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Research

Participatory monitoring and evaluation to enable social learning, adoption, and out-scaling of regenerative agriculture

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ABSTRACT. The advanced state of land degradation worldwide urges the large-scale adoption of sustainable land management (SLM). Social learning is considered an important precondition for the adoption of innovative and contextualized SLM. Involving farmers and researchers in participatory monitoring and evaluation (PM&E) of innovative SLM such as regenerative agriculture is expected to enable social learning. Although there is a growing body of literature asserting the achievement of social learning through participatory processes, social learning has been loosely defined, sparsely assessed, and only partially covered when measured. Here, we assess how PM&E of regenerative agriculture, involving local farmers and researchers in southeast Spain, enabled social learning, effectively increasing knowledge exchange and shared understanding of regenerative agriculture effects among participating farmers. We measured whether social learning occurred by covering its social-cognitive (perceptions) and social-relational (social networks) dimensions, and discussed the potential of PM&E to foster SLM adoption and out-scaling. We used fuzzy cognitive mapping and social network analysis as graphical semiquantitative methods to assess changes in farmers' perceptions and shared fluxes of information on regenerative agriculture over approximately three years. Our results show that PM&E enabled social learning among participating farmers, who strengthened and enlarged their social networks for information sharing and presented a more complex and broader shared understanding of regenerative agriculture effects and benefits than pre PM&E. We argue that PM&E thereby creates crucial preconditions for SLM adoption and out-scaling. Our findings are relevant for the design of PM&E processes, living labs, and landscape restoration initiatives that aim to support farmers' adoption and out-scaling of innovative and contextualized SLM.

Key Words: *fuzzy cognitive mapping; living labs; natural resource management; perceptions; social networks; sustainable land management*

INTRODUCTION

The way of thinking defines the way of acting, and our actions define how to build the future of the living planet (Andean farming community).

The advanced state of land degradation, affecting more than 3.2 billion people worldwide, has raised international concern regarding the sustainability of social-ecological systems (IPBES 2018) and urges the large-scale adoption of contextualized sustainable land management (SLM; Cherlet et al. 2018). SLM is also of vital importance for nature-based climate change adaptation and mitigation strategies (Sanz et al. 2017, Eekhout and de Vente 2019). While both scientific and local knowledge have strongly advanced our understanding of the effectiveness of SLM practices, large-scale implementation is lagging behind and is only possible when farmers' and landowners' livelihoods and communities are at the heart of such initiatives (Reed et al. 2011, Bouma 2019, Albaladejo et al. 2021).

Farmers' SLM adoption remains a major contemporary challenge, particularly in light of the need to change dominant farming paradigms and engage in more sustainable farming practices across all sectors and farm types. This challenge and quest for a transition toward more sustainable land use is also reflected in the Land Degradation Neutrality targets of the United Nations Convention to Combat Desertification (https://www.unccd.int/actions/ldn-target-setting-programme), the United Nations Sustainable Development Goals, and the European Union Green Deal and its Farm to Fork and Biodiversity Strategies (European Commission 2019, European Environment Agency 2019; European Commission Just Transition Mechanism https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/finance-and-green-deal/just-transition-mechanism_en). A myriad of factors influences the complexity surrounding farmers' SLM adoption, including: assets; ambitions; values; agronomic, financial, market, and policy barriers and opportunities; farmland characteristics; knowledge and access to information on SLM; and social networks (Schoonhoven and Runhaar 2018, Chinseu et al. 2019). Enabling environments, including policy and legal frameworks, regulations, markets, sector infrastructures with stable configurations, and education and extension systems are needed to support the transition to SLM (Sutherland et al. 2015, Pinto-Correia and Azeda 2017, Kuhmonen 2018). It is particularly important to stimulate the creation of tight collaborative networks that enhance farmers' acquisition and sharing of knowledge and to stimulate social learning that is an increasingly recognized key factor for successful SLM adoption (Wals 2007, Kristjanson et al. 2014, Ensor and Harvey 2015, Hermans et al. 2017).

Social learning is important to facilitate the adoption of SLM and for transitions in environmental management in general (Pahl-Wostl et al. 2007) because farmers' mental constructions and perceptions have great influence on their farming practices (Segnon et al. 2015, Vuillot et al. 2016, Teixeira et al. 2018). For instance, Liu and Luo (2018) found that knowledge of land

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conservation practices most influenced farmers' land use behavior. Similarly, Dessie et al. (2012) found that participatory research involving farmers and researchers enabled social learning, which translated into higher farmer adoption of soil terraces compared to farmers who did not participate in the research. Participatory processes characterized by discursive fairness fostering knowledge exchange between farmers, researchers, and other stakeholders to address issues of common interest may strengthen the creation of relations of support and trust among participants and the integration of different knowledge gleaned from one another to develop new shared understanding (Scholz et al. 2014).

Social learning acquires special relevance when it comes to innovative SLM for which there are no or limited previous experiences that can serve as reference upon which farmers can build. Innovative SLM refers to novel and alternative practices and methods that aim to integrate the management of land, water, and environmental resources and that challenge the status quo of mainstream approaches commonly used in an area. Like all innovations, innovative SLM therefore involves higher implementation risk than SLM that is well established and tested in the area.

Social learning processes for adoption of sustainable land management

To increase its impact, research needs to be designed effectively to fit, accompany, and facilitate the processes through which individuals, communities, and societies learn and adapt their behavior to environmental and socioeconomic changes (Ensor and Harvey 2015). Research supporting social learning through an iterative process of working together with farmers in a continuous partnership, in which new knowledge and collective understanding emerge by integrating different knowledge systems, may substantially contribute to expedite SLM adoption (Harvey et al. 2013). This idea is particularly relevant because farmers' perceptions and beliefs about farm management practices are often grounded in tradition and long-term practice, supporting path dependency (Darnhofer 2020). Together with the lack of knowledge and the uncertainty regarding the effects of adopting innovative SLM, this idea often hampers the transition to SLM (Zinck and Farshad 1995, Schwilch et al. 2011, Marques et al. 2015). However, there is evidence that bottom-up and locally driven processes stimulate the accumulation of experience and learning; as knowledge increases, initial beliefs are updated, the use of the innovation becomes increasingly efficient (Darnhofer et al. 2016, Fieldsend et al. 2021), and uncertainty about innovation performance and perceived barriers tend to ameliorate, eventually leading to farmers' innovation adoption (Monge et al. 2008, Harvey et al. 2013).

Following Reed et al.'s (2010) definition, we understand "social learning" as (1) a change in understanding that takes place in the individuals involved; (2) it goes beyond individuals and becomes situated within the community of practice; and (3) it occurs through social interactions and processes between actors within a social network. Social learning is expected to happen when stakeholders interact, share their experiences, collaborate, negotiate, and consult each other, building relationships and developing networks for information sharing and mutual support (Reed et al. 2010, Johnson et al. 2012, van der Wal et al. 2014). Social learning implies increased shared understanding, or in other words, a higher convergence of perceptions of the individuals involved in participatory processes (Scholz et al. 2014).

Participatory research involving farmers and researchers in a horizontal manner represents an opportunity to integrate local and scientific knowledge and facilitate knowledge sharing, thereby stimulating social learning, co-innovation, and co-creation of solutions to help the transition toward sustainable food systems (Raymond et al. 2010, Cuéllar-Padilla and Calle-Collado 2011, De Vente et al. 2016, Reed et al. 2018, Wiget et al. 2020). Within participatory research involving farmers and researchers in participatory monitoring and evaluation (PM&E), the effects of innovative SLM can potentially lead to enhanced innovation adoption by improving farmers' access to information on and knowledge of the effectiveness of SLM and by developing relationships and trust among stakeholders (Reed et al. 2007, Stringer et al. 2014, De Vente et al. 2016).

Participatory monitoring and evaluation of sustainable land management

We understand PM&E as the joint collaboration between farmers and researchers in assessing the effectiveness of SLM practices at multiple levels. It implies making use of different participatory activities and tools (Reed et al. 2013, Ensor and Harvey 2015, Ernst 2019) to facilitate interaction; integrate local, Indigenous, and scientific knowledge; reduce power imbalances; and engage stakeholders to support long-term SLM (Luján Soto et al. 2020). By participation, we mean the active involvement of participants in the whole research process, supported by facilitation. We understand monitoring and assessment of SLM as a continuous learning and adaptation feedback process that involves intensive local and scientific data gathering, trial and test of SLM, and the joint discussion of results by farmers and researchers (Luján Soto et al. 2020).

PM&E involving farmers and researchers in a horizontal manner can stimulate social learning through various mechanisms. First, farmers can learn from their own experiences, i.e., "seeing is believing", via self-evaluation and self-reflection about the effects of the adopted SLM practices (Ball et al. 2017). Second, farmers can learn from others' experiences, i.e., "peer to peer", by sharing information with farmers involved in PM&E (Wood et al. 2014). Third, farmers can learn from scientific knowledge, i.e., "different expertise", by integrating and contrasting scientific and local knowledge based on SLM observations and technical results (Estrella et al. 2000, Cardoso et al. 2001, Stringer et al. 2014, Ball et al. 2017, García-Nieto et al. 2019). Finally, PM&E can potentially lead to SLM out-scaling by increasing the number of farmers with access to SLM information, i.e., "contagion effect", by creating a dense collaborative PM&E network that facilitates the exchange and dissemination of SLM information (Parra-Lopez et al. 2007, Wood et al. 2014, Tran et al. 2018, Skaalsveen et al. 2020). Out-scaling is therefore understood as the replication of successful innovations through horizontal diffusion processes to increase the number of people or communities affected (Hermans et al. 2013, López-García et al. 2021). It is a horizontal process that concerns how knowledge and innovations travel between different types of organizations. It differs from up-scaling, which entails vertical or hierarchical links to translate the results of innovation in political terms by changing laws and policies (Hermans et al. 2013, 2017, Moore et al. 2015). It also differs from scaling deep, which implies affecting cultural roots, changing cultural values, beliefs, and norms (Moore et al. 2015).

Therefore, it is expected that PM&E of SLM will enhance the relevance, legitimacy, and credibility of the solution, broadening the basis of support for its implementation (van der Wal et al. 2014, Luján Soto et al. 2020), and eventually leading to enhanced ownership and community empowerment, attitudinal change, and collective action for SLM adoption (Sol et al. 2013, Phuong et al. 2018, Suškevičs et al. 2018). This focus on collective action also helps to show why social learning is considered crucial in landscape, environmental, and natural resource management, innovation adoption, and climate change adaptation (Muro and Jeffrey 2008, Ensor and Harvey 2015, Hermans et al. 2017). These ideas directly connect to the recent renewed interest in setting up "living labs" and "lighthouse farms" to foster social learning by doing and facilitate knowledge exchange between researchers and farmers, as is also evidenced in the European "Mission for Soil Health and Food" (Veerman et al. 2020).

Although social learning has been used for decades in the literature, there has been little consensus on a definition, the processes involved, and its outcomes (Reed et al. 2010). Unsurprisingly, there is a lack of empirical evidence showing that participatory research actually promotes social learning (Reed et al. 2010) because cognitive change has rarely been investigated (Ernst 2019), and social interactions in participatory settings are commonly presumed. In recent years, there has been increasing effort to demonstrate the potential of multistakeholder participatory research approaches to enable social learning about SLM, natural resource management, and related topics such as participatory modeling (Henly-Shepard et al. 2015, Voinov et al. 2016), participatory mapping (García-Nieto et al. 2019), and participatory development of future scenarios for community-based management (Johnson et al. 2012). However, scientific studies of PM&E of SLM providing empirical evidence on social learning continue to be scarce, especially regarding innovative SLM.

Our objective is to evaluate the potential of PM&E to enable social learning in support of the adoption and out-scaling of innovative SLM by: (1) favoring the co-creation of knowledge and a common understanding of the effects of innovative SLM on participating farmers, and (2) strengthening and enlarging farmers' social networks and potential for knowledge and innovative SLM information sharing. For this purpose, we initiated a PM&E project to assess the impacts of regenerative agriculture (RA) in a farming region in southeastern Spain, involving 12 local farmers pioneering in applying RA in the region. We assessed how PM&E affected farmers' perceptions and social networks over time and discussed the relevance of the results regarding innovative SLM adoption and out-scaling. To our knowledge, this is one of the first scientific studies in the field of PM&E of innovative SLM that assessed social learning, including both the social-cognitive (perceptions) and the social-relational (social networks) dimensions. We believe this PM&E project could serve as inspiration for the design of future living labs and restoration initiatives based on innovative SLM.

METHODS

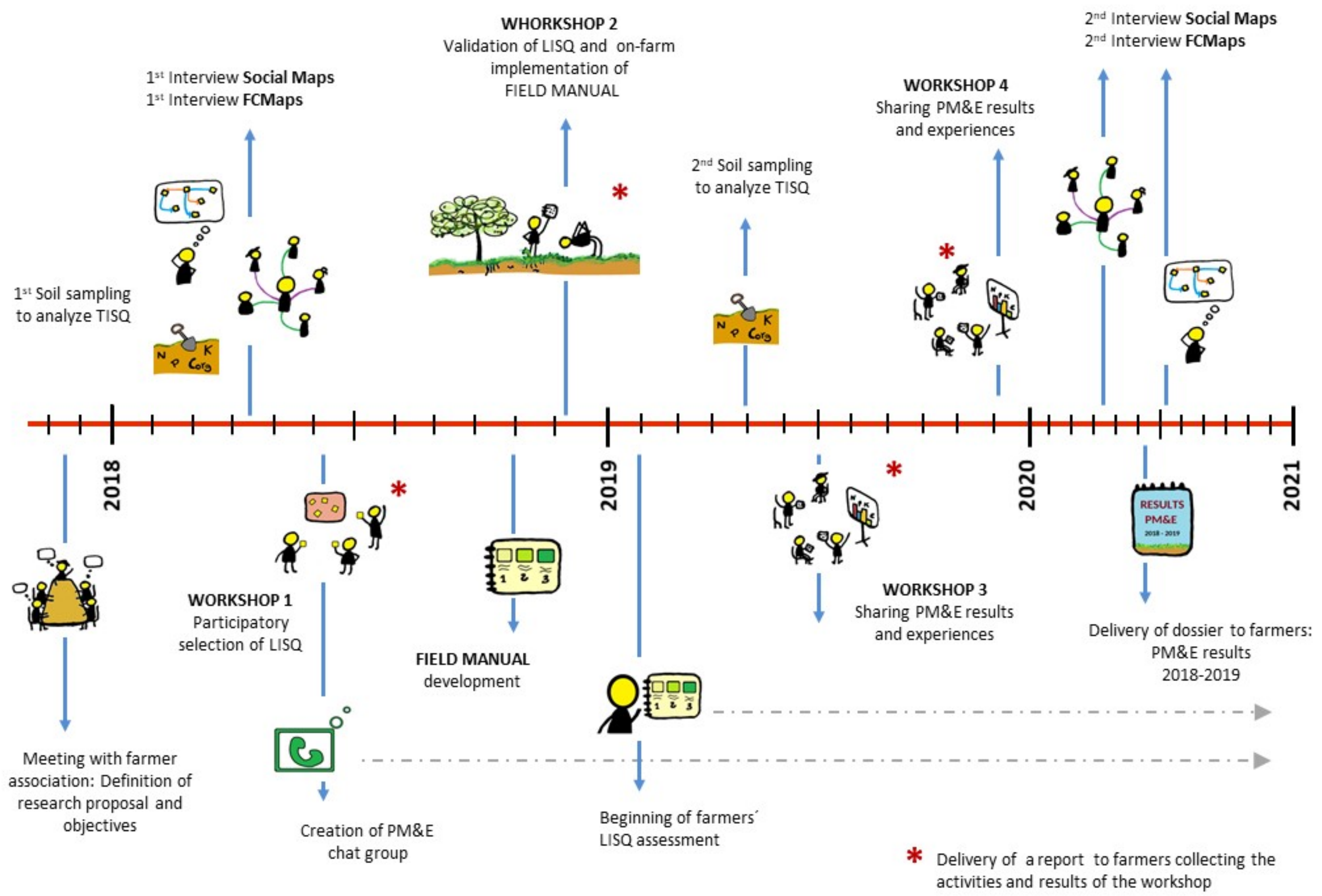
Study context

This participatory research was conducted in the steppe high plateau in the semiarid southeast of Spain in collaboration with members of the farmer association AlVelAl. The semiarid southeast of Spain is one of Europe's regions most affected by land degradation and desertification (Martínez-Valderrama et al. 2016) and represents one of the world's largest areas for the production of rainfed organic almonds. Since the 1950s, the region has experienced major farm management changes. The mechanization of farming activities and the application of agrochemicals was patently promoted by the green revolution model and endorsed by governmental institutions through subsidies to farmers until the late 1990s. This transition from traditional, essentially organic farming to conventional farming resulted in multiple environmental, social, and economic impacts. Environmentally, it led to the abandonment of soil and water conservation structures (Bellin et al. 2009), a shift from cereal to woody perennial farming (Cruz Pardo et al. 2010), the near total disappearance of sheep farming (Toro-Mujica et al. 2015), and the intensification of tilling practices (Clar et al. 2018), resulting in a considerable increase in erosion rates and land degradation (García-Ruiz 2010, van Leeuwen et al. 2019). Socially, it led to a break from the traditional peasant lifestyle and a loss of autonomy in a self-controlled resource-based system, including the loss of non-material resources such as farmers' social networks and transfer of traditional knowledge. The loss of farmers' autonomy was also reflected in the economic sphere, particularly evidenced by reduced economic profits and higher dependence on subsidies to make farming economically viable (van Leeuwen et al. 2019).

Confronted with this panorama, in 2015, local farmers created the AlVelAl association. The AlVelAl association is supported by the Commonland foundation, regional governments, local businesses, and research institutions, and aims to restore vast extensions of degraded land, promoting and facilitating the adoption of RA by offering technical advice and economic support. RA is an innovative SLM approach foreseen as a promising solution to reverse and prevent further land degradation and enhance the delivery of ecosystem services through the adoption of soil restoration practices under four main principles: (1) minimize soil disturbance, (2) enhance soil fertility, (3) reduce spatio-temporal events of bare soil, and (4) diversify cropping systems by integrating livestock (Rhodes 2012, 2017, Elevitch et al. 2018, LaCanne and Lundgren 2018). RA includes practices at both landscape and farm levels. The most commonly promoted RA practices at farm level include reduced tillage, organic amendments, and cover crops used as green manure, but also practices such as crop diversification, inclusion of livestock in agro(silvo)pastoral systems, and water harvesting.

While promising (De Leijster et al. 2019, Luján Soto et al. 2021*b*), RA has had limited adoption in the high steppe plateau in southeastern Spain and in semiarid regions in general. This limited adopton might be because of a lack of empirical data showing its effectiveness (Lee et al. 2019) and the generally slow response of soils to management changes in semiarid conditions, which may delay the appearance of visible results, discouraging farmers from adopting RA.

Fig. 1. Timeline of the participatory monitoring and evaluation (PM&E) project, displaying the main events. The current research presents the results and analysis of the first and second interview rounds applying fuzzy cognitive mapping and social network analysis. Monthly spacing has been reduced in the timeline each year to enhance the representation of events. TISQ = technical indicators of soil quality, LISQ = local indicators of soil quality, FCMaps = fuzzy cognitive maps.



Participatory monitoring and evaluation in southeastern Spain

In view of the needs and potentials for social learning to help design, adopt, and enhance the implementation of RA in the high steppe plateau, we designed and initiated a PM&E research project (Luján Soto et al. 2020; Fig. 1) involving local pioneering farmers already implementing RA that were members of AlVelAl (Table 1) and researchers to assess RA impacts on soils and related ecosystem services (Luján Soto et al. 2021*b*). The PM&E research project formally started in 2017 with a get together with AlVelAl board members to define the participatory research objectives and approach. Subsequently, we initiated the PM&E project with 12 almond farmers who expressed interest in participating (Luján Soto et al. 2020). This first meeting was followed by several participatory activities using a diversity of participatory tools to incentivize social learning (Ensor and Harvey 2015, Ernst 2019, Suškevičs et al. 2019). The activities included field visits; soil assessments using technical indicators of soil quality; two participatory workshops to identify, select, prioritize, and validate local indicators of soil quality; the development and on-farm implementation of a field manual for farmers to perform quarterly visual assessment of RA; and a series of participatory workshops and activities to facilitate the exchange of monitoring and evaluation results from local indicators and technical indicators of soil quality between participating farmers and researchers, reflect on RA impacts and effectiveness, and keep participants engaged (Luján Soto et al. 2020). Additionally, we created a telephone chat group to accompany farmers in the PM&E process, solve doubts, share information, and enhance discussion of RA practices (Fig. 1). To evaluate whether PM&E enabled social learning, we assessed two aspects at the start of the project and in the third year of farmers' active involvement in PM&E: farmers' social networks on RA information sharing using social network analysis, and farmers' perceptions of RA impacts and benefits using fuzzy cognitive mapping (FCM; Fig. 1).

Constructing fuzzy cognitive maps with farmers

FCM is an integrated and semiquantitative research tool that is simple to use in participatory settings and was developed to assess, compare, and reveal changes in people's knowledge systems by

Table 1. Description of participating farmers and farms according to the main regenerative agriculture principles and practices implemented in the parcels selected for participatory monitoring and evaluation.

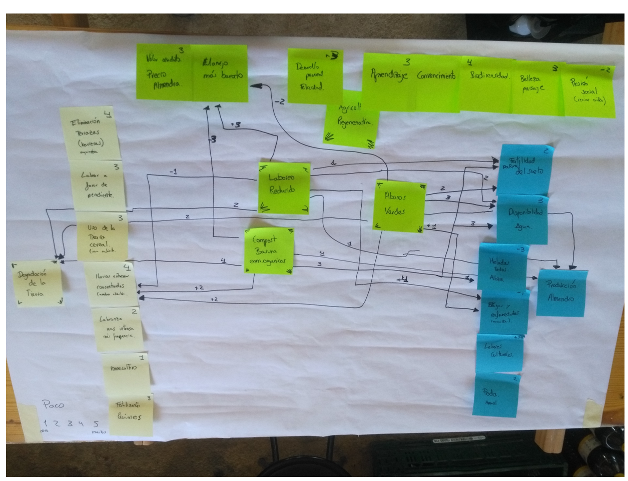
				Regenerative principles and practices applied			
Farmer	Role in farmer association	Year of regenerative agriculture implementation	Farm size (ha)	Minimum soil disturbance	Organic amendments	Reduction of bare soil spatio-temporal events	Diversification and integration of livestock
S1	Board member	2015	1700	Reduced tillage	Bokashi compost	Winter natural covers	Sheep integration
S2	Member	2014	36	Reduced tillage	Sheep and goat manure	Winter natural covers	
S3	Member	2014	70	Reduced tillage	Bokashi and sheep manure	Winter natural covers	
S4	Member	2008	200	No tillage	Bokashi compost	Permanent natural covers; prunings mulched	Sheep integration
S5	Member	2016	250	Reduced tillage	Sheep manure	Winter natural covers	Sheep integration
S6	Member	2017	78	No tillage	Green manure	Permanent natural covers	Sheep integration
S7	Board member	2008	250	Reduced tillage	Bokashi compost	Vegetation strips between almond lines; prunings mulched	Sheep integration
S8	Member	2014	18	Reduced tillage	Bokashi compost	Winter natural covers; prunings mulched	
S9	Research technician	2013	35	Reduced tillage	Compost and sheep manure, green manure	Winter natural covers; prunings mulched	
S10	Member	2006	100	Reduced tillage	Bokashi and pelletized organic fertilizers	Winter natural covers; prunings mulched	Sheep integration
S11	Member	2016	12	Reduced tillage	Green manure	Winter natural covers; prunings mulched	
S12	Secretary	2015	120	Reduced tillage	Green manure	Winter natural covers	Sheep integration

illustrating changes in perceptions of a particular issue from a systems understanding (Özesmi and Özesmi 2004). We carried out individual interviews using FCM in spring 2018 (pre PM&E) and summer 2020 (post PM&E) to map farmers' perceptions regarding RA impacts. To evaluate the influence of PM&E on shaping farmers' perceptions, we generated 10 individual fuzzy cognitive maps (FCMaps; one per farmer) before (pre PM&E) initiating monitoring activities, and 10 FCMaps in the third year of the project (post PM&E; Fig. 1). We discarded the perceptions of two participating farmers in the comparative assessment because we could not conduct the FCM interview either at the beginning or at the end of the PM&E project for logistical reasons. Interviews for creating these individual FCMaps were conducted around three main questions related to farmers' specific realities: (Q1) "Which factors influenced land degradation in the region?" (Q2) "Which factors influence crop production?" and (Q3) "What are the impacts of regenerative agriculture and, particularly, the three most common implemented RA practices (i.e., organic amendments, green manure, and reduced tillage), on land degradation, crop production, and other socioeconomic factors you consider important?"

To facilitate responses to these questions, a short explanation of FCM was given to the farmers before the interview, highlighting relevant aspects of the methodology and emphasizing the fact that there is no right or wrong answer. The interviews were carried out following a sequence of steps to guarantee that all factors farmers considered relevant were being mapped. Each step was also explained in detail to ensure that the instructions were clear to all farmers.

In Step 1, we presented an A0 sheet of paper to the farmer with six adhesive "entry notes". Each entry note had a key word written on it related to the question being asked. We used colored notes to facilitate visual differentiation. The six entry notes and colors used were: "land degradation" in yellow (related to Q1), "production" in blue (Q2), and "regenerative agriculture", "green manure", "compost or organic amendments", and "reduced tillage", in green (all Q3; Fig. 2).

Fig. 2. Example of a fuzzy cognitive map constructed with a participating farmer in summer 2020.



Once the entry notes were provided, we proceeded with Step 2, in which Q1 was asked to the farmer. Answers were collected in keywords identified by the researcher-facilitator and written on separate adhesive notes, which were then placed on the A0 sheet of paper close to the related entry note to facilitate drawing connections between items in the subsequent steps.

When the farmer concluded answering Q1, we moved to Step 3, in which the farmer was asked to establish and value relations between mapped items and the related entry note. In this step, the farmer had to indicate the direction, type, and strength of the relations. First, the direction of the relation was indicated, and drawn with an arrow when necessary, starting at the influencing item and pointing toward the item being influenced. Second, the type of relation, which could be either positive or negative, was marked with a (+) or (-) symbol, respectively. Finally, the strength of connections was ranked using a scale of 1 (weak) to 5 (strong; Fig. 2).

In FCM, arrows are used to draw connections between items, ending up, in many cases, with numerous intersecting arrows that can complicate the visual picture and ranking of the established relations. To avoid arrow jumbles, each keyword answering a question was collected on an adhesive note with the same color as its related entry note, that is, factors influencing land degradation were written on yellow notes, factors influencing crop production on blue notes, and impacts of RA and specific RA practices on green notes. In this way, we could establish connections between items without the need to draw arrows. Arrows were only drawn when an item was previously mentioned to answer a question and to establish connections between already mapped items. Once connections were established and Q1 was completed, we moved to Q2 and Q3, following the same procedure as described above. The farmer was reminded of the possibility to establish connections between any mapped items if they found a relation.

To facilitate the response to Q3, the farmer was first asked to draw connections between each RA practice and land degradation, production, and their influencing factors. If the farmer found the impact of all RA practices to be the same for one item (in direction, type, and strength) or could not establish differences between RA practices, just one arrow to the RA entry note would be drawn, indicating the direction, type, and strength of the connection. Lastly, the farmer was asked about the social and economic impacts of RA. Before concluding the exercise, farmers were asked if they agreed with the resulting map and to make any modifications or additions they felt necessary.

Fuzzy cognitive maps processing and statistical analysis

We followed a set of good practices for FCMap-building to ensure transparency and reproducibility of the process (Olazabal et al. 2018). Good practices included interpretation and pre-processing of individual maps, selection of common terminology, renaming of concepts, and reversal of weight signs to increase consistency in the creation of individual maps and adjacency matrices (Appendixes 1–4) and aggregation of individual adjacency matrices into collective FCMaps (Olazabal et al. 2018).

FCMaps were analyzed using the software FCMapper version 1.0 developed by Bachhofer and Wildenberg in 2009 (http://www.fcmappers.net/joomla). The analysis included the total number of factors (nodes), total number of connections (arrows), and the factor type categorized depending on the type of arrow it received or transmitted. Transmitter factors only have outgoing arrows, indicating they influence other factors. Receiver factors only have ingoing arrows, indicating they are influenced by other factors. Ordinary factors have outgoing and ingoing arrows, indicating they influence and are influenced by other factors in the system. The strengths of arrows were rescaled to a range from 0.2 to 1.0 (positive connections) and −0.2 to −1.0 (negative connections). The centrality of factors was determined by the sum of absolute weights of ingoing and outgoing arrows. In addition, factors were categorized into five groups: biophysical and environmental, management, economic, social, and political and cultural.

Individual FCMaps were combined to obtain two collective maps: one collective FCMap integrating the 10 individual FCMaps of farmers' perceptions before starting the PM&E, and one collective FCMap integrating the perceptions of these same 10 farmers in the third year of PM&E. Collective FCMaps were created by merging the factors and summing the connections between the same factors of all farmers in each time period. The weight of connections was divided by the number of farmers to derive mean centrality scores. Positive and negative connections between the same factors cancelled each other out. We used Gephi Software version 0.9.2 (Bastian et al. 2009) for graphical representation of FCMaps.

To assess differences in farmers' perceptions before taking part (pre PM&E) and in the third year (post PM&E) of the PM&E project and evaluate whether individual and collective learning occurred, we analyzed the evolution of individual farmers' perceptions, i.e., the change in individual FCMaps pre and post PM&E, and compared it with the evolution of farmers' perceptions as a group, i.e., the change in collective FCMaps pre and post PM&E. We analyzed FCM indices, categorical groups of factors, and centrality of RA practices using the nonparametric Wilcoxon Signed Rank statistical test for paired dependent samples in R version 3.6.2 (R Core Team 2020) with $N = 10$ and significance level set at $P < 0.05$.

Interviews to construct social networks on regenerative agriculture information fluxes

We carried out 12 interviews in spring 2018 (pre PM&E) and 12 interviews in spring 2020 (post PM&E) to measure and map the evolution of RA information fluxes within the social networks of farmers taking part in PM&E. Interviews in 2018, prior to the start of monitoring activities, were held in person, whereas interviews in 2020 were done by telephone due to COVID-19 quarantine restrictions enforced by the national government. The interview included two parts. The first part consisted of obtaining baseline information, including the farmer's name, function within the AlVelAl association, profession and working institution or organization, and time practicing RA. The second part consisted of two main "name generator" questions to compose: (1) a list of people who transfer information ("Alters") and (2) a list of people who receive information ("Egos"). The questions were: "Who are the people from whom you receive information on RA? Specify the frequency" and "Who are the people to whom you give information on RA? Specify the frequency". The frequency of information exchange was measured using a Likert scale with scores to streamline the

Table 2. Definition of social network analysis metrics regarding information sharing and interpretation of responses to stimulate social learning about regenerative agriculture and enhance its adoption and out-scaling.

Metric	Definition	Response
Dimension	Network size or number of actors. It is critical for a network structure because resources are limited for each actor to build up or maintain social relations and fluxes of information	The higher the dimension (number of connected actors) the greater the network cohesion; more actors have access to regenerative agriculture (RA) information
In-degree centrality	Number of information fluxes an actor receives. It is characteristic of people or networks that require information, are eager to learn and adapt, and are innovative	The higher the average in-degree of the participatory monitoring and evaluation (PM&E) network, the higher the consolidation potential of RA practices; farmers involved in PM&E receive RA information from more people than those who are not involved in PM&E
Out-degree centrality	Number of information fluxes shared by an actor. It is a measure of empowerment, characteristic of persons or networks with a lot of knowledge and experience or access to information	The higher the average out-degree of the PM&E, the higher the consolidation potential of RA practices and the higher the capacity to influence adoption beyond the group of farmers involved in PM&E; farmers involved in PM&E share RA information with more people than farmers who are not involved, increasing their capability to induce RA adoption
Betweenness centrality	A measure of power. It calculates the frequency with which an actor is situated in the shortest geodesic paths between other actors in the network. That is, it is necessary to pass through that actor to reach the others, thus indicating the ability to control information sharing paths	The higher the betweenness centrality, the higher the brokerage of information, but also the higher the innovation potential; higher capacity to propagate RA information
Two-step reach betweenness	The percentage of all actors involved in a network that an actor can reach in two steps. It indicates efficiency, independence, and empowerment. It can be used as an alternative for average geodesic distance and closeness	The higher the percentage, the faster RA information could reach all actors; RA information is easily available for anyone in the network, or actors have more rapid access to RA information
Homophily	The E-Index measures homophily, which is the tendency of people to choose people who are similar to themselves in socially significant attributes (e.g., profession, gender, race)	E-Index goes from −1 to +1: negative values indicate information sharing occurs more among farmers than with other actors; positive values indicate the opposite

answering process (very often = 5, often = 4, occasionally = 3, seldom = 2, and very seldom = 1).

Social network processing and analysis

We used Gephi software version 0.9.2 (Bastian et al. 2009) for graphical representation of information fluxes for PM&E farmers within their social networks. We included all fluxes of information mentioned by PM&E farmers; therefore, when a PM&E farmer mentioned that they received or transferred information to another person, it was included in the analysis regardless if the appointee did not mention the same flux of information. We analyzed survey data using UCINET software (Borgatti et al. 2002) for egocentric metrics calculations. We used descriptive analysis and selected a set of metrics to analyze the temporal evolution of farmer social networks during the PM&E (Table 2). Centrality measures (indegree centrality, outdegree centrality, betweenness centrality) are commonly used to understand the potential for knowledge creation and sharing in networks (Simpson and de Loë 2017, Beaman and Dillon 2018, Skaalsveen et al. 2020). The level of homophily indicates whether information and knowledge sharing occurs between the same type of actors (e.g., mostly farmer-to-farmer interactions) or between different actors (Beaman and Dillon 2018, Skaalsveen et al. 2020). Two-step reach betweenness indicates how fast information can reach actors in a network (Hanneman and Riddle 2011). Centrality, betweeness, and homophily metrics are widely used to assess knowledge sharing and potential diffusion of SLM and agricultural innovations in farmers' networks (Simpson and de Loë 2017, Beaman and Dillon 2018, Skaalsveen et al. 2020).

RESULTS

Farmers' perceptions

The most relevant result from the evolution of individual FCM is that farmers mentioned significantly more factors ($P = 0.006$) and more connections between factors ($P = 0.022$) after taking part in PM&E (Table 3, Fig. 3; Appendix 4). When we combined all individual FCMaps into collective FCMaps (Fig. 3), we observed that the number of factors mentioned by farmers was higher post PM&E, but there were 14 fewer connections between factors (Table 3). Moreover, just 10 of the 65 mentioned factors (i.e., 15%) were cited by five or more farmers pre PM&E, and the number increased to 22 of 73 factors post PM&E (i.e., 30%). Furthermore, a higher number of farmers connected common RA practices to land degradation and production (Table A5.1 and A5.2 in Appendix 5).

Individually, farmers also mentioned significantly more transmitter ($P = 0.012$) and more receiver ($P = 0.005$) factors post PM&E, but there was no significant difference between ordinary factors (Table 3). Moreover, there were no significant differences between the amount of "biophysical and environmental" and "political and cultural" factors farmers mentioned pre and post PM&E, whereas farmers mentioned significantly more "management" ($P = 0.016$), "social" ($P = 0.011$), and "economic" ($P = 0.042$) factors post PM&E (Table 3). Collectively, farmers identified 10 more transmitter factors, and there were few differences in receiver and ordinary factors, post PM&E (Table 3).

Farmers perceived water availability, soil fertility, organic matter, and soil biodiversity as the most central factors both pre and post

Table 3. Overview results of fuzzy cognitive mapping indices on farmers' individual and collective perceptions pre and post involvement in participatory monitoring and evaluation (PM&E).

	Individual perceptions					Collective perceptions		
	P	*Z*	Pre PM&E†	Post PM&E†	Difference	Pre PM&E	Post PM&E	Difference
Factors (number)	0.006	−2.762	24.6 ± 1.1	30.0 ± 0.9	5.4	65	73	8
Connections (number)	0.022	−2.296	32.6 ± 2.6	39.0 ± 2.6	6.4	142	128	−14
Transmitter (number)	0.012	−2.505	11.3 ± 1.2	15.5 ± 1.1	4.2	23	33	10
Receiver (number)	0.005	−2.762	8.2 ± 0.6	11.2 ± 0.4	3.0	22	23	1
Ordinary (number)	0.280	1.079	4.7 ± 0.9	3.3 ± 0.9	−1.4	20	17	−3
Management (number)	0.016	−2.399	4.7 ± 0.6	7.0 ± 0.6	2.3	16	20	4
Biophysical and environmental (number)	0.173	−1.360	6.7 ± 0.4	7.6 ± 0.6	0.9	18	21	3
Political and cultural (number)	0.522	−0.639	0.8 ± 0.4	1.2 ± 0.4	0.4	5	6	1
Economical (number)	0.042	−2.035	3.3 ± 0.3	4.0 ± 0.3	0.7	9	9	0
Social (number)	0.011	−2.525	3.1 ± 0.3	4.2 ± 0.3	1.1	11	11	0
Green manure centrality	0.674	0.420	2.8 ± 0.7	2.7 ± 0.5	−0.1	2.62	2.46	−0.2
Organic amendments centrality	0.250	−1.150	2.5 ± 0.5	3.4 ± 0.6	0.9	2.5	3.08	0.6
Reduced tillage centrality	0.843	−0.245	2.3 ± 0.6	2.4 ± 0.4	0.1	1.82	1.7	−0.1

†Mean ± standard error.

PM&E (Fig. 3; Table A5.3 in Appendix 5). Water availability was mentioned as an influencing factor for crop production by all 10 farmers (Table A5.2 in Appendix 5) and was the most central factor pre and post PM&E (Table A5.3 in Appendix 5). Soil fertility and organic matter gained importance over soil biodiversity post PM&E (Table A5.3 in Appendix 5).

Farmers perceived the impact of all three RA practices on land degradation as similar pre PM&E (Table 4, Fig. 3). Post PM&E, they perceived green manure as the RA practice most beneficial to prevent land degradation, followed by organic amendments, and then reduced tillage. Farmers perceived organic amendments as the most influencing RA practice for production, followed by green manure and reduced tillage. This perception remained similar along the PM&E project; however, farmers perceived a higher positive influence of organic amendments and a lower influence of reduced tillage and green manure on production post PM&E (Table 4, Fig. 3). For the factors with highest centrality, farmers perceived organic amendments as the RA practice with the most positive effect on water availability, soil fertility, and organic matter. This perception remained similar, though with a perceived higher positive effect post PM&E. However, post PM&E, farmers perceived a slightly more positive effect of green manure than organic amendments on water availability, whereas organic amendments were perceived as the practice most positively influencing soil biodiversity, which was initially attributed to green manure. Pre and post PM&E, reduced tillage was perceived as the RA practice with least influence on land degradation, production, and all of the most central factors (Table 4, Fig. 3).

Table 4. Influence, or strength of relation, of the three most common regenerative agriculture practices on land degradation, production, and the four most central factors as expressed by farmers pre and post participatory monitoring and evaluation (PM&E).

Variable	Timing	Reduced tillage	Organic amendments	Green manure
Land degradation	pre PM&E	0.38	0.38	0.38
	post PM&E	0.26	0.50	0.56
Production	pre PM&E	0.28	0.58	0.34
	post PM&E	0.22	0.72	0.28
Water availability	pre PM&E	0.18	0.36	0.34
	post PM&E	0.38	0.44	0.48
Soil fertility	pre PM&E	0.06	0.14	0.08
	post PM&E	0.18	0.34	0.20
Organic matter	pre PM&E	0.18	0.18	0.12
	post PM&E	0.18	0.26	0.24
Soil biodiversity	pre PM&E	0.04	0.26	0.28
	post PM&E	0.02	0.20	0.18

Farmers' social networks

The social network analysis shows that the dimension of the PM&E farmers' network was bigger in the third year of the PM&E project than just before its start, involving 45 more people with whom farmers established 65 new fluxes of information (Fig. 4, Table 5). Post PM&E, within the group of PM&E farmers, 26 more fluxes of RA information were reported (i.e., sent and received), of which 15 more fluxes of information were sent by PM&E farmers, maintaining a similar frequency of communication (i.e., occasionally) with each receiver (Table 5). PM&E farmers received 11 more fluxes of information within the group, but the frequency decreased one point, from occasionally to seldom. Post PM&E, PM&E farmers shared RA information with more people from outside the group (mainly farmers), whereas they received slightly fewer fluxes of information from outside the group. In particular, there were fewer nongovernmental organization technicians providing information, whereas the main researcher facilitating the PM&E gained centrality (Fig. 4). The frequency with which PM&E farmers sent to and received information from outside the group slightly

Fig. 3. Combined fuzzy cognitive maps of farmers pre and post (in the third year) participatory monitoring and evaluation (PM&E). N = 10 farmers. Circle size indicates the relative centrality score of each factor. Arrow thickness represents the relative strength of the connection. Arrow color indicates connections, i.e., influences of one factor on another factor: blue = positive, orange = negative.

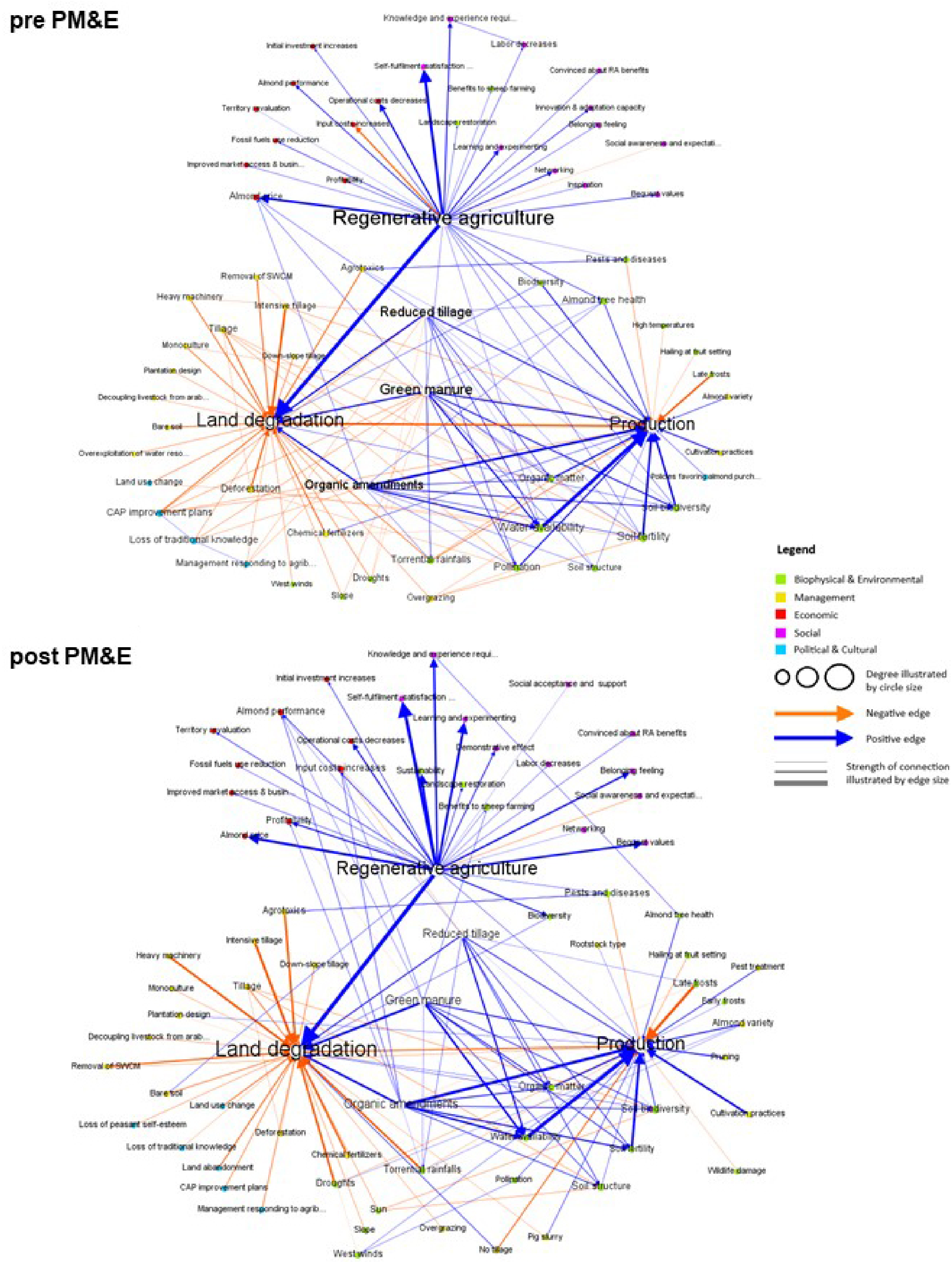


Fig. 4. Social networks of farmers involved in participatory monitoring and evaluation (PM&E) of regenerative agriculture. Pre PM&E = regenerative agriculture information fluxes of farmers (*N* = 12) before initiating the PM&E project. Post PM&E = regenerative agriculture information fluxes of farmers (*N* = 12) in the third year of taking part in the PM&E project. Centrality is the sum of absolute weights of in-going and out-going connections. Circle size indicates the relative centrality score of each person. Arrow thickness represents the relative strength of the information flux. Arrow color indicates the direction of the information flux: green = received, purple = shared.

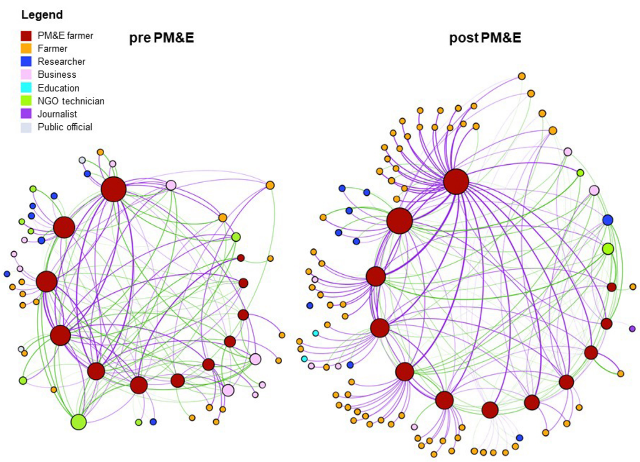


Table 5. Comparison of egocentric social network parameters on information sharing generated from individual farmer interviews pre and post (after three years) involvement in participatory monitoring and evaluation (PM&E).

	Information sharing	
Parameter	Pre PM&E	Post PM&E
Dimension	54	99
Information fluxes	175	236
Within PM&E		
Sent (number / frequency)	28 / 3.1	43 / 3.0
Received (number / frequency)	34 / 2.9	45 / 1.8
Outside PM&E		
Sent (number / frequency)	56 / 3.6	97 / 3.1
Received (number / frequency)	57 / 3.4	51 / 2.3
Metric		
In-degree centrality	31.8	27.0
Out-degree centrality	32.4	42.6
Betweenness centrality	57.5	120.3
Two-step reach betweenness (%)	39.3	81.3
Homophily	−0.21	−0.61

decreased in time, as reflected by a slightly lower indegree centrality, but higher outdegree centrality after the PM&E process. Higher RA information sharing between PM&E farmers and with other nonparticipating farmers is reflected by the negative homophily index, meaning that RA information sharing occurs mostly between farmers. Lastly, betweenness and two-step reach betweenness were higher after PM&E.

DISCUSSION

In the following sections we discuss whether PM&E enabled social learning among participating farmers, addressing both the social-cognitive (perceptions) and the social-relational (social networks) dimensions. Based on these insights, we further elaborate on the potential for PM&E to support adoption and out-scaling of innovative SLM such as RA.

Social cognitive dimension

Analysis of the social cognitive dimension on how farmers' perceptions evolved during the PM&E research project revealed that PM&E enabled social learning regarding RA. More specifically, PM&E facilitated a process of individual and collective learning, resulting in converging views and opinions among participating farmers about the effect of different RA practices on land degradation and production, and factors influencing and being influenced by them.

Greater and more complex individual knowledge about regenerative agriculture

Considering the evolution of individual perceptions (Appendix 4), the significantly higher number of factors and connections between factors mentioned by farmers in the FCM results (Table 3) after three years of PM&E indicate that PM&E enhanced farmers' acquisition of knowledge. The significantly higher number for receiver and transmitter factors mentioned by farmers post PM&E shows that farmers gained insights on influencing and influenced factors regarding RA, land degradation, and production. In addition, significant differences show that farmers broadened their comprehension of the importance of management, social, and economic factors playing a role in their agroecosystems and livelihoods. In other words, after almost three years of PM&E research, farmers showed a more complex understanding of the social-ecological system around RA, land degradation, crop production, and related factors.

Farmers' self-evaluation of SLM experiences has proven to be crucial for individual learning (Tran et al. 2018). The development process carried out through: participatory workshops in which participating farmers identified, selected, prioritized, and validated local indicators of soil quality; farmers monitoring RA by using the field manual; and the collective sharing and discussion of monitoring results by farmers and researchers appears to have assisted farmers' self-evaluation and self-reflection on RA practices, management, and impacts. This reflection process should help them in decision making toward SLM (Triste et al. 2014, Ball et al. 2017) and enhance farmers' ownership and empowerment to adapt and adopt RA (Darnhofer et al. 2008). Learning mechanisms crucial for collective learning, such as communication and knowledge exchange with other participating farmers and researchers, are intrinsically linked to individual learning (Reed et al. 2010, De Vente et al. 2016). Therefore, individual learning was enabled in PM&E through individual and collective learning processes such as during facilitated participatory workshops and in the telephone chat group. Thus, we state that involving farmers in PM&E enhanced individual learning, complying with the first requirement to achieve social learning (Reed et al. 2010).

Cohesive and broad common understanding of regenerative agriculture

While the individual FCMaps presented significantly more connections between factors post PM&E, the collective FCMap had fewer connections (Table 3, Fig. 3). This observation indicates that by participating in the PM&E project, farmers showed more complex individual perceptions and more consensus regarding RA effects on land degradation, production, and environmental, social, cultural, economic, and political factors involved in their agroecosystems and livelihoods. This greater consensus can be observed as well in the higher citation frequency of the mentioned factors (Fig. A5.1 in Appendix 5) and the larger number of farmers that linked RA practices to land degradation and production (Tables A5.1 and A5.2 in Appendix 5). Furthermore, post PM&E, farmers differentiated more between the influence of regenerative practices on land degradation, production and those factors perceived as most central. Farmers' perceptions of the influence of RA practices on the four most central factors were consistent with the monitoring results obtained by the researchers involved in PM&E on the impact of the different RA practices on soil physical, chemical, and biological indicators of soil quality on the monitored farms (Luján Soto et al. 2021*b*). This result indicates that PM&E favored knowledge exchange between farmers and researchers and the development of a broad, shared understanding of RA among the farmers involved, thereby complying with the second requirement for social learning (Reed et al. 2010). Interaction and deliberation involving different stakeholders in research processes to foster the appreciation of others' perspectives has been noted as having greater potential to favor social learning than when only one type of actor is involved (García-Nieto et al. 2019). Converging perceptions is an expected outcome from knowledge exchange in social learning processes (Scholz et al. 2014). However, it is important to pay attention to the influence of some inputs such as scientific inputs in influencing the perceptions of participating stakeholders. Skilled and structured facilitation to manage power dynamics allows the hierarchical relationships among actors to be reduced to prevent biased orientation of participating farmers' perceptions toward the direction of actors with higher decision-making power (i.e., researchers and technicians; Dessie et al. 2012, De Vente et al. 2016).

Moreover, it is worth noting that pre PM&E, participating farmers already had some experience, knowledge, and positive predispositions toward RA. This condition, added to the fact that learning processes take time, might explain why, despite farmers deepening their knowledge of RA, only a few new factors were added, and we did not find very large changes between pre and post PM&E farmers' perceptions.

Different participatory research processes can enable social learning for natural resource management, sustainable development, and climate change adaptation, for example, participatory modeling in multistakeholder innovation platforms (Henly-Shepard et al. 2015), community-based management with participatory future scenarios (Johnson et al. 2012), and participatory mapping of ecosystem services (García-Nieto et al. 2019). The design of participatory research processes should be adapted to local contexts and established objectives to maximize their relevance and impact (De Vente et al. 2016, Reed et al. 2018), with facilitation being critical to ensure social learning (Harvey et al. 2013, Suškevičs et al. 2019). Ensor and Harvey (2015) noted that "minimum sets" of participatory activities and tools are necessary to stimulate social learning in participatory processes, suggesting that the greater the integration of these activities and tools, the greater the opportunities for successful social learning. Our results on farmer perceptions provide empirical evidence to support that a well-designed PM&E process combining different participatory activities and tools to facilitate participation, knowledge exchange, and engagement among farmers and researchers accelerates collective understanding and social learning about innovative SLM practices, which are important prerequisites for SLM out-scaling and large-scale adoption. Nevertheless, social learning is influenced by multiple, context-dependent factors (Ernst 2019, Suškevičs et al. 2019) and does not necessarily translate into collective action (Muro and Jeffrey 2008, Nykvist 2014, Newig et al. 2018).

Social relational dimensions

Analysis of the social-relational dimension of how farmers' social networks for RA information evolved during the PM&E project highlights that PM&E processes boost farmers' numbers of relations, interactions, and knowledge sharing, enabling social learning.

Strengthened farmer networks: empowerment, trust, and confidence for regenerative agriculture adoption

Higher exchange of regenerative agriculture information within the group of farmers involved in participatory monitoring and evaluation

PM&E enhanced information sharing between participating farmers, increasing the number of information fluxes among farmers after 3 years of PM&E while maintaining a similar frequency of communication as in the beginning of the project. The increase in information fluxes within the group after three years of research reflects farmers' increased mutual help, collaboration, and proactivity, but foremost, their increased access to knowledge about RA experiences. PM&E strengthened the group's cohesion and facilitated farmers' social learning, as was also evidenced in the analysis of farmers' perceptions. The increased number of interactions resulted in a denser collaborative network, facilitating information and knowledge exchange and dissemination. This result aligns with the findings of Hermans et al. (2017), who showed that knowledge exchange was significantly correlated with the number of ties in the collaborative network.

Denser networks tend to generate more cohesive groups, which are more likely to form their own sets of values, beliefs, and behaviors in new belief systems (Monge et al. 2008). This process is crucial because farmers who are more concerned about land degradation and SLM practices and their effects are more likely to adopt those practices (Marques et al. 2015, Carlisle 2016, Liu and Luo 2018, Teixeira et al. 2018). Because participating farmers were open and willing to share their knowledge and to listen and understand each other, we argue that PM&E boosted trust, confidence, and empowerment among farmers and about RA, which helped them deal with differences and reach agreements. Trust and confidence are emergent properties of social learning processes that can facilitate SLM adoption (Sol et al. 2013, De Vente et al. 2016). While relational social capital is key to fostering transitions (Darnhofer et al. 2016, Darnhofer 2020), moving from social learning to collective action goes beyond farmers' agency and relies on a diversity of factors and actors in an enabling environment. Thus, these other factors and actors should also be addressed to achieve large-scale SLM adoption (Pinto-Correia and Azeda 2017, Darnhofer et al. 2019, Pinto-Correia et al. 2019, Darnhofer 2020), for instance, considering innovative ways of participatory governance (Armitage et al. 2012), building multistakeholder partnerships, business model innovation, and policy support.

Reduced information fluxes from farmers not invovled in participatory monitoring and evaluation

The social network analysis shows that farmers involved in PM&E received less information (fluxes and frequency) from outside the group after three years of PM&E compared to the beginning of the research project (Fig. 4, Table 5). This result can be explained by the fact that they were less dependent on external sources of information, suggesting increased empowerment of farmers about RA understanding. The PM&E project stimulated them to share empirical information with peer farmers and provided them access to new scientific information about the adopted RA practices from participating researchers (Fig. 4, Table 5). Many organizations working with agroecology, sustainable farming, and natural resource management have emphasized the crucial role of farmers as co-producers of knowledge through the exchange of ideas, experiences, and innovations (e.g., Via Campesina, Latin American Scientific Society of Agroecology, Consortium of International Agricultural Research Centers [CGIAR], Associação Brasileira de Agroecologia, World Overview of Conservation Approaches and Technologies). These organizations frequently use farmer-to-farmer diffusion of knowledge to strengthen farmers' networks and to break with hierarchical top-down power relations and dependence on outside experts (Val et al. 2019). Our social network analysis showed that PM&E enabled social learning because greater individual and collective knowledge sharing occurred through social interactions and knowledge exchange within their social network, complying with the third requirement for social learning (Reed et al. 2010). Farmers' evaluation of their participation in the PM&E project through individual interviews showed that PM&E helped them to view their land and restoration efforts differently and facilitated the creation of relationships for support, trust, learning, and capacity building (Luján Soto et al. 2021*a*). This result further validates the causal relation between farmers' participation in the PM&E project, relationship development, and individual and collective learning.

Enlarged social networks: stimulating regenerative agriculture out-scaling

Farmers shared regenerative agriculture information with a large number of farmers

After three years of PM&E, farmers almost doubled the number of people with whom they shared information about RA, mostly other farmers (Fig. 4), as indicated by the homophily indicator. PM&E also enforced farmers' central role in communication and propagation of RA information, as evidenced by the increase in farmers' betweenness index. In addition, the larger and more complex social network generated after three years of PM&E favors faster and easier access to RA information for other farmers and anyone forming part of the network, as demonstrated by the large increase in the two-step betweenness indicator, a metric indicating efficiency, independence, and empowerment. Therefore, although there may have been other factors involved, based on our findings, we argue that PM&E stimulated farmer empowerment, which is reflected in the wider diffusion of RA information among farmers. The dynamics of diffusion processes depend mostly on horizontal communication among farmers (Parra-Lopez et al. 2007, Wood et al. 2014, Tran et al. 2018, Skaalsveen et al. 2020) because new ideas are more easily adopted when they come from others who are considered to be similar. This process is, for instance, one of the reasons why the peasant-to-peasant method, prompted by social movements such as "La Via Campesina", has been used for decades for horizontal diffusion of knowledge and learning and to enhance agroecology and SLM out-scaling worldwide (Val et al. 2019). Furthermore, it has been previously documented that farmers who are exposed to more intense and better informed persuasion by the promoters of innovation are more likely to adopt it (Monge et al. 2008).

As reflected in our results, the PM&E research favored the creation of a more collaborative and supportive social network with more interactions between farmers and increased the potential for a contagion effect, which may lead to enhanced RA out-scaling. Although post PM&E interviews for developing the social network analysis were held by telephone due to COVID-19 mobility restrictions, the short period of time from the lock-down until interviews were held, the questionnaire's simplicity, researcher guidance on the interviewee process, and farmers' previous experience with the methodology minimized potential limitations of shifting from in-person to telephone format. It is important to highlight that multiple other factors also influence farmers' information and knowledge diffusion, such as education level, gender, full-time or part-time dedication to the job, and type of job. For instance, Beaman and Dillon's (2018) social network analysis showed that women have less access than men to knowledge about composting, and gender intersected with other factors such as the geographic distance to the informant and the power of the actor (betweenness centrality) who shared the information. Furthermore, it is worth noting that social learning goes beyond information and knowledge sharing and has aspects of emotional sharing, relationship building, and mutual support (Reed et al. 2010, Johnson et al. 2012, van der Wal et al. 2014), aspects that we did not address. As a final remark, we highlight that although social learning about innovative SLM can be expedited by well-designed PM&E research processes involving farmers and researchers (García-Nieto et al. 2019, Luján Soto et al. 2020), PM&E is eminently empirical and nourished by field experimentation. Thus, social learning about SLM is also conditioned by the biophysical and climate conditions of the study region. For instance, in our study context, where RA is applied in a semiarid region, water scarcity limits soil biological activity, and soil quality and agroecosystems changes may take time to occur, thereby slowing down learning processes.

Participatory monitoring and evaluation and living labs to support out-scaling regenerative agriculture and sustainable land management

Participatory research to support social learning, out-scaling, and large-scale adoption of SLM is increasingly promoted by researchers and policy makers worldwide (Reed et al. 2011, Bouma 2019, Albaladejo et al. 2021), and is also preeminent on the European Union agenda in the context of agricultural transition in Europe. The European Green Deal and related strategic guidelines (European Commission 2019; European Commission Just Transition Mechanism https://ec.europa.eu/

info/strategy/priorities-2019-2024/european-green-deal/finance-and-green-deal/just-transition-mechanism_en) focus much more strongly than before on innovation in farming by joint learning and interaction. For sustainable management of soils and a transition toward RA and agroecology, the science–practice interface is to be supported by a dense network of "living labs" across all European regions. Living labs are spaces for co-innovation through participatory, transdisciplinary, and systemic research (Veerman et al. 2020; European Network of Living Labs https://enoll.org/about-us/). They are expected to foster the codesign, evaluation, and assessment of innovative practices beyond current understanding with inputs from citizens, practitioners (e.g., farmers, foresters, landscape managers), advisory services, scientists, planners and policy makers, businesses, educators, and trainers. Accelerating the adoption of SLM innovations such as RA requires a close fit between the features of a solution and the needs of its potential adopters (Lahmar et al. 2012, Chinseu et al. 2019). Thus, the user-centric living labs approach to develop and co-create innovative solutions in partnership with stakeholders and tested in their real-life contexts holds great promise for accelerating the transition of the agri-food system toward greater sustainability and resilience (Schuurman and Tõnurist 2017, Zavratnik et al. 2019). Considering the urgency of addressing global land degradation and the increasing importance put on participatory research and PM&E to promote social learning and adoption of SLM in main international agendas, further research on factors that can favor or impede social learning in PM&E is highly needed. Addressing this knowledge gap is of great help to improve the design and development of future PM&E research projects and to nourish and support the development of living labs to enhance the long-term adoption of SLM and to favor sound transitions toward sustainable agroecosystems. We consider that the findings from our research can inform more targeted and effective design of the living labs model, adapted to each context. Moreover, promotion of living labs integrating PM&E and co-development of solutions may provide a very powerful tool to support social learning and out-scaling of SLM in different land-use systems.

Reflection on methodologies

Aggregating individual FCMaps into collective FCMaps is a commonly used method that can be helpful to reveal and contrast patterns in the evolution of perceptions for one group of actors (Scholz et al. 2014) or to compare different actor groups (Teixeira et al. 2018). Given that collective FCMaps are created by merging the factors and adding the connections raised by all farmers in the PM&E group, special attention must be paid in the interpretation of FCMaps to avoid misinterpretations. When merging individual FCMaps into collective ones, obtaining fewer connections in the collective maps than by adding the connections from individual maps can correspond to two different causes. If the connection between two factors is perceived by two individual farmers to have the same sign, then fewer connections in the collective map would indicate more cohesion in collective farmers' perceptions. In contrast, one negative connection and one positive connection for two factors perceived by two individual farmers will only be represented by one connection based on the average weight of the two connections, representing one single connection. In this case, fewer connections in the collective map will not indicate more cohesion. Therefore, the interpretation of collective FCMaps needs to take into account potential artifacts associated with merging individual farmer responses into group responses, and data must be well analyzed, interpreted, and discussed by the researchers to avoid misinterpretations. In this study, fewer connections in the collective FCMap after farmer participation in PM&E provided a fair representation of the higher cohesion in individual farmer's responses. This finding is confirmed by several observations: contrasting farmers' individual pre and post PM&E FCMaps and the higher citation frequency of the mentioned factors (Fig. A5.1 in Appendix 5), the large number of farmers that linked RA practices to land degradation and production, and the farmers differentiating among the regenerative practices' influences on land degradation, production, and the factors perceived as most central post PM&E. Therefore, we are confident that the analysis of individual and collective FCMaps provides representative insights on participating farmers' complex and common understanding of RA and social learning.

The social network analysis revealed the evolution of farmers' networks for RA information and knowledge sharing. Some information fluxes between farmers were mentioned by only one of the farmers, which could be attributed to farmers forgetting to mention some connections. This is a common limitation of open data collection methods for conducting social network analysis interviews (Borgatti et al. 2013). Using open questionnaires and closed lists for the interviewees to select names have other limitations. Restricting choice is simpler but can induce false quotations; therefore, it is preferable to provide greater freedom rather than restriction (Borgatti et al. 2013). By using an open questionnaire, we assumed that all information fluxes mentioned by farmers were real, and we took them as valid.

CONCLUSIONS

Well-designed PM&E research processes favor the creation of dense collaborative networks, generating the conditions to stimulate enhanced knowledge exchange between farmers and researchers. Their creation significantly contributes to faster and easier access to information about innovative SLM to stakeholders in the network, thus stimulating social learning to support SLM adoption and out-scaling. This outcome of PM&E in our study was revealed in three ways. First, farmers broadened and increased the complexity of their understanding about the potential for RA to counter land degradation and enhance production, including environmental, social, and economic factors. Second, farmers developed a more cohesive collective perception and greater consensus about the effects of RA over environmental, social, cultural, economic, and political factors involved in their agroecosystems and livelihoods, and the effects of most common RA practices over water availability, soil fertility, organic matter, and soil biodiversity. Third, farmers strengthened and enlarged their social networks for sharing RA nformation, with a more central role of participating farmers as drivers of innovation, thereby increasing the potential for RA adoption and out-scaling. Therefore, we argue that PM&E is an effective tool for individual and collective knowledge acquisition and co-creation and dissemination of knowledge that has relevance for designing living labs and similar science–practice co-innovation spaces to enhance adoption and out-scaling of innovative SLM.

Responses to this article can be read online at:
https://www.ecologyandsociety.org/issues/responses.php/12796

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Data Availability:

The data/code that support the findings of this study are openly available in the Open Science Framework at https://doi.org/10.17605/OSF.IO/TZADE

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Appendix 1: Lists of original concepts, transformations and final concepts

ID	Original concept	English concept	Homogenization	Final concept	Is reverse
1	Laboreo intensivo (frecuencia)	Intensive tillage (frequency)	Intensive tillage	Intensive tillage	n
2	Laboreo intensivo (profundidad)	Intensive tillage (depth)	Intensive tillage	Intensive tillage	n
3	Laboreo: el hecho de labrar	Tillage: the fact of tilling	Tillage	Tillage	n
4	Labrar a favor de pendiente	Down-slope tillage	Down-slope tillage	Down-slope tillage	n
5	Lluvias torrenciales	Torrential rainfalls	Torrential rainfalls	Torrential rainfalls	n
6	Sol	Sun	Sun	Sun	n
7	Cambio climático	Climate change	Torrential rainfalls Droughts	Torrential rainfalls Droughts	n n
8	Aumento de sequías	Increment of droughts	Droughts	Droughts	n
9	Sequias	Droughts	Droughts	Droughts	n
10	Pendiente	Slope	Slope	Slope	n
11	Monocultivo	Monoculture	Monoculture	Monoculture	n
12	Deforestación	Deforestation	Deforestation	Deforestation	n
13	Sobrepastoreo	Overgrazing	Overgrazing	Overgrazing	n
14	Cambio usos del suelo: de cereal a leñosos	Land use change: from cereal to woody crops	Land use change	Land use change	n
15	Desvincular la ganadería y la agricultura	Decoupling livestock from arable farming	Decoupling livestock from arable farming	Decoupling livestock from arable farming	n
16	Mecanización	Mechanization	Mechanization	Heavy machinery	n
17	Maquinaria pesada	Heavy machinery	Heavy machinery	Heavy machinery	n
18	Adaptación de la agricultura a la maquinaria	Adaptation of farming to heavy machinery	Heavy machinery	Heavy machinery	n
19	Desaparición de lindes y su vegetación	Elimination of field boundaries and hedgerows	Removal of barriers	Removal of soil and water conservation measures	n
20	Eliminación de barreras	Removal of barriers	Removal of barriers	Removal of soil and water conservation measures	n
21	Eliminación de linderos, ribazos y barreras naturales	Removal of boundaries, hedgerows and natural barriers	Removal of barriers	Removal of soil and water conservation measures	n
22	Eliminación de atochás	Removal of mud barriers	Removal of barriers	Removal of soil and water conservation measures	n
23	Eliminación de terrazas	Removal of terraces	Removal of barriers	Removal of soil and water conservation measures	n
24	Eliminación de terrazas y barreras	Removal of terraces and barriers	Removal of barriers	Removal of soil and water conservation measures	n
25	Falta de cubiertas	Lack of ground covers	Bare soil	Bare soil	n
26	Capitalismo: políticas públicas equivocadas	Capitalism: wrong public policies	CAP subsidies responding agribusiness interests	CAP subsidies responding agribusiness interests	n
27	Incentivar prácticas que	Promotion of farming	CAP subsidies responding	CAP subsidies	n

	responden a intereses empresas y no del agricultor	practices that respond to agribusiness interests and not to farmers	agribusiness interests	responding agribusiness interests	
28	Manejo favorables a intereses económicos de empresas	Farming managements that respond to agribusiness interests	Management responding to agribusiness interests	Management responding to agribusiness interests	n
29	Abandono de la tierra	Land abandonment	Land abandonment	Land abandonment	n
30	Falta de mano de obra (éxodo rural)	Lack of labor (rural exodus)	Land abandonment	Land abandonment	n
31	Subvenciones (PAC - Políticas Públicas)	PAC subsidies - Improvement plans	CAP subsidies responding agribusiness interests	CAP subsidies responding agribusiness interests	n
32	Concentración de tierras	Land concentration	Land concentration	Land concentration	n
33	Pesticidas	Pesticides	Agrotoxics	Agrotoxics	n
34	Fitosanitarios	Agrotoxics	Agrotoxics	Agrotoxics	n
35	Abonos químicos	Chemical fertilizers	Chemical fertilizers	Chemical fertilizers	n
36	Abonos sintéticos	Synthetic fertilizers	Chemical fertilizers	Chemical fertilizers	n
37	Regadío y sobreexplotación de recursos hídricos	Irrigation and overexploitation of water resources	Overexploitation of water resources	Overexploitation of water resources	n
38	Sobrexplotación recursos hídricos	Overexploitation of water resources	Overexploitation of water resources	Overexploitation of water resources	n
39	Purines	Pig slurry	Pig slurry	Pig slurry	n
40	Falta de materia orgánica	Lack of organic matter	Lack of organic matter	Organic matter	y
41	Suelos descubiertos (falta de cubiertas)	Bare soil (Lack of ground covers)	Bare soil	Bare soil	n
42	Falta y pérdida de conocimientos de manejo y prácticas	Lack and loss of traditional/folk knowledge on sustainable farming practices and management	Loss of traditional knowledge	Loss of traditional knowledge	n
43	Pérdida de conocimiento en el manejo "sabiduría popular"	Loss of traditional/folk knowledge on farming managements (farming wisdom)	Loss of traditional knowledge	Loss of traditional knowledge	n
44	Pérdida de autoestima campesina	Loss of peasant self-esteem	Loss of peasant self-esteem	Loss of peasant self-esteem	n
45	Lluvias fuertes época de floración	Torrential rainfalls during blossoming	Torrential rainfalls	Torrential rainfalls	n
46	Altas temperaturas (por encima de 40ºC)	High temperatures (over 40ºC)	High temperatures	High temperatures	n
47	Disponibilidad de agua	Water availability	Water availability	Water availability	n
48	Heladas tardías (congelan la alloza o almendruco)	Late frosts that freeze the green almond nut	Late frosts	Late frosts	n
49	Heladas tempranas	Early frosts	Early frosts	Early frosts	n
50	Granizadas después de que cuaje	Hailing during/after fruit setting	Hailing at fruit setting	Hailing at fruit setting	n
51	Viento de poniente (fuerte y cálido)	West winds	West winds	Warm West winds	n
52	Fertilidad del suelo	Soil fertility	Soil fertility	Soil fertility	n
53	Biodiversidad del suelo	Soil biodiversity	Soil biodiversity	Soil biodiversity	n
54	Equilibrio (parte viva, orgánica y mineral)	Soil balance (organisms, organic and mineral fractions)	Soil balance	Soil balance	n

55	Estructura del suelo	Soil structure	Soil structure	Soil structure	n
56	Materia orgánica	Organic matter	Organic matter	Organic matter	n
57	Nutrición del árbol	Almond tree nutrition	Almond tree nutrition	Almond tree nutrition	n
58	Polinización	Pollination	Pollination	Pollination	n
59	Niebla en floración	Fog at blossoming	Fog	Fog	n
60	Labores culturales	Cultural practices	Cultivation practices	Cultivation practices	n
61	Manejo con abejas	Management with bees	Cultivation practices	Cultivation practices	n
62	Variedad del almendro	Almond variety	Almond variety	Almond variety	n
63	Falta de ganado	Lack of livestock	Lack of livestock	Decoupling livestock from arable farming	n
64	Plagas	Pests	Pests and diseases	Pests and diseases	n
65	Salud del cultivo	Almond tree health	Almond tree health	Almond tree health	n
66	Biodiversidad	Biodiversity	Biodiversity	Biodiversity	n
67	Insumos químicos	Chemical inputs	Chemical fertilizers	Chemical fertilizers	n
68	Poda	Pruning	Pruning	Pruning	n
69	Poda (en verde)	Green pruning	Pruning	Pruning	n
70	Pie franco	Ungrafted rootstock	Rootstock type	Rootstock type	n
71	Pie franco/ hibrido (tipo de pie)	Ungrafted or hybrid rootstock (type)	Rootstock type	Rootstock type	n
72	Plagas y enfermedades (exceso de lluvia en primavera)	Pests and diseases (excessive rainfall in spring)	Pest and diseases	Pest and diseases	n
73	Plagas y enfermedades (tratamiento preventivos con cobre)	Pests and diseases (Preventive pest treatments using copper)	Pest treatment	Pest treatment	n
74	Tratamiento de plagas	Pest treatments	Pest treatment	Pest treatment	n
75	No laboreo	No tillage	No tillage	No tillage	n
76	Daños animales (arruí, jabalí)	Damage caused by arrui and wild pigs	Wildlife damage	Wildlife damage	n
77	Diseño de la plantación	Plantation design	Plantation design	Plantation design	n
78	Pérdida de suelo	Soil loss	Land degradation	Land degradation	n
79	Acceso a mejores mercados	Access to better markets	Access to better markets	Improved market access & business opportunities	n
80	Adaptación a cambios	Adaptation to changes	Adaptation to changes	Innovation & adaptation capacity	n
81	Aumento precio almendra	Almond price increases	Almond price	Almond price	n
82	Sentimiento de pertenencia (arraigo territorio)	Belonging feeling (deep roots in the territory)	Belonging feeling	Belonging feeling	n
83	Rendimiento (calibre de la almendra y peso)	Performance (Caliber and weight of kernel nut)	Almond performance	Almond performance	n
84	Generaciones futuras	Coming generations	Coming generations	Bequest values	n
85	Efecto contagio/demostrativo a vecinos	Contagion and demonstrative effect	Contagion and demonstrative effect	Demonstrative effect	n
86	Contribución al planeta (Sostenibilidad)	Contribute to planet earth (sustainability)	Contribute to planet earth (sustainability)	Bequest values	n
87	Convencido de los beneficios de RA	Convinced about RA benefits	Convinced about RA benefits	Convinced about RA benefits	n
88	Dar que hablar al pueblo	Create a buzz	Demonstrative effect	Demonstrative effect	n

89	Por experimentar y aprender	Eager for learning and experimenting	Learning and experimenting	Learning and experimenting	n
90	Facilidad de manejo por adaptación a ciclos naturales	Easiness in management following natural cycles	Easiness in management following natural cycles	Labor decreases	n
91	Necesidad de experiencia (profesionalización)	Experience requirements (professionalization)	Experience requirements (professionalization)	Knowledge and experience requirement (Professionalization)	n
92	Compartir experiencias	Sharing experiences	Learning and experimenting	Learning and experimenting	n
93	Reducción combustibles fósiles	Fossil fuels use decreases	Fossil fuels use decreases	Fossil fuels reduction	n
94	Felicidad	Happiness	Happiness	Self-fulfillment, satisfaction and personal development	n
95	Favorece a los pastores por alimento al ganado	Helps shepherds because of fodder	Benefits to sheep farming	Benefits to sheep farming	n
96	Aumento de la demanda de las empresas	Companies´ demands increase	Companies´ demands increase	Improved market access & business opportunities	n
97	Incremento solicitud de productos, conocimientos, charlas	Higher demands (products, talks, knowledge)	Higher demands (products, talks, knowledge)	Improved market access & business opportunities	n
98	Mejor rendimiento a largo plazo	Higher economic performance	Profitability	Profitability	n
99	Producción	Production	Production	Production	n
100	Inversión inicial aumenta	initial investment increases	initial investment increases	Initial investment increases	n
101	Coste insumos aumenta a corto plazo	Input costs increases (short term)	input costs increases	Input costs increases	n
102	Reducción costes de insumo	Inputs costs decreases	input costs increases	Input costs increases	y
103	Inspiración	Inspiration	Inspiration	Inspiration	n
104	Necesidad de conocimientos (RA mayor complejidad)	Knowledge requirements (RA higher complexity)	Knowledge requirements	Knowledge and experience requirement (Professionalization)	n
105	Necesidad de conocimiento técnicos	Technical knowledge requirements	Knowledge and experience requirement (Professionalization)	Knowledge and experience requirement (Professionalization)	
106	Reducción de mano de obra	Reduction of working force	Labor decreases	Labor decreases	n
107	Reducción horas de trabajo	Reduction of working hours	Labor decreases	Labor decreases	n
108	Mano de obra aumenta	Labor increases	Labor decreases	Labor decreases	y
109	Belleza del paisaje	Landscape aesthetics	Landscape aesthetics	Landscape restoration	n
110	Recuperación del Paisaje	Landscape recovery/restoration	Landscape restoration	Landscape restoration	n
111	Aprender	Learning	Learning	Learning and experimenting	n
112	Reducción de enfermedades ganado	Livestock diseases decreases	Livestock diseases decreases	Benefits to sheep farming	n
113	Amor a la tierra	Love for the land	Belonging feeling	Belonging feeling	n
114	Necesidad de adaptar la maquinaria	Machinery adaptation requirements	Machinery adaptation requirements	Innovation & adaptation capacity	n
115	Reducción gastos maquinaria	Machinery costs decreases	Machinery costs decreases	Operational costs decreases	n
116	Aumento costes manejo	Operational costs increases	Operational costs increases	Operational costs	y

				decreases	
117	Manejo más complicado	Management is more complex	Management complexity	Knowledge and experience requirement (Professionalization)	n
118	Conocer personas dentro de RA interesantes	Meeting interesting people working with RA	Networking	Networking	n
119	Aprendizaje mutuo	Mutual learning	Mutual learning	Learning and experimenting	n
120	Políticas que incentiven la compra de almendras	Need of policies to promote almond purchases	Need of policies to promote almond purchases	Policies favoring almond market purchases	n
121	Acceso de redes: Contactos	Access to networks: contacts	Networking	Networking	n
122	Networking	Networking	Networking	Networking	n
123	Nuevas oportunidades de negocio (Agroturismo)	New business opportunities (agro-tourism)	New business opportunities (agro-tourism)	Access to better markets & business opportunities	n
124	Apertura a nuevas tecnologías	Openness to new technologies	Openness to new technologies	Innovation & adaptation capacity	n
125	Reducción de costes operacionales	Operational costs decreases	Operational costs decreases	Operational costs decreases	n
126	Desarrollo personal	Personal development	Personal development	Self-fulfillment, satisfaction and personal development	n
127	Disfrute personal de la finca	Personal enjoyment of the farm	Personal enjoyment of the farm	Self-fulfillment, satisfaction and personal development	n
128	Reducción tratamientos fitosanitarios (curas para Plagas)	Pest treatments decreases	Pest treatments decreases	Pest treatment	n
129	Rentabilidad	Profitability	Profitability	Profitability	n
130	Calidad de la almendra	Quality of almond nut (kernel)	Quality of almond nut (kernel)	Almond quality	n
131	Reducción de costes a largo plazo	Reduction of costs (long term)	Reduction of costs (long term)	Operational costs decreases	n
132	Respeto al planeta (Sostenibilidad)	Respect to planet earth (sustainability)	Bequest values	Bequest values	n
133	Satisfacción y desarrollo personal	Satisfaction and personal development	Satisfaction and personal development	Self-fulfillment, satisfaction and personal development	n
134	Ahorro de tiempo	Saves time	Saves time	Labor decreases	n
135	Incremento consciencia social (ayudar a la gente)	Social consciousness increases (help people)	Social consciousness increases (help people)	Social awareness and expectation	n
136	Presión social	Social pressure	Social pressure	Social acceptance and support	y
137	Aumento sensibilización y expectación en la sociedad	Social awareness and expectation increases	Social awareness and expectation increases	Social awareness and expectation increases	n
138	Espiritualidad	Spirituality	Spirituality	Self-fulfillment, satisfaction and personal development	n
139	Sostenibilidad	Sustainability	Sustainability	Sustainability	n
140	Revalorización del territorio	Territory revaluation	Territory revaluation	Territory revaluation	n
141	Reducción de costes de	Tillage cost decreases	Tillage cost decreases	Operational costs	n
142	Validación y apoyo social	Validation and social support	Validation and social	Validation and social	n

143	Orgullo y éxito personal	Pride and personal success	Self-fulfillment, satisfaction	Self-fulfillment,	n
144	Degradación de la Tierra	Land degradation	Land degradation	Land degradation	n
145	Enmiendas orgánicas	Organic amendments	Organic amendments	Organic amendments	n
146	Abonos verdes	Green manure	Green manure	Green manure	n
147	Laboreo reducido	Reduced tillage	Reduced tillage	Reduced tillage	n
148	Salud física y mental del agricultor	Farmer´s physical and mental health	Self-fulfillment, satisfaction and personal development	Self-fulfillment, satisfaction and personal	n
149	Necesidad de maquinaria	Need of machinery	Innovation & adaptation capacity	Innovation & adaptation capacity	n
150	Ver para creer	Seeing for believing	Learning and experimenting	Learning and experimenting	n
151	Sistemas de conservación de agua	Water conservation measures	Removal of soil and water conservation measures	Removal of soil and water conservation	y
152	Tratamiento con cobre	Pest treatment	Pest treatment	Pest treatment	n
153	Despoblación	Depopulation	Land abandonment	Land abandonment	n

Appendix 2: Lists of concepts in the aggregated map and their meaning

ID	Final concept	Interpretation/definition based on farmers´ interviews
1	Intensive tillage	Tillage frequency higher than 4 times per year, moldboard plowing and/or deep plowing
2	Tillage	The fact of tilling
3	Down-slope tillage	Tillage direction following the direction of the slope, favoring erosion processes and soil loss
4	West winds	Winds coming from the west usually strong and warm. In spring negatively affect pollination
5	Sun	High temperatures, insolation and evapotranspiration
6	Droughts	Periods of water scarcity
7	Slope	Steep slopes
8	Monoculture	Cultivation of one single crop occupying large land extensions
9	Deforestation	Clear cutting or clearing a forest to convert it to farm land
10	Overgrazing	Excessive grazing causing damage to grasslands, such as compaction and fertility loss
11	Land use change	Conversion from cereal to woody crops, mainly to almond trees
12	Decoupling livestock from arable farming	Separation of livestock from arable production. Disappearance of traditional integrated systems based on woody crops, pastures and sheep
13	Heavy machinery	Change from oxen plow to heavy machinery, leading to the intensification of tillage activities and adaptation of farming practices to machinery
14	Removal of SWCM	Removal of soil and water conservation measures and erosion barriers, such as stone walls, hedgerows, vegetation on field borders, and mainly “atochadas”, a small barrier made of mud and esparto grass or other woody plants for retaining water within terraces
15	Bare soil	Soil without surface protection due to elimination of ground covers
16	CAP improvement plans	Policies from the 90´s prompted by the EU which initially subsidized the use of chemical fertilizers, agrotoxics, tillage and other farming practices, while in later stages of agricultural surpluses, PAC subsidies were destined for not producing, thereby fostering land abandonment and cessation of farming activities
17	Management responding to agribusiness model	Farm management coupled to the green revolution and agribusiness farming model, which has led to the removal of terraces, contour lines, use of heavy machinery, agrochemicals and agrotoxics
18	Land abandonment	Land abandonment partly due the industrialization of agriculture, and relates services and industry. Less labor is needed, and the lack of opportunities in rural areas led to the flight of people from rural areas to cities (rural exodus)
19	Land concentration	Concentration of land ownership in a few owners due to the reduction of the number of farms and the increment of the farm size
20	Agrotoxics	Pesticides and herbicides used in agriculture to eliminate weeds, insects, fungi or any other living organisms affecting crop performance
21	Chemical fertilizers	Mineral fertilizers including mainly simple and mixed N, P, K fertilizers
22	Overexploitation of water resources	Water extraction rates beyond natural recharge. This includes groundwater extraction from (i)legal drilled wells and water reservoirs to water traditional rain-fed crops, high-yielding horticultural crops, or intensive fruit tree plantations
23	Pig slurry	Watery and nutrient concentrated amendment mixed of feces, urine and water wastes from pig farming, that after treatment is often used as fertilizer
24	Organic matter	Organic matter component of soil, consisting of plant and animal detritus, cells and tissues of soil microbes, and substances that soil microbes synthesize
25	Loss of traditional knowledge	Loss of traditional knowledge of farming practices and management used by farmers before the arrival of "Green Revolution model". Traditional knowledge includes understandings to maintain soil fertility through careful management of organic material; to avoid pest outbreaks through intercropping and natural remedies, and about crop varieties, soil types and their best combination, involving a deep connection to the land and its stewardship

26	Loss of peasant self-esteem	Loss of sense of self, the value of the community and the value of the peasant´s profession, as a result of years of denigration and prejudice fostered by the green revolution model
27	Torrential rainfalls	Extreme and concentrated rainfall events occurring in the southeast, and the Mediterranean coast, of Spain. Usually occur during the beginning of Autumn and Spring with the arrival of the Cold Drop phenomenon. In agricultural lands these events often cause huge soil losses via water erosion affecting crop production due to the fall of flowers and fruits
28	High temperatures	Temperatures over 40ºC. During blossoming bees do not visit flowers at high temperatures, negatively affecting pollination.
29	Water availability	Water supply to meet crop requirements as a crucial factor in drought-prone agricultural areas
30	Late frosts	Frost occurring in spring that freeze blossoms and green almond nuts
31	Early frosts	Frost occurring in early winter which delays blossoming avoiding possible yield losses caused by late frosts
32	Hailing at fruit setting	Hailing during fruit setting damages almond nuts and produces the fall of fruits jeopardizing annual crop production
33	Soil fertility	Natural fertility intrinsic of the different soil types
34	Soil biodiversity	Number and diversity of organisms present in the soil required for soil health, fertility and overall soil functioning
35	Soil balance	Equilibrium between the organic and mineral fractions of the soil and the soil organisms
36	Soil structure	How particles are aggregated in the soil. Good soil structure enhances soil porosity, water holding capacity and decomposition processes fostering nutrient cycling
37	Pollination	Fertilization of almond flowers by bees and other pollinators
38	Fog	Fog. During blossoming negatively affects pollination
39	Cultivation practices	All the processes involved in the production of plant-based systems carried by the farmer, from seedling to harvesting, including fertilization, tillage, planting, pruning, pest treatments…
40	Almond variety	Almond varieties belong to the hard shell type and have different characteristics such as flowering time and sensibility to pests and diseases, and include Guara, Ferragnes, Marcona, Vairo, Desmayo Largueta, Marta, Constanti, Antoñeta, Penta and Marinada among others. The variety of almond can highly condition annual yields depending on the biophysical and climatic conditions where it is planted
41	Pests and diseases	Organisms that cause damage to almond trees conditioning yield. Most important pest and diseases include big head worm (*Capnodis tenebrionis*), almond-tree leaf skeletonizer moth (*Aglaope infausta*) and the monilinia fungus (*Monilinia laxa)*
42	Almond tree health	Includes all factors that contribute to a good performance of the almond tree, including the nutritional status of almond trees
44	Biodiversity	Aboveground biodiversity (insects, plants, crops, animals)
45	Pruning	Type, frequency and timing (green or dry) of the pruning
46	Rootstock type	Ungrafted or hybrid. The rootstock type influences the tree life time, performance and susceptibility to pests and diseases
47	Pest treatment	Preventive and in-situ management of pests using copper and other products allowed in organic farming
48	No tillage	Farming without disturbing the soil profile through tillage activities
49	Wildlife damage	Damage caused to almond trees by wild goats (*Ammotragus lervia*), wild pigs and rabbits
50	Plantation design	Factors to take into account for the establishment of an almond plantation such as the planting frame, the contour lines, terraces, almond variety…
51	Almond price	Organic certified almonds have an added value as "regenerative" branded which translates into the increase of price
52	Almond performance	Caliber and weight of kernel nuts, and amount of empty almonds in 1kg of shell almonds. Higher performance implies higher proportion of filled almonds with higher caliber and weight

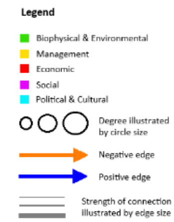
53	Feeling of belonging	Strong emotional feeling, need or desire of belonging to a community of people, a territory or a place
54	Benefits to sheep farming	Better nutritional status and health of the herd due to the supply of high quality fodder to sheep, which translates into less veterinary costs for the shepherd
55	Bequest values	Value that the current generation places on ensuring the availability of biodiversity and ecosystem services to future generations. This is determined by a person's concern that future generations should have access to resources and opportunities. It indicates a perception of benefit from the knowledge that resources and opportunities are being passed to descendants
56	Convinced about RA benefits	Farmers´ conviction regarding RA restoration capacity based on their own experience or perceptions
57	Demonstrative effect	Effects on the behavior of individuals, mainly neighbors, caused by observation of the results achieved through the adoption of regenerative agriculture
58	Fossil fuels use reduction	Diesel and oil use reduction due to the minimization of tillage activities, the non-use of chemical fertilizers and agrotoxics used in conventional farming
69	Happiness	Feeling of pleasure and joy experienced by a person from doing what she/he beliefs is right
60	Improved market access & business opportunities	Higher demand of products by companies, and better access to markets and business opportunities such as agro-tourism, supported by higher media visibility
61	Initial investment increases	Initial investment necessary to adapt a farm to regenerative which entails the implementation of landscape and soil restoration practices such as erosion barriers, swales, key-line design, replanting of hedgerows and borders, composts, green manure, and machinery for RA practices management
62	Innovation & adaptation capacity	Willingness and capacity to innovate in farming, adapt the farming system and farming management, invent or adapt new farming practices and technologies
63	Input costs increases	Cost from compost, green manure seeds, and other RA practices. When input costs decrease is mainly due to diesel saving from reducing tillage operations
64	Inspiration	People's hope, sense of purpose and personal drive to make a difference and contribute to society
65	RA Knowledge and experience requirements	RA is a farming approach that works with natural processes to maximize the provisioning of ecosystem services and requires a farmer´s complex understanding of the biophysical and climatic context, and knowledge and experience on RA practices and management strategies for an effective implementation
66	Labor decreases	Reduction of the need of work force and time dedicated to farming activities as the farming system works more closely to natural processes, making farming activities less labor demanding
67	Landscape restoration	Includes restoration of landscape functioning, including crucial ecosystem processes, aesthetics, and territory revaluation
68	Learning and experimenting	Farmers´ eagerness to learn and experiment from own and shared experiences
69	Networking	Meeting people working with RA, exchanging knowledge and information with people with a common interest
70	Operational costs decreases	Cost reduction of farming activities. Cost reduction in the short term results mainly from the minimization of tillage activities and pest treatments. In the long term other operational costs might decrease as the systems gets restored, benefiting from natural processes and becoming more simple to manage
71	Policies favoring RA almond purchases	Public policies favoring purchases of regenerative almonds to incentivize a large-scale adoption of RA
72	Profitability	Economic performance considering all production economic costs and benefits. Regenerative almond farming might be more profitable than conventional farming in the medium-long term
73	Self-fulfillment, satisfaction and personal development	Fulfillment of one´s objectives and dreams. Enjoyment of the farm, pride and personal success
74	Social awareness and expectation increases	Society becomes more conscious of the damage caused by unsustainable farming practices, and gains awareness of the restoration potential and benefits of RA
75	Spirituality	Sense of connection with something higher than ourselves

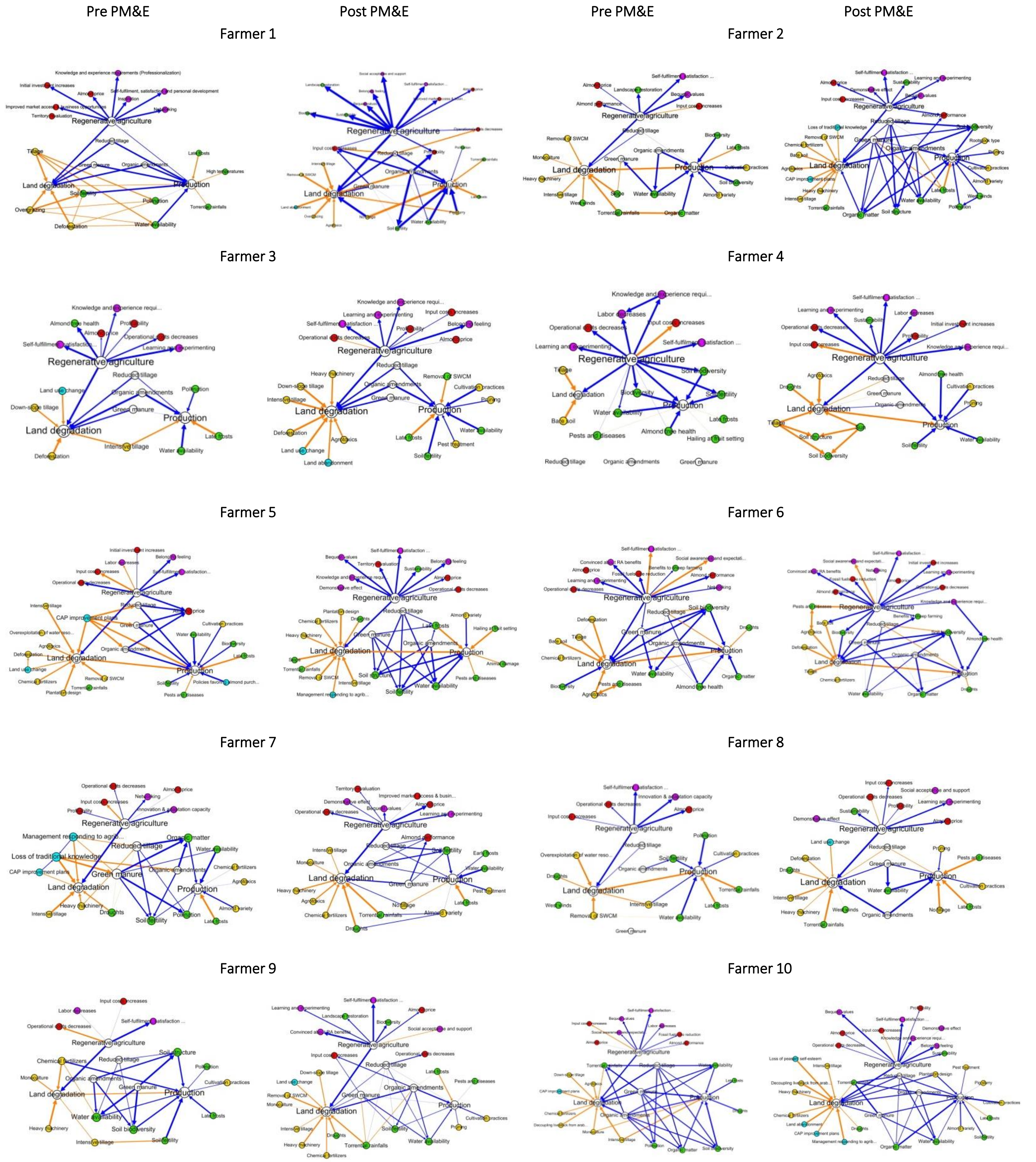
76	Sustainability	Maintaining or enhancing the availability of natural resources and well-functioning farming systems in the long term
77	Social acceptance and support	Social support to RA farmers, initiatives and products enhancing RA adoption. Contrary to social pressure against RA.
78	Territory revaluation	Add value to the territory
79	Land degradation	Natural or human-induced processes like soil erosion that disturb ecosystem functioning leading to reduced production potential and loss of functionality
80	Production	Yield
81	Organic amendments	Animal and plant based fertilizers, such as compost, bokashi, sheep manure and excluding green manure
82	Green manure	Leguminous or mixed cereal-leguminous covers that are used to increase soil fertility
83	Reduced tillage	Shallow plowing (less than 20 cm) carried out a maximum of 2 times per year to minimize soil disturbance

Appendix 3: Classification of final terms in groups

Management (technical & productive)	Biophysical & Environmental	Economic	Political & Cultural	Social
• Agrotoxics	• Biodiversity	• Almond performance	• CAP improvement plans	• Belonging feeling
• Almond variety	• Droughts	• Almond price	• Policies favoring almond purchases	• Bequest values
• Bare soil	• Early frosts	• Improved market access & business opportunities	• Land use change	• Convinced about RA benefits
• Chemical fertilizers	• Fog	• Initial investment increases	• Management responding to agribusiness model	• Demonstrative effect
• Cultivation practices	• Hailing at fruit setting	• Input costs increases	• Land abandonment	• Innovation & adaptation capacity
• Decoupling livestock from arable farming	• High temperatures	• Operational costs decreases	• Land concentration	• Inspiration
• Deforestation	• Late frosts	• Profitability	• Loss of traditional knowledge	• Knowledge and experience requirements (Professionalization)
• Down-slope tillage	• Organic matter	• Territory revaluation	• Loss of peasant self-esteem	• Labor decreases
• Heavy machinery	• Pests and diseases	• Fossil fuels use reduction		• Learning and experimenting
• Intensive tillage	• Pollination			• Networking
• Monoculture	• Slope			• Self-fulfilment, satisfaction and personal development
• No tillage	• Soil biodiversity			• Social awareness and expectation increases
• Overexploitation of water resources	• Soil fertility			• Social acceptance and support
• Overgrazing	• Soil structure			
• Pest treatment	• Sun			
• Pig slurry	• Torrential rainfalls			
• Plantation design	• Water availability			
• Pruning	• West winds			
• Removal of SWCM	• Wildlife damage			
• Rootstock type	• Almond tree health			
• Tillage	• Benefits to sheep farming			
	• Landscape restoration			
	• Sustainability			

Appendix 4: Evolution of farmers´ individual perceptions pre and post PM&E





Appendix 5 Most cited factors, centrality and frequency

Table 1 Regenerative practices linked to Land degradation, times cited by participating farmers and strength of influence (weight) before and after PM&E

LAND DEGRADATION	pre PM&E		Post PM&E	
	times cited	weight	times cited	weight
Regenerative practices				
Organic amendments	5	0,38	7	0,50
Green Manure	4	0,38	9	0,56
Reduced tillage	4	0,38	8	0,26

Table 2 Most cited factors and regenerative practices linked to production, times cited by participating farmers and strength of influence (weight) before and after PM&E

PRODUCTION	pre PM&E		post PM&E	
	times cited	weight	times cited	weight
Water availability	10	0,90	10	0,88
Soil fertility	6	0,52	7	0,60
Soil biodiversity	5	0,48	-	-
Late frosts	9	-0,46	8	-0,70
Organic matter	4	0,36	6	0,30
Cultivation practices	-	-	3	0,50
Regenerative practices				
Organic amendments	4	0,58	8	0,72
Green Manure	3	0,34	7	0,28
Reduced tillage	4	0,28	8	0,22
Land degradation		-0,52		-0,30

Table 3 Factors mentioned before and after PM&E organized from higher to lower centrality

pre PM&E		post PM&E	
FACTORS	Centrality	FACTORS	Centrality
Land degradation	7,18	Land degradation	8,58
Production	6,84	Regenerative agriculture	7,66
Regenerative agriculture	6,44	Production	7,20
Green manure	2,62	Organic amendments	3,08
Organic amendments	2,50	Green manure	2,46
Water availability	2,22	Water availability	2,18
Reduced tillage	1,82	Reduced tillage	1,70
Soil biodiversity	1,26	Soil fertility	1,32
Soil fertility	1,20	Organic matter	1,06
Organic matter	0,94	Soil biodiversity	0,90
Pollination	0,92	Soil structure	0,82

Almond price	0,84	Torrential rainfalls	0,80
Intensive tillage	0,72	Self-fulfillment, satisfaction and personal development	0,80
Self-fulfillment, satisfaction and personal development	0,70	Late frosts	0,78
Torrential rainfalls	0,70	Agrotoxics	0,70
CAP improvement plans	0,70	Droughts	0,62
Deforestation	0,66	Intensive tillage	0,62
Tillage	0,60	Almond price	0,60
Almond tree health	0,58	Learning and experimenting	0,58
Agrotoxics	0,50	Knowledge and experience requirements (Professionalization)	0,56
Biodiversity	0,48	Sustainability	0,52
Late frosts	0,46	Heavy machinery	0,52
Chemical fertilizers	0,44	Cultivation practices	0,50
Loss of traditional knowledge	0,40	Bequest values	0,48
Operational costs decreases	0,40	Almond performance	0,46
Knowledge and experience requirements (Professionalization)	0,38	Tillage	0,46
Pests and diseases	0,38	Pests and diseases	0,44
Input costs increases	0,34	Profitability	0,44
Overgrazing	0,32	Chemical fertilizers	0,44
Removal of SWCM	0,30	Removal of SWCM	0,42
Learning and experimenting	0,30	No tillage	0,42
Soil structure	0,30	Almond variety	0,40
Heavy machinery	0,30	Belonging feeling	0,40
Cultivation practices	0,28	Biodiversity	0,38
Networking	0,26	Input costs increases	0,32
Management responding to agribusiness model	0,26	Operational costs decreases	0,32
Monoculture	0,26	Pruning	0,30
Droughts	0,22	Sun	0,30
Labor decreases	0,22	Almond tree health	0,30
Almond performance	0,22	Bare soil	0,28
Bare soil	0,20	Land abandonment	0,26
Land use change	0,20	Demonstrative effect	0,24
Bequest values	0,18	Land use change	0,22
Innovation & adaptation capacity	0,18	Pest treatment	0,20
Fossil fuels use reduction	0,16	Pig slurry	0,20
Almond variety	0,16	Pollination	0,20
Down-slope tillage	0,16	Management responding to agribusiness model	0,18
Slope	0,16	West winds	0,18
Initial investment increases	0,14	Benefits to sheep farming	0,18
Profitability	0,12	Initial investment increases	0,16
Overexploitation of water resources	0,12	Landscape restoration	0,16
Plantation design	0,10	Territory revaluation	0,16
Policies favoring almond purchases	0,10	CAP improvement plans	0,16

West winds	0,10
Belonging feeling	0,10
Convinced about RA benefits	0,10
Improved market access & business opportunities	0,10
Inspiration	0,10
Landscape restoration	0,10
Benefits to sheep farming	0,08
Decoupling livestock from arable farming	0,08
Hailing at fruit setting	0,06
High temperatures	0,06
Social awareness and expectation increases	0,04
Territory revaluation	0,04

Down-slope tillage	0,16
Improved market access & business opportunities	0,12
Deforestation	0,12
Decoupling livestock from arable farming	0,10
Hailing at fruit setting	0,10
Loss of peasant self-esteem	0,10
Plantation design	0,10
Slope	0,10
Convinced about RA benefits	0,10
Fossil fuels use reduction	0,10
Social awareness and expectation increases	0,10
Labor decreases	0,08
Monoculture	0,08
Overgrazing	0,08
Networking	0,06
Early frosts	0,06
Loss of traditional knowledge	0,06
Rootstock type	0,06
Wildlife damage	0,06
Social acceptance and support	0,04

Legend
Biophysical & Environmental
Management
Economic
Political & Cultural
Social
Entry Notes (Given)

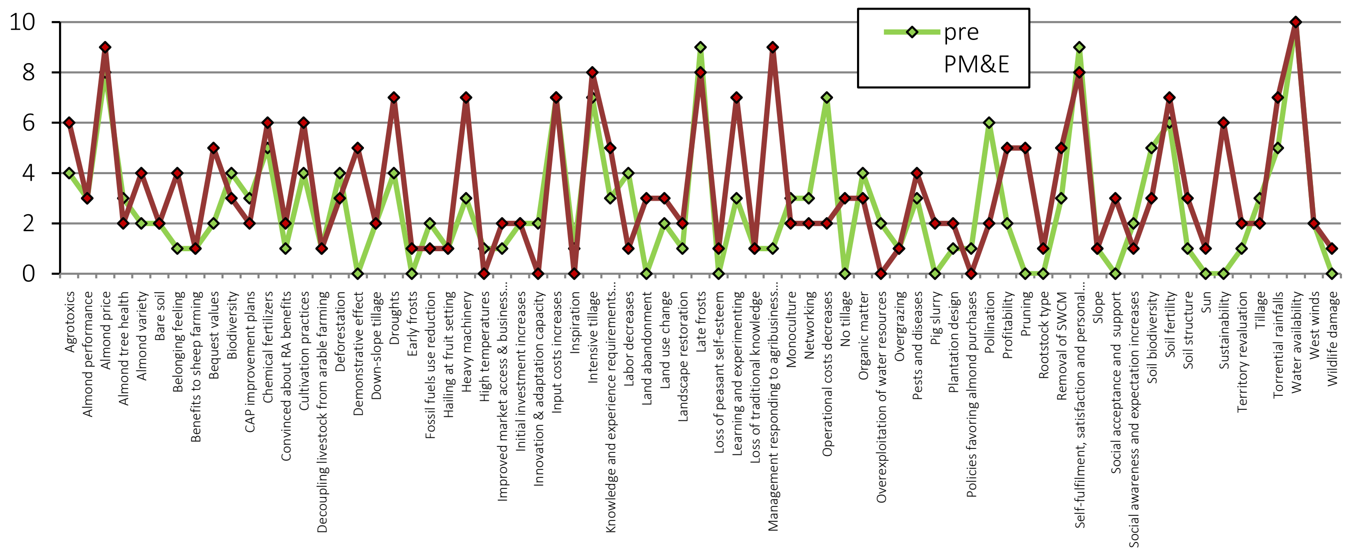


Figure 1 Frequency of citation of mentioned factor pre and post PM&E