describes the capacity of a system to absorb disturbances without changing the structure or losing its function (Adger 2000)

Data and methods

We co-created an exploratory online survey to learn about the experiences and perceptions of farmers engaged in sustainable food production. Our motivation is to give a voice to farmers who are weakly institutionalized but of high importance for the ecological transition in agriculture by providing agroecosystem services and complying with the SDGs (Reynolds et al. 2014). Often, individual farmers are part of a wider network or association promoting sustainable agricultural practices. Collaborating with these associations enabled our exploratory survey. This survey aims to identify characteristics of this growing group of farmers.

Co-creation of exploratory survey

We identified the interviewed farmers from five Spanish associations promoting sustainable food production and biodiversity.

- Sociedad Española de Agricultura Ecológica y Agroecología[1] (SEAE, Spanish Society of Ecological Agriculture and Agroecology)
- Olivares Vivos[2] (Living Olive Trees)
- Asociación de Agricultura Regenerativa Ibérica[3] (Iberian Regenerative Agriculture Association)
- Asociación Española de Agricultura de Conservación[4] - Suelos Vivos (Spanish Association of Conservation Agriculture - Living Soils)
- Associación para la Agricultura Biodinámica[5] (Association for Biodynamic Agriculture)

All associations aim to increase agroecosystem services, but they vary in the degree of appliance of agroecological practices. For example, farmers who use conservation agriculture might focus on the use of soil cover, reduction of tillage, and diversification of crops, while tolerating the use of agrochemicals. In other associations, the use of agrochemicals is not tolerated. Certified and non-certified organic farmers are included in the sample, besides hobby- and full-time farmers. The Association for Biodynamic Agriculture integrates the Demeter certification office. Demeter farmers, processors, and merchants are members of the association (Associación para la Agricultura Biodinámica 2023). Farmers' affiliations to the five associations appeared as an important aspect after conducting the survey. In consequence, a telephone and email tracing of the interviewees who left their contacts in the exploratory online survey was carried out to reconstruct their affiliations in Table 3.

In the first step of co-creation, we developed a draft version of the online questionnaire, including quantitative and qualitative questions, about sustainable practices, their perceived effects on the environment, and farm development. We sent this draft to the associations and asked for their feedback and edits to include their perspective from the beginning. After receiving their versions, we tried to bring as much perspectives as possible together in the final exploratory survey. The final questionnaire was conducted using LimeSurvey. It is structured in six sections: introduction, agroforestry practices, the state of agricultural land, agricultural practices, farm development, and demographic information. We queried the farmers about the practices they applied and their perception of the effectiveness of such practices. We contacted the farmers through their agricultural associations and networks, which distributed our survey among their members or subscribers via email or social media. After a successful test run, we announced the survey, distributed the link to the survey, and sent two subsequent reminders between October and November 2020. We assessed the results, using content analysis for qualitative questions, and statistical analysis for quantitative questions (Kuckartz 2014). The questionnaire contained 51 questions, lasting approximately 40 min. No financial compensation was paid. While our sample cannot be considered statistically representative for all farmers in Spain, it reflects the actual perceptions of a significant

[1] Sociedad Española de Agricultura Ecológica y Agroecología. Link: https://agroecologia.net/
[2] Olivares Vivos. Link: https://www.olivaresvivos.com/
[3] Asociación de Agricultura Regenerativa Ibérica. Link: https://www.agriculturaregenerativa.es/
[4] Asociación Española de Agricultura de Conservación. Link: http://www.agriculturadeconservacion.org/
[5] Associación para la Agricultura Biodinámica. Link: https://biodinamica.es/

group of farmers pioneering the integration of sustainable agricultural practices in the region.

Based on the survey results, we assessed the usage of sustainable practices. The selection of practices is based on a literature review focusing on agroecological practices and principles. The selected practices are shown in Table 1. Any given farm can score between zero (no practice applied) and 14 (all selected practices applied). Based on the practices, we calculated the implementation of sustainable practices per farm, and an overall appliance of sustainable practices among the consulted farmers. For each principle, the absolute and relative arithmetic mean is calculated based on the associated practices (Table 4).

Perceived effects of using sustainable practices

We asked for the farmers' (a) perception of the effects of their agricultural practices and (b) the changes they observed after using such practices. Regarding (a), they should classify their agreement between 0 (I don't agree) and 10 (I totally agree) for the following statements: My agricultural practices (1) build soil, (2) preserve biodiversity, and (3) do not contaminate water. For the assessment, we calculated the arithmetic mean of all farmers who answered these questions. Regarding (b), they should classify observed changes after applying sustainable practices (i.e., for soil properties from highly degraded to highly improved; for quantity/diversity of flora and quantity of fauna from much less to much more; for the occurrence of pests from much more to much less). In the statistical analysis, we quantified these qualitative answers on a scale from −2 (very negative) to 2 (very positive). The results of the perceived changes might be biased by motivated reasoning (Kunda 1990) and should not be considered actual outcomes. Instead, they should be interpreted as exploratory insight among a group of weakly institutionalized farmers engaged in sustainable food production. The results should be followed up by objective scientific measurements, which validate or falsify farmer's perceived effects.

Regression model

In the following step, we developed a regression model to find statistically significant independent variables that explain perceived improvements in biodiversity (dependent variable). Perceived improvements in biodiversity include increases in vegetation diversity, vegetation quantity, and animal diversity. We aggregated independent variables for the regression model based on the answers of farmers in the online survey. We used Stata 15 to conduct the regression analysis, the code being available upon request.

The reason for using this ordered regression model is the numeric categories of the dependent variables (e.g., possible values between −2 and 2). Furthermore, the ordered regression model avoids the uncertainty about distances between categories (Long and Freese 2006). We introduce the regression table for the dependent variable and add stepwise independent and control variables from left to right in the regression table (see Table 9). We use different versions of the model to show the stability of the results.

Given the limitations of our survey (i.e., sample size and representativeness), results should be interpreted carefully, also considering inherent weaknesses for surveys in the business context, i.e., possible response bias of a given profile of farmers (McCann et al. 2005) or underestimation of profitability. In the following, we present the selected independent variables for the models and our hypothesis about the relationship with the dependent variable perceived improvements in biodiversity.

Explaining perceived changes in biodiversity

Biodiversity and sustainable practices (PRAC): Biodiverse production systems are one of the outcomes of sustainable agricultural management (Altieri and Nicholls 2012; Tscharntke et al. 2012; Tuck et al. 2014; Reganold and Wachter 2016; Agroforestry Network 2018). Therefore, we test the hypothesis of a positive impact of sustainable practices on biodiversity.

Biodiversity and soil improvements (SOIL): Diverse and abundant vegetation contributes to healthy soils, and healthy soils favor biodiversity (Sinclair et al. 2019). Therefore, we test the hypothesis of a positive relationship between biodiversity and soil improvements.

Biodiversity and farm size (AREA): Biodiverse farms under agroecological management are often discussed in the context of smallholders or landscapes with small or irregularly shaped fields (Altieri and Nicholls 2012; Oliver 2016; Morel et al. 2017; Björklund et al. 2019; FAO 2019; Martin et al. 2019;

Mestmacher and Braun 2020). Therefore, we test the hypothesis of a positive impact of small farm size on biodiversity.

Biodiversity and farm profitability (PROFIT): In the literature, authors discuss the yield gap between conventional and organic farming (Seufert et al. 2012; Muller et al. 2017). Generally, yields are lower under organic management but opportunities to close the yield gap may arise under drought conditions and sustainable intensification (Reganold and Wachter 2016; Pretty 2018). Furthermore, reduced costs due to low inputs and price premiums represent advantages for farm profitability under organic management (Pretty et al. 2003; IPES-FOOD 2016; Reganold and Wachter 2016; Morel et al. 2017; Pretty 2018). Consequently, the relationship between biodiversity and farm profitability remains unclear.

Biodiversity and self-supply (SELFSU): Increasing agrobiodiversity creates diverse local food production, which serves self-sufficiency and local consumption (food sovereignty) (Altieri and Nicholls 2012; Björklund et al. 2019; Altieri and Nicholls 2020). Farmers who cultivate a high diversity of crops are more likely to cover a larger share of their diet. Therefore, we test the hypothesis of a positive impact of biodiversity on self-supply.

Biodiversity and gender (GENDER): Several authors state the important role of women in promoting biodiversity (Sardaro et al. 2016; Mestmacher and Braun 2020). Therefore, we test the hypothesis of a positive impact of self-declared non-male farmers on biodiversity.

Online discussion of results

As part of the co-creation, we organized an online presentation and discussion of results for the representatives of the associations on July 14th, 2023, receiving valuable feedback and further insights on their principles, common visions, and collaborations. Extracts are integrated in the "Results" section.

Results

Overall, 56 farmers completed the online survey. Most of the farmers are male, with an average age of 48 years. More than 60% studied at university (Table 2). On average, they have been farming for 15 years. Their farm size is very heterogenous, varying between 3 m^2 and 2000 hectares (median value: 12 hectares, 25% of farms are smaller than 4250 m^2). As mentioned above, we include hobby- and full-time farmers. Frequently cultivated plants include olives, cereals (i.e., barley, wheat, corn, and oat), vegetables (including legumes), and a variety of fruits. Half of the consulted farmers do not irrigate (mostly cultivating olives, almonds, cereals, and meadow), 20% use an irrigation system, and 30% apply both. Some farmers have livestock (e.g., chickens, sheep, and cows). Most of the farms are in Andalucía, followed by Catalunya, Castilla y León, and Castilla-La Mancha (Fig. 1, from dark green to light green).

Table 2 Demographic information of consulted farmers who completed the exploratory survey

Demographic variable	Sample ($N = 56$)
Gender	
Female	14.3%
Male	82.1%
Diverse	1.8%
No answer	1.8%
Average age	48
Education	
Obligatory school education	7.1%
A-levels	12.5%
Professional formation	12.4%
University studies	66.1%
No answer	1.8%

The affiliations of the consulted farmers are shown in Table 3. All associations that collaborated in this study are represented by a minimum of three respondents (i.e., c. 6–12% of the overall sample). Over a quarter (30%) of the farmers in the sample did not provide their affiliation, perhaps because they no longer work on the farm, and/or due to "questionnaire fatigue." Some 8% of the respondents (i.e., 4) responded "None of these" under affiliation. A reason might be that they are not official members and accessed the questionnaire through the social media channels of the associations. Another 16% (i.e., 8) declared belonging to "Several associations, others."

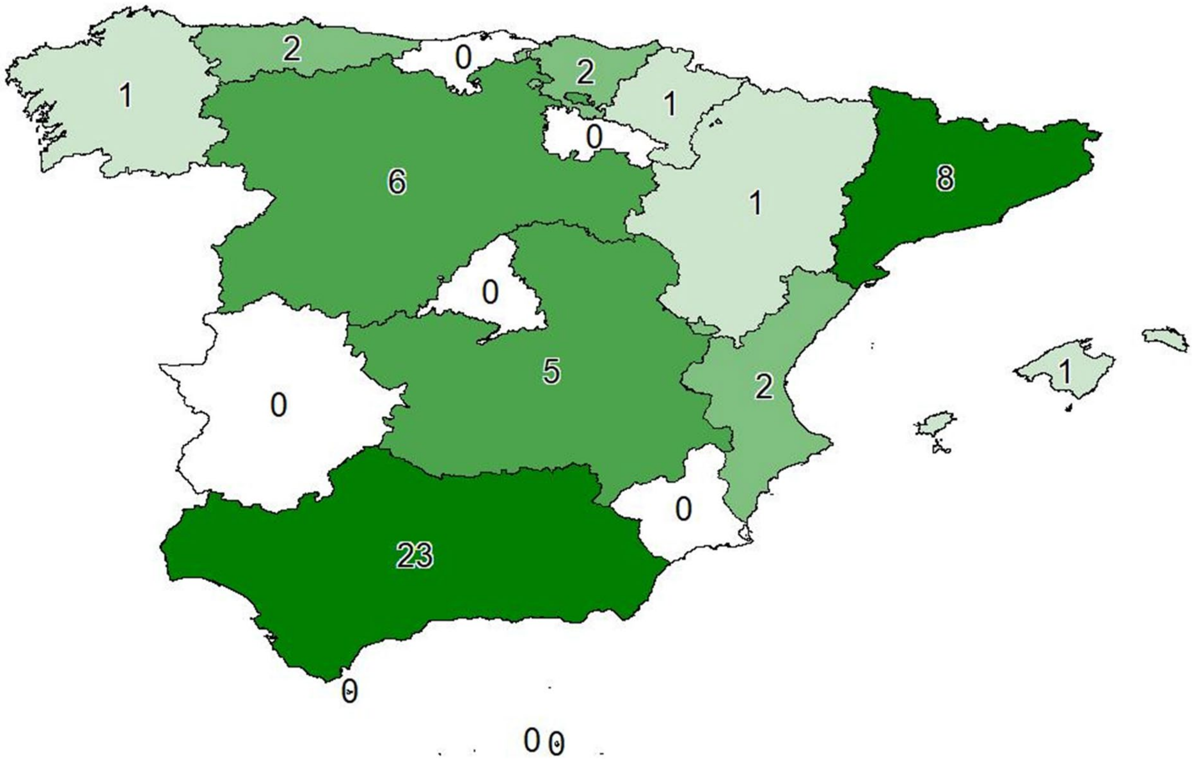

Fig. 1 Location of 52 farmers who shared their geographic location in the exploratory online survey

Table 3 Affiliation of consulted farmers who completed the exploratory survey (*N* = 50)

Affiliation variable	Absolute	Relative [%]
No answer	15	30
Sociedad Española de Agricultura Ecológica (SEAE)	6	12
Olivares Vivos	3	6
Asociación de Agricultura Regenerativan Ibérica	6	12
Asociación Española de Agricultura de Conservación – Suelos Vivos	3	6
Associación para la Agricultura Biodinámica	5	10
None of these	4	8
Several associations, others	8	16
Total	50	100

In the following analyses, the sample size might change in the result tables. Some analyses are based on the answers of 56 farmers who completed the exploratory survey entirely, including the demographic information (i.e., Table 2). Other analyses are based on the answers of 69 farmers who completed the first part of the exploratory survey and associated topics (i.e., Tables 4 and 5).

Assessment of applied sustainable practices

In this section, we present the sustainable practices used among the consulted farmers. Table 4 shows the appliance among farmers of 14 sustainable agricultural practices in three categories (i.e., increasing (agro)biodiversity, maintaining soil health, and efficient water use). The subsequent agroecosystem

Table 4 Percentage of farmers applying agroecological practices. Practices are assigned to three agroecological principles (bold): increasing (agro)biodiversity, maintaining soil health, efficient water use

Agroecological practices	Absolute	Relative [%]	*N*
Principle: increasing (agro) biodiversity	**34.8**	**55.2**	**63**
Diversification of crops	32	50.8	63
Integration of trees and bushes	46	73.0	63
Crop rotation	34	54.0	63
Integration of livestock	23	36.5	63
Integration of natural zone	39	61.9	63
Principle: maintaining soil health	**46.4**	**73.7**	**63**
Reduction of external inputs:			
No herbicide	44	69.8	63
No pesticide	47	74.6	63
No chemical fertilizer	42	66.7	63
Reduction of tillage	49	77.8	63
Use of natural fertilizers, e.g., compost, green manure, legume cultivation	50	79.4	63
Principle: efficient water use	**35**	**55.6**	**63**
Cover crops	49	77.8	63
Contour farming and terraces	31	49.2	63
Water harvesting	29	46.0	63
Only locally adapted crops	31	49.2	63

Table 5 Overview of practices used to adapt to climate change ($N = 63$)

Practice	Absolute	Relative [%]
Soil cover	14	22.2
Reduction of tillage	7	11.1
Rainwater collection	6	9.5
Integration of livestock	5	7.9
Change of harvest/sowing date	3	4.8
Installation of drip irrigation	3	4.8
Usage of solar panels for irrigation	3	4.8
Cultivation of plants adapted to climate	2	3.2
Contour farming (keyline approach)	2	3.2

services provided depend on the practices used (see Table 1). On average, 55.2% of the farmers applied sustainable practices from the first category: increasing (agro)biodiversity, i.e., diversification of crops, integration of trees and bushes, crop rotation, integration of livestock, and integration of natural zone. The most popular practices in this category are integrating trees and bushes (73% appliance) and integrating a natural undisturbed zone (61.9%). Furthermore, all consulted farmers who integrated livestock described their grazing as extensive (e.g., Holistic Management in Savory and Butterfield 1999, Voisin Rational Grazing in Pinheiro Machado Filho et al. 2021, traditional grazing on olive and almond fields). Most of the livestock farmers apply a recovery period for their pasture between 10 and 365 days.

On average, 73.7% of the farmers applied the practices from the second category: maintaining soil health. In this category, every practice was applied by at least 66.7% of the farmers. The most popular practices are the use of natural fertilizers (79.4%) and the reduction of tillage (77.8%). The practices from the category increasing water use efficiency were applied by 55.6% of the farmers on average, and the most common practice is the usage of cover crops (77.8%). The least popular practices among all categories are the integration of livestock (36.5%) and three practices to increase water use efficiency, i.e., water harvesting (46%), contour farming (49.2%), and the use of locally adapted crops (49.2%).

On average, farmers apply 8.7 practices (out of the 14 listed above), the maximum number of practices reached among 63 farmers is 13, and the minimum 2.

Economic or cultural services are not included in Table 4. Nevertheless, the results from the exploratory online survey show that 68% of farmers have employees promoting the local economy.

Adaptation to climate change

Climate change affects the life of farmers. The agricultural activity of almost all farmers suffered under climate-related extreme events. A drought had negative effects on agricultural production for 84.1% of farmers, and heat waves affected 66.7% of farmers. A total of 41.3% of farmers mentioned negative effects on agriculture due to heavy rainfall.

Many sustainable practices help to adapt to a changing climate. Sixty-five percent of 63 farmers adapted their agricultural activity consciously to climate change. Table 5 shows which practices are used by the consulted farmers to adapt to climate change: 22.2% of farmers applied soil cover as an adaptation strategy, followed by the reduction of

Table 6 Perception of the environmental effects of own agricultural practices on soil building, biodiversity preservation, and water quality. Farmers classified their agreement between 0 (I don't agree) and 10 (I totally agree) for the following statements: My agricultural practices (1) build soil, (2) preserve biodiversity, and (3) do not contaminate water

	Min	Max	Mean	Median	Std. dev	*N*
Soil building	0	10	8.42	10	2.1	69
Biodiversity preservation	2	10	8.69	10	1.8	69
No water contamination	2	10	8.63	10	1.9	69

Table 7 Perception of degradation and recovery of agricultural lands after using sustainable agricultural practices. Farmers were asked to classify land degradation and recovery after applying agroecological practices from highly degraded (−2) to highly improved (2) as well as the effect on biodiversity from much less (−2) to much more (2) and pests from much more (−2) to much less (2)

	Min	Max	Mean	Median	Std. dev.	*N*
Change of soil properties						
Biological properties	0	2	1.44	2	0.66	63
Chemical properties	0	2	1.28	1	0.52	60
Physical properties	0	2	1.33	1	0.62	63
Hydrological properties	−1	2	1.37	1	0.65	62
Biodiversity						
Quantity of flora	0	2	1.40	1	0.61	62
Diversity of flora	0	2	1.28	1	0.66	61
Diversity of fauna	−1	2	1.20	1	0.65	60
Pests	−1	2	0.67	1	0.75	60

tillage (11.1%). A total of 9.5% of farmers adapted their activity by collecting rainwater for irrigation, and 7.9% integrated livestock. Due to observed changes in the growing period, 4.8% of farmers adapted their sowing and harvesting dates. The same percentage installed drip irrigation using solar panels as a renewable energy source mitigating emission from the irrigation system. Furthermore, 3.2% of farmers changed their cultivated crops to climate-adapted crops, and the same percentage applied contour farming to reduce runoff, soil erosion, and better use of water and nutrients (i.e., the keyline approach in Yeomans 1958).

Perceived effects of using sustainable practices

Table 6 shows the farmers' perception of the effects of their agricultural practices on the environment. We analyzed the agreement between 0 (I don't agree) and 10 (I totally agree) for the following statements: My agricultural practices (1) build soil, (2) preserve biodiversity, and (3) do not contaminate water. The arithmetic means for all three statements vary between 8.42 and 8.69, and the medians are 10 (i.e., more than half of the answers were 10) with standard deviations between 1.8 and 2.1. Consequently, farmers perceive their agricultural practices as positive or very positive for the environment.

Table 7 shows the perceived changes in soil properties, biodiversity, and the occurrence of pests since the farmers introduced sustainable management practices. A negative change is represented by a negative value (−2, −1), no change is shown as 0, and a positive change as a positive value (2, 1). Table 7 shows that the arithmetic means of the observed changes after applying agroecological practices are positive for all categories. In almost all cases, the arithmetic means lie between improved (1) and highly improved (2). Only the arithmetic mean of pest occurrence lies between no change (0) and improved (1). The highest value is reached for the change of biological soil properties, where the arithmetic mean is 1.44 and the median value 2.

Table 8 Challenges (N = 36) and opportunities (N = 50) for farm profitability (multiple answers are possible)

	Absolute	Relative [%]
Challenges		
Low price	14	39
High costs	8	22
Not enough production	6	17
Bureaucracy	4	11
Lack of climate adaptation	3	8
Difficulty of sale	3	8
Lack of motivated workers	2	6
Opportunities		
Low inputs/costs	15	30
High quality/organic	9	18
Processing of products	5	10
Direct sale	5	10
Diversity/diversification	3	6
Dedication/pleasure	3	6

Challenges and opportunities for farm profitability

Finally, we present the results regarding farm profitability as well as the challenges and opportunities farmers are facing (Table 8). Overall, 36% of the farmers responded that their farm is profitable, 53% responded partly profitable, and 11% responded not profitable (N = 56). The most important source of subsidies for farmers is the CAP. Seventy-seven percent of consulted farmers receive subsidies from the CAP, and 63% of these farmers explained that their farm would not be profitable without these subsidies.

The farmers mentioned as most important challenges (1) the low prices they obtain for their agricultural production, (2) the comparatively high costs they have, and (3) a lack of production to cover their costs (Table 8). Furthermore, they complained about the high bureaucracy in Spain, e.g., the permission procedure to integrate livestock in agriculture using a holistic management approach (Savory and Butterfield 1999). Farmers mentioned a lack of climate adaptation, especially regarding the high irrigation needs for the cultivated crops conflicting with the water scarcity in some regions. Moreover, some farmers mentioned difficulties selling their products due to a lack of clients in the surrounding area, difficulties in selling their products online, and the expectation of clients for low prices of agricultural products. Finally, farmers mentioned a lack of motivated workers.

Nevertheless, the consulted farmers identified multiple opportunities for agroecological projects in Spain. The most important opportunities for agroecological projects are seen in (1) the low costs, mainly due to low inputs used under agroecological management, (2) the high quality of products and/or organic production, which differentiates their products from products under conventional management, the latter being exposed to the use of agrochemicals during the production, (3) in-house processing of products and direct sales, which enable to add value and a higher income for farmers as well as the exclusion of intermediaries. Furthermore, (4) the farmers identified the diversity of products and a diversification of on-farm activities as an opportunity, which makes them more resilient to disturbances. Finally, (5) some farmers mentioned their dedication and pleasure as an important non-monetary opportunity for a good life.

Comparing the support farmers receive for more sustainable production, they felt the strongest support coming from associations, followed by clients. In contrast, they identified a lack of political support on multiple levels (i.e., EU, Comunidad Autónoma, and village/city).

Regression analysis

The regression model shows two statistically significant variables to explain perceived changes in biodiversity (Table 9). The coefficients show that the higher the number of sustainable practices applied (PRAC), the higher the perceived biodiversity; similarly, the higher the perceived soil improvement (SOIL), the higher the perceived biodiversity. The other selected variables were not found to be statistically significant and are therefore not further discussed. Moreover, all the models are statistically significant (χ^2) at 5%. The model's explanatory power is expressed in the pseudo-R^2 and must be interpreted carefully because the certainty of pseudo-R^2 is not similar to an R^2 of the ordinary least square method (Long and Freese 2006). The coefficients of the logistic regression are difficult to interpret numerically. It is more interesting whether the statistically significant relationships are positive or negative.

Table 9 Regression model: ordered logit regression models to explain biodiversity changes. Model 1 without demographic information. Models 2–4 aggregate stepwise demographic and control variables

	Model 1		Model 2		Model 3		Model 4	
	Coef.	Std. error	Coef.	Std. error	Coef.	Std. error	Coef.	Std. error
PRAC	0.252*	0.145	0.241	0.148	0.272*	0.156	0.265*	0.158
SOIL	4.611***	0.862	4.442***	0.854	4.445***	0.858	4.364***	0.854
AREA	−0.000	0.001	−0.000	0.001	−0.000	0.001	−0.000	0.001
PROFIT	−0.122	0.465	−0.129	0.466	−0.180	0.479	−0.156	0.486
SELFSUF	0.008	0.009	0.008	0.009	0.009	0.009	0.009	0.010
EDUCATION	-	-	−0.060	0.319	−0.006	0.331	−0.012	0.329
GENDER	-	-	-	-	−0.581	0.877	−0.544	0.876
LOCATION	-	-	-	-	-	-	0.084	0.247
LR χ^2	46.58		43.78		44.22		43.20	
Prob > χ^2	0.0000		0.00		0.00		0.00	
No. of observations	49		47		47		46	
Log likelihood	−53.16		−51.64		−51.42		−50.44	
Pseudo-R^2	0.3046		0.2977		0.3007		0.2999	

*Statistically significant at a level of 0.1, **statistically significant at a level of 0.05, ***statistically significant at a level of 0.01; *PRAC*, sustainable practices; *SOIL*, perceived improvements in soil; *AREA*, farm size; *PROFIT*, profitability; *SELFSUF*, self-sufficiency; *EDUCATION*, education of farmers; *GENDER*, self-declared gender of farmers; *LOCATION*, farm location

The partner associations, their visions, and collaborations

After completing the analysis, we organized an online presentation and discussion of the results with the partner associations involved in the project, integrating new knowledge and reflections from the perspective of the stakeholders. For example, we gained insight on how the representatives of the associations perceive the frameworks (principles and practices) of each other and how they work together.

> *I think all [associations] have more or less the same objective (…) to go towards sustainable agriculture. It is true that there are things that I think we have in common and others perhaps not. We differ in how to get there, perhaps the means (Representative of Conservation Agriculture – Suelos Vivos, 07/14/2023).*

During the discussion of the results, some interventions provided a sample of existing types of collaboration between associations:

> *We have collaborated with Olivares Vivos. They started to integrate livestock in the olive groves and started to use grazing as a management tool (Representative of Agricultura Regenerativa Ìberica, 07/14/2023).*
> *On occasion, we have worked with environmental organizations, and we have also worked on topics related to organic agriculture (…), especially in woody crops, where it is easier to bring together the principles of conservation agriculture and organic agriculture. But in other cases, it is not that easy, because conservation agriculture uses, for example, phytosanitary products in no tillage farming (…). In this case, we have different ways of approaching sustainability, but this does not mean that any of these approaches cannot be accommodated in the current production model (Representative of Conservation Agriculture).*
> *Yes, I agree (…)We want to improve the lives of producers to begin with, to help that their conditions and opportunities improve, so that the agricultural landscape does not die. That is a huge common goal. And that this land remains in the hands of the farmers who work on it and is not bought by huge investment funds (…) (Representative of Agricultura Regenerativa Ìberica).*

Virtual fencing was mentioned as a solution for the use of steep and inaccessible landscapes, or for managing unfenced grazing areas while also enabling regeneration of previously grazed lands. The technique uses a "collar" with geolocation, and sensors to control the location of livestock remotely without the need for an actual fence. This solution has the potential to expand the frontier of extensive grazing to common lands where traditional fencing cannot be implemented.

The last excerpt below exemplifies instances where cooperation among associations is impeded by the CAP (common agricultural policy of the European Union).

> *Unfortunately, we have seen where we use grazing as a management tool, that the new CAP, although it favors and encourages people to use cover crops in woody crops, it does not favor grazing as a management tool. Unfortunately, they pay you more if you use machinery (…) The CAP is like a lost opportunity to go a little further with what could be done (Representative of Agricultura Regenerativa Ìberica).*

Discussion

This study shows that the consulted farmers perceive positive effects on the environment after applying sustainable management practices. In detail, they observed the most positive changes in soil properties and biodiversity (see Table 7) confirming the result of, e.g., Santoni et al. (2022). The average number of practices applied is 8.7 (out of 14) among 63 farmers. We found the highest level of application for practices to maintain soil health (73%). Additionally, more than 50% of farmers applied sustainable agricultural practices to increase (agro)biodiversity and efficient water use. Applying these practices contributes to reducing negative effects from agriculture (e.g., GHG emissions, soil degradation, and biodiversity loss) and increasing agroecosystem services (e.g., climate regulation, soil health, and biodiversity), establishing climate-resilient and biodiverse agriculture (see Table 1). Some of these practices have been subsidized by the CAP under the keywords of cross-compliance and greening (e.g., crop diversification and integration of natural zones). However, there have been low demands requiring little changes and numerous exemptions from applying these practices. Therefore, the effectiveness of greening measures for biodiversity has been assessed as low (Pe'er et al. 2017).

The loss of genetic diversity is among the main transgressions of the planetary boundaries and has entered the zone of high risk for abrupt and irreversible changes (Persson et al. 2020; Rockström et al. 2009; Steffen et al. 2015). Agriculture is estimated to play a major role in this transgression (Campbell et al. 2017), and further loss of biodiversity hotspots is projected (Habel et al. 2019). Thus, it is important to reduce negative impacts and identify factors that support biodiversity in agriculture. Based on the exploratory survey results, we conducted a regression model to better understand which variables interrelate with the perceived biodiversity improvements. In the model, we saw that biodiversity improvements, soil improvements, and applying sustainable practices (Table 1) go hand in hand.

In this study, we focused intentionally on the perspectives of farmers engaged in sustainable food production or in the transition to a more sustainable system, avoiding another comparison between conventional and organic agriculture (Debuschewitz and Sanders 2022). In collaboration with agricultural associations and networks engaged in sustainable food production, we co-created our exploratory survey with the advantage of including the knowledge of our stakeholders already in an early research stage. This process led to an extensive questionnaire with 51 questions and we relied on the goodwill of farmers to spend approx. 40 min to fill it out. To address the study's limitations of its small sample size in the future, we suggest expanding this exploratory survey among a larger number of farmers, in several Mediterranean countries, by reducing the number of questions to gain a more representative sample size. Moreover, the perceived effects should be interpreted carefully under consideration of potential bias due to motivated reasoning (Kunda 1990). While our results need to be validated by regular scientific measurements in the long-term, our exploratory study gives a first impression of the experiences and perceptions of farmers engaged in sustainable food production, opening new research questions.

European, national, and local policies must include the experiences of farmers who provide agroecosystem services and therefore avoid land degradation and land abandonment in the future. Therefore, we suggest concentrating on the practices applied and the agroecosystem services produced for the attribution of financial aid. Following the principle of public money for public (agroecosystem) services would give smallholders and sustainable land management the chance to expand. This is especially important because the most important challenge mentioned by the consulted farmers is the low income. Unfortunately, most public funding is still granted to large-scale agriculture applying conventional practices and producing negative effects for the environment (Foley et al. 2011; Reganold and Wachter 2016; Campbell et al. 2017; Chemnitz 2019; Eyhorn et al. 2019). At the same time, the consulted farmers, who produce agroecosystem services for the environment and society, struggle to make a living. Most of them are dependent on subsidies from the EU and claim a lack of political support. Here, we suggest an assessment of sustainable practices applied as a tool to include public services provided by agroecosystems as an incentive for public investment. Moreover, full-cost accounting, which includes the negative effects of unsustainable agricultural management in the price of food, would remove price distortions and incentivize sustainable consumption (Arbenz et al. 2016; Eyhorn et al. 2019; Rahmann et al. 2017). High costs for farm activities are the second most important challenge mentioned by the consulted farmers, confirming experiences of farmers related to mechanization costs and the need of buying fodder in response to frequent droughts (Veysset et al. 2023).

Moreover, we suggest using an assessment of sustainable practices as a tool for different actors. First, local, regional, and national authorities can use it to redirect public investments in projects and programs, which support sustainable development based on agroecology. The assessment could also be used to monitor the advances in the ecological transition in a territory, in the context of the European Green Deal, for example. Second, farmers can assess their practices themselves on the way to organic management or agroecology, which helps them implement new methods as best practices. Furthermore, they can use it in their communication, considering the increasing demand for local organic food.

On an international scale, the support of sustainable agricultural management allows a country to comply with its international obligations regarding the reduction of CO_2 emissions (Paris Agreement), biodiversity protection (Convention on Biological Diversity), combating land degradation (Convention to Combat Desertification), and complying with the SDGs (Van Leeuwen et al. 2019). At the same time, it offers an inestimable potential for food autonomy, regenerating degraded lands and increasing resilience to extreme events. Currently, agriculture is one of the biggest GHG emitters and one of the main drivers for biodiversity loss (Campbell et al. 2017), but using agroecology, the sector can be one of the biggest GHG storages, while contributing to increased biodiversity. This preliminary study explores the experiences of farmers beginning the transition to sustainable food production in Spain. This transition is led by committed farmers organized in associations, regional cooperatives, and networks (i.e., SEAE, Olivares Vivos, Associación de Agricultura Regenerativa Íbera, Associación de Agricultura Biodinámica, and Associación de Agricultura de Conservación). Reckoning and addressing their challenges, as well as incentivizing their work, promotes this transition.

Conclusion

In this study, we explored the experiences and perceptions of farmers engaged in sustainable food production in Spain, based on an in-depth exploratory online survey. Addressing their needs and challenges is important to avoid land degradation and future abandonment of land, while also incentivizing multifunctional agriculture. Our exploratory and preliminary results show: most of the farmers (75%) used practices to maintain soil health, such as the use of natural fertilizers, reduction of tillage, and no use of pesticides. Moreover, many farmers integrate trees, bushes, and cover crops. After applying sustainable management practices, the farmers perceived positive changes in soil, biodiversity, and pest occurrence. Perceived biodiversity improvements, improvements in soil properties, and the use of sustainable practices are strongly related. Any perceived effects will need to be validated in the next step with long-term scientific measurements.

The most important opportunities offered by sustainable practices that were mentioned by the farmers were the low inputs. It enabled them to reduce costs and produce high/organic quality. However, the most pressing challenge was the low selling price. Therefore, we argue that farmers who use sustainable management practices and produce positive services for society and the environment should receive strong financial support from European, national, and local policies.

We argue for an assessment of sustainable practices to examine agroecosystem services at the farm level. Various actors can use these assessments. Local, regional, and national authorities can use them to redirect public investment, and farmers can use them for self-assessment and communication with customers.

This study was limited by its small sample size and by a potential bias due to the motivated reasoning of the farmers. Additionally, our results are not representative of farmers across Spain because we included only farmers engaged in sustainable food production via affiliations to associations or networks. However, our exploratory survey was co-created with agricultural associations across Spain and the results give insides to the experiences and perceptions of a group of farmers who promote the ecological transition in agriculture. Further research is needed to quantify the multiple services produced under sustainable agricultural management using a holistic approach in long-term studies.

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Declarations

Ethical approval All farmers gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the principles of ethics in research as outlined by the Bylaws for Safeguarding Good Scientific Practice and Avoiding Scientific Misconduct at Universität Hamburg (Universität Hamburg, 2014) and the Guidelines for Safeguarding Good Research Practice (DFG, 2019) in Germany.

Conflict of interest The authors declare no competing interests.

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