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...
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, Cuellar-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, Skaalsvæen 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. 2012, 2016). 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 semi-arid southeast of Spain in collaboration with members of the farmer association AlVelAl. The semi-arid 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, LaCaine 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 Leijst et al. 2019, Luján Soto et al. 2021b), RA has had limited adoption in the high steppe plateau in southeastern Spain and in semi-arid regions in general. This limited adoption 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 semi-arid conditions, which may delay the appearance of visible results, discouraging farmers from adopting RA.
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. 2021b). 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.

| 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                      | Sheep integration                        |
| S3     | Member                      | 2014                                          | 70             | Reduced tillage          | Bokashi and sheep manure | Winter natural covers                      | Sheep integration                        |
| 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    | Sheep integration                        |
| S9     | Research technician         | 2013                                          | 35             | Reduced tillage          | Compost and sheep manure, green manure | Winter natural covers; prunings mulched | Sheep integration                        |
| 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    | Sheep integration                        |
| 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 (Appendices 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 FC 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 AIVelAI 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
The E-Index measures homophily, which is the tendency of individuals to associate and interact with others like themselves. Network size or number of actors is critical for a social network to evolve and develop, and it is essential to maintain social relations and fluxes of information. Betweenness and homophily metrics are widely used to assess social network evolution, and the level of homophily indicates whether information sharing occurs more among farmers than with other actors; positive values indicate information sharing occurs more among farmers than with other actors; positive values indicate the opposite.

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

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 FCMs into collective FCMs (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
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).

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

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.

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         |
| Production        | pre PM&E     | 0.26            | 0.50               | 0.56         |
| Water availability| post PM&E    | 0.18            | 0.36               | 0.34         |
| Soil fertility    | pre PM&E     | 0.38            | 0.44               | 0.48         |
| Organic matter    | pre PM&E     | 0.18            | 0.18               | 0.12         |
| Soil biodiversity | post PM&E    | 0.02            | 0.20               | 0.18         |
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.
**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 FCMs 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. 2021b). This result indicates that PM&E favorized 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, Suškėvičs 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, Suškėvičs 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

https://www.ecologyandsociety.org/vol26/iss4/art29/
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 involved 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. 2021a). 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/
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 information, 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 | Torrential rainfalls | n |
| 8  | Aumento de sequías | Increment of droughts | Droughts | Droughts | n |
| 9  | Sequías | Droughts | Droughts | Droughts | n |
| 10 | Pendiente | Slope | Slope | Slope | n |
| 11 | Monocultivo | Monoculture | Monoculture | Monoculture | n |
| 12 | Deforestarion | 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 | Maquinaria pesada | Heavy machinery | Heavy machinery | Heavy machinery | n |
| 17 | Adaptación de la agricultura a la maquinaria | Adaptation of farming to heavy machinery | Heavy machinery | Heavy machinery | n |
| 18 | Desaparición de lindes y su vegetación | Elimination of field boundaries and hedgerows | Removal of barriers | Removal of soil and water conservation measures | n |
| 19 | Eliminación de barreras | Removal of barriers | Removal of barriers | Removal of soil and water conservation measures | n |
| 20 | 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 |
| 21 | Eliminación de terrazas y barreras | Removal of terraces and barriers | Removal of barriers | Removal of soil and water conservation measures | n |
| 22 | Falta de cubiertas | Lack of ground covers | Bare soil | Bare soil | n |
| 23 | Capitalismo: políticas públicas equivocadas | Capitalism: wrong public policies | CAP subsidies responding agribusiness interests | CAP subsidies responding agribusiness interests | n |
| 24 | Incentivar prácticas que | Promotion of farming | CAP subsidies responding | CAP subsidies | n |
| Nº | Maniobra | Descripción | Descripción | Descripción |
|----|----------|-------------|-------------|-------------|
| 28 | Manejo favorables a intereses económicos de empresas | Management responding to agribusiness interests | Management responding to agribusiness interests | n |
| 29 | Abandono de la tierra | Land abandonment | Land abandonment | n |
| 30 | Falta de mano de obra (éxodo rural) | Land abandonment | Land abandonment | n |
| 31 | Subvenciones (PAC - Políticas Públicas) | CAP subsidies responding agribusiness interests | CAP subsidies responding agribusiness interests | n |
| 32 | Concentración de tierras | Land concentration | Land concentration | n |
| 33 | Pesticidas | Agrotoxics | Agrotoxics | n |
| 34 | Fitosanitarios | Agrotoxics | Agrotoxics | n |
| 35 | Abonos químicos | Chemical fertilizers | Chemical fertilizers | n |
| 36 | Abonos sintéticos | Chemical fertilizers | Chemical fertilizers | n |
| 37 | Regadío y sobreexplotación de recursos hídricos | Overexploitation of water resources | Overexploitation of water resources | n |
| 38 | Sobrexplotación recursos hídricos | Overexploitation of water resources | Overexploitation of water resources | n |
| 39 | Purines | Pig slurry | Pig slurry | n |
| 40 | Falta de materia orgánica | Lack of organic matter | Organic matter | y |
| 41 | Suelos descubiertos (falta de cubiertas) | Bare soil | Bare soil | n |
| 42 | Falta y pérdida de conocimientos de manejo y prácticas | 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 practices and management | Loss of traditional knowledge | n |
| 44 | Pérdida de autoestima campesina | Loss of peasant self-esteem | Loss of peasant self-esteem | n |
| 45 | Lluvias fuertes época de floración | Torrential rainfalls during blossoming | Torrential rainfalls | n |
| 46 | Altas temperaturas (por encima de 40ºC) | High temperatures | High temperatures | n |
| 47 | Disponibilidad de agua | Water availability | Water availability | n |
| 48 | Heladas tardías (congelan la alloza o almendruco) | Late frosts | Late frosts | n |
| 49 | Heladas tempranas | Early frosts | Early frosts | n |
| 50 | Granizadas después de que cuaje | Hailing at fruit setting | Hailing at fruit setting | n |
| 51 | Viento de poniente (fuerte y cálido) | Warm West winds | Warm West winds | n |
| 52 | Fertilidad del suelo | Soil fertility | Soil fertility | n |
| 53 | Biodiversidad del suelo | Soil biodiversity | Soil biodiversity | n |
| 54 | Equilibrio (parte viva, orgánica y mineral) | Soil balance (organisms, organic and mineral fractions) | Soil balance | n |
|   | Estructura del suelo | Soil structure | Soil structure | Soil structure |
|---|---------------------|---------------|---------------|---------------|
| 55 | Materia orgánica     | Organic matter| Organic matter| Organic matter|
| 56 | Nutrición del árbol | Almond tree nutrition| Almond tree nutrition| Almond tree nutrition|
| 57 | Polinización         | Pollination   | Pollination   | Pollination   |
| 58 | Niebla en floración | Fog at blossoming| Fog            | Fog           |
| 59 | Labores culturales  | Cultural practices| Cultivation practices| Cultivation practices|
| 60 | Variedad del almendro| Almond variety | Almond variety | Almond variety |
| 61 | Falta de ganado      | Lack of livestock| Lack of livestock| Decoupling livestock from arable farming|
| 62 | Plagas               | Pests         | Pests and diseases| Pests and diseases|
| 63 | Salud del cultivo    | Almond tree health| Almond tree health| Almond tree health|
| 64 | Biodiversidad        | Biodiversity  | Biodiversity  | Biodiversity  |
| 65 | Insumos químicos     | Chemical inputs| Chemical fertilizers| Chemical fertilizers|
| 66 | Poda                 | Pruning       | Pruning       | Pruning       |
| 67 | Pie franco           | Ungrafted rootstock| Rootstock type| Rootstock type|
| 68 | Pie franco/ hibrido  | Ungrafted or hybrid rootstock (type)| Rootstock type| Rootstock type|
| 69 | Plagas y enfermedades| Pests and diseases (excessive rainfall in spring)| Pest and diseases| Pest and diseases|
| 70 | Plagas y enfermedades| Pests and diseases (Preventive pest treatments using copper)| Pest treatment| Pest treatment|
| 71 | Tratamiento de plagas| Pest treatments| Pest treatment| Pest treatment|
| 72 | No laboreo           | No tillage    | No tillage    | No tillage    |
| 73 | Dafños animales      | Damage caused by arrui and wild pigs| Wildlife damage| Wildlife damage|
| 74 | Diseño de la plantación| Plantation design| Plantation design| Plantation design|
| 75 | Pérdida de suelo     | Soil loss     | Land degradation| Land degradation|
| 76 | Acceso a mejores mercados| Access to better markets| Access to better markets| Improved market access & business opportunities|
| 77 | Adaptación a cambios | Adaptation to changes| Adaptation to changes| Innovation & adaptation capacity|
| 78 | Aumento precio almendra| Almond price increases| Almond price| Almond price|
| 79 | Sentimiento de pertenenciaregião territorial | Belonging feeling (deep roots in the territory)| Belonging feeling| Belonging feeling|
| 80 | Rendimiento (calibre de la almendra y peso) | Performance (Caliber and weight of kernel nut)| Almond performance| Almond performance|
| 81 | Generaciones futuras | Coming generations| Coming generations| Bequest values|
| 82 | Efecto contagio/demostrativo a vecinos | Contagion and demonstrative effect| Contagion and demonstrative effect| Demonstrative effect|
| 83 | Contribución al planeta (Sostenibilidad) | Contribute to planet earth (sustainability)| Contribute to planet earth (sustainability)| Bequest values|
| 84 | Convencido de los beneficios de RA | Convinced about RA benefits| Convinced about RA benefits| Convinced about RA benefits|
| 85 | Dar que hablar al pueblo | Create a buzz| Demonstrative effect| Demonstrative effect|
| N°  | Fase                                                                 | Beneficio                                                                 | Argumentación                                                                 |
|-----|----------------------------------------------------------------------|--------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| 89  | Por experimentar y aprender                                         | Eager for learning and experimenting                                      | Learning and experimenting                                                      |
| 90  | Facilidad de manejo por adaptación a ciclos naturales                | Easiness in management following natural cycles                           | Labor decreases                                                               |
| 91  | Necesidad de experiencia (profesionalización)                        | Experience requirements (professionalization)                            | Knowledge and experience requirement (Professionalization)                     |
| 92  | Compartir experiencias                                              | Sharing experiences                                                       | Learning and experimenting                                                      |
| 93  | Reducción combustibles fósiles                                       | Fossil fuels use decreases                                               | Fossil fuels reduction                                                         |
| 94  | Felicidad                                                            | Happiness                                                                | Self-fulfillment, satisfaction and personal development                      |
| 95  | Favorece a los pastores por alimento del ganado                       | Helps shepherds because of fodder                                        | Benefits to sheep farming                                                      |
| 96  | Aumento de la demanda de las empresas                                | Companies’ demands increase                                              | Improved market access & business opportunities                                |
| 97  | Incremento solicitud de productos, conocimientos, charlas           | Higher demands (products, talks, knowledge)                              | Improved market access & business opportunities                                |
| 98  | Mejor rendimiento a largo plazo                                      | Higher economic performance                                              | Profitability                                                                  |
| 99  | Producción                                                           | Production                                                               | Production                                                                     |
| 100 | Inversión inicial aumenta                                            | initial investment increases                                             | initial investment increases                                                   |
| 101 | Coste insumos aumenta a corto plazo                                  | Input costs increases (short term)                                       | Input costs increases                                                         |
| 102 | Reducción costes de insumo                                           | Inputs costs decreases                                                   | Input costs increases                                                         |
| 103 | Inspiración                                                          | Inspiration                                                              | Inspiration                                                                    |
| 104 | Necesidad de conocimientos (RA mayor complejidad)                    | Knowledge requirements (RA higher complexity)                            | Knowledge and experience requirement (Professionalization)                     |
| 105 | Necesidad de conocimiento técnicos                                   | Technical knowledge requirements                                          | Knowledge and experience requirement (Professionalization)                     |
| 106 | Reducción de mano de obra                                            | Reduction of working force                                               | Labor decreases                                                               |
| 107 | Reducción horas de trabajo                                           | Reduction of working hours                                               | Labor decreases                                                               |
| 108 | Mano de obra aumenta                                                 | Labor increases                                                          | Labor decreases                                                               |
| 109 | Belleza del paisaje                                                  | Landscape aesthetics                                                      | Landscape restoration                                                          |
| 110 | Recuperación del Paisaje                                             | Landscape recovery/restoration                                             | Landscape restoration                                                          |
| 111 | Aprender                                                             | Learning                                                                 | Learning and experimenting                                                     |
| 112 | Reducción de enfermedades ganado                                      | Livestock diseases decreases                                              | Benefits to sheep farming                                                      |
| 113 | Amor a la tierra                                                     | Love for the land                                                         | Belonging feeling                                                             |
| 114 | Necesidad de adaptar la maquinaria                                   | Machinery adaptation requirements                                         | Innovation & adaptation capacity                                              |
| 115 | Reducción gastos maquinaria                                          | Machinery costs decreases                                                | Operational costs decreases                                                    |
| 116 | Aumento costes manejo                                                | Operational costs increases                                              | Operational costs                                                             |
| Page | Spanish Text | English Translation | Decreases | Notes |
|------|--------------|---------------------|-----------|-------|
| 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 decreases | 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 | n |
| 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 laboreo | Tillage cost decreases | Tillage cost decreases | Operational costs decreases | n |
| 142  | Validación y apoyo social | Validation and social support | Validation and social | Validation and social | n |
| Página | Tema/Concepto                      | Traducción                       | Descripción                                      | Número |
|--------|-----------------------------------|----------------------------------|--------------------------------------------------|--------|
| 143    | Orgullo y éxito personal          | Pride and personal success       | Self-fulfillment, satisfaction                    |        |
| 144    | Degradación de la Tierra          | Land degradation                 | Land degradation                                 | n      |
| 145    | Enmiendas orgánicas               | Organic amendments               | Organic amendments                               | n      |
| 146    | Abonos verdes                     | Green manure                     | Green manure                                     | n      |
| 147    | Laboreo reducido                  | Reduced tillage                  | Reduced tillage                                  | n      |
| 148    | Salud física y mental del cultivador | Farmer’s physical and mental health | Self-fulfillment, satisfaction and personal development | n      |
| 149    | Necesidad de maquinaria           | Need of machinery                | Innovation & adaptation capacity                 | n      |
| 150    | Ver para creer                    | Seeing for believing             | Learning and experimenting                        | n      |
| 151    | Sistemas de conservación de agua  | Water conservation measures      | Removal of soil and water conservation measures   | y      |
| 152    | Tratamiento con cobre             | Pest treatment                   | Pest treatment                                   | n      |
| 153    | Despoblación                      | Depopulation                     | Land abandonment                                 | n      |
| 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 |
|   | 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 |
| 60 | Happiness | Feeling of pleasure and joy experienced by a person from doing what she/he believes 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

| 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       |
| Factor                                      | Weight | Factor                                      | Weight |
|---------------------------------------------|--------|---------------------------------------------|--------|
| 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       | 0.38   | Tillage                                     | 0.46   |
| Pests and diseases                          | 0.38   | Almond price                                | 0.46   |
| Input costs increases                       | 0.34   | Profitability                               | 0.44   |
| Overgrazing                                 | 0.32   | Chemical fertilizers                        | 0.44   |
| Removal of SWCM                             | 0.30   | No tillage                                  | 0.42   |
| Learning and experimenting                  | 0.30   | Almond variety                              | 0.40   |
| Soil structure                              | 0.30   | Belonging feeling                           | 0.40   |
| Heavy machinery                             | 0.30   | Biodiversity                                | 0.38   |
| 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   |
| Factor                                      | Pre | PM&E |
|---------------------------------------------|-----|------|
| West winds                                  | 0.10| 0.16 |
| 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|      |
| Convinced about RA benefits                 |      | 0.10 |
| Fossil fuels use reduction                  |      | 0.10 |
| Social awareness and expectation increases  |      | 0.10 |
| Labor decreases                             |      | 0.08 |

**Legend**

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

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