Title: Participatory selection of soil quality indicators for monitoring the impacts of regenerative agriculture on ecosystem services

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Highlights

• Our proposed methodological framework guides farmers and researchers to identify and select the most relevant local and technical indicators of soil quality for collaborative monitoring the impacts of Regenerative Agriculture.

• The combination of local and technical indicators improved the feasibility, coverage and suitability in impact assessment of soil erosion control, water regulation, soil fertility improvement and crop performance.

• The co-created monitoring system can improve the understanding of the impacts of Regenerative Agriculture and optimize the delivery of ecosystem services in Mediterranean woody-crop systems.

Abstract

Improving the understanding and fostering large-scale adoption of Regenerative Agriculture (RA) requires monitoring systems of soil quality integrating farmers´ and researchers´ knowledge. This is especially relevant for participatory impact assessment in semi-arid areas prone to land degradation that typically show a slow soil response to management changes, often resulting in low RA adoption rates. We developed a framework for the identification and selection of local and technical indicators of soil quality and for the development of a visual soil assessment tool, to participatory monitor the impacts of RA by farmers and researchers. We applied this framework in a large-scale restoration project in southeast Spain together with almond farmers implementing RA. Results show that local indicators selected by farmers focused mostly on water regulation and soil erosion control, improvement of soil fertility, crop performance and other main ecosystem services. Technical indicators selected by researchers focused mostly on soil properties including bulk density, aggregate stability, total and available nutrients, microbial biomass and activity, and leaf nutrients as proxy indicators of soil quality and crop performance. The combination of local and technical indicators provided complementary information, improving the relevance, coverage and feasibility of RA impact assessments. This integrated soil quality monitoring system offers a practical tool for farmers and researchers to jointly embark on a monitoring process enhancing knowledge exchange and mutual learning to support the implementation of RA and optimize the provision of ecosystem services.

Keywords: ecosystem services, land degradation, restoration, agroecology, almond production, southeast Spain

1. Introduction

There is no unique or generally applicable system to assess and monitor soil quality. Soil quality has an enormous influence on the functioning and sustainability of agroecosystems and on the delivery of ecosystem services worldwide (Adhikari and Hartemink, 2016; Baveye et al., 2016; Schulte et al., 2014), but people's perception of soil quality varies depending on their environmental and sociocultural context (Ericksen and Ardón, 2003; Mairura et al., 2007; Richelle et al., 2017). This difference in perception strongly influences how research is designed, which questions are considered important, how to address them, and which type of knowledge is accepted or neglected (Raymond et al., 2010). Consequently, multiple frameworks to generate soil quality indicators for monitoring and assessment of agroecosystem sustainability have been proposed (Bünemann et al., 2018). Nevertheless, most frameworks focused either on the identification of technical indicators based on expert knowledge, or on the identification of local indicators involving farmers in monitoring and assessment activities. Focusing only on one type of indicators implies either limited relevance and accessibility for most land users, reducing the potential to enhance farmer commitment in the implementation of sustainable solutions or, on the contrary, losing technical accuracy and insight of crucial process interactions.

During the past decades, the great potential of collaboration between farmers and researchers to identify relevant and accessible indicators for the assessment of agroecosystem sustainability has been increasingly recognized (Chambers, 1994; González-Esquivel et al., 2012; Hoffmann et al., 2007; Reed et al., 2008; Reed and Dougill, 2002). Several authors have argued that including both technical and local indicators can enlarge the accuracy, coverage and feasibility of impact assessment and enhance farmer adoption of sustainable management practices (Cardoso et al., 2001; Dougill et al., 2006; Reed et al., 2008; Stringer and Reed, 2007). Consistent with the above, a recent review on soil quality research (Bünemann et al., 2018) displayed the growing tendency to integrate different analytical and visual methods to assess soil quality, moving the research approach from sustainability for crop production to multifunctionality and provision of ecosystem services. An ecosystem services approach provides a common means for different stakeholders, disciplines and expertise to reflect the multiple, diverse, and complex views of the value of soils to human-wellbeing (Robinson et al., 2012). In this line, soil ecosystem services has become a priority research area at EU level (see projects) within which a soil ecosystem framework has been recently developed (EU-RECARE project; Schwilch et al., 2016) proposing linking soil quality indicators to ecosystem services to facilitate the impact assessment of soil management measures with multiple stakeholders at various scales (Schwilch et al., 2018), potentially influencing decision and policymaking and leading to improved and upscaled land management (Schwilch et al., 2016).Although soil quality is central to ecosystems potential to deliver supporting,regulating, provisioning and cultural services (Dominati et al., 2010), the assessment of the latter remains missing or underrepresented in soil quality research with regard to the former (Dominati, 2013; Mader, 2015; Stavi et al., 2016). One reason for this is that cultural services are complex to be empirically measured (Small et al., 2017) because they are commonly intangible and dependent on people's perceptions, (La Notte et al., 2017), and their assessment generally requires of specific methodologies (Oteros-Rozas et al., 2018; Plieninger et al., 2013).

To assess soil quality, researchers commonly use soil properties as technical indicators since they can be measured quantitatively. Technical indicators usually include a range of physical, chemical and biological soil properties, and are frequently one-off measured to elicit relations between causes and effects of agroecosystem processes (Costantini et al., 2016; Mader, 2015). Farmers´ knowledge of soil quality often relies on a continual observation of the impacts of farming practices on agroecosystem functioning (Kuria et al., 2019). Commonly, farmers use local indicators that are qualitative, context specific, include parameters easy to assess by touch, sight and smell (Bicalho and Peixoto, 2017), and often relate to the benefits they obtain from agroecosystems such as crop production or water provisioning. In short, while technical indicators are often relatively complex, reductionist, and can provide insight into detailed ecosystem properties, processes and interactions that support ecosystem services (Adhikari and Hartemink, 2016; Baveye et al., 2016; Prado et al., 2016), local indicators are often relatively simple, cheap and easy to measure, and help obtaining a direct impression of ecosystem service delivery (Bicalho and Peixoto, 2017).

Combining local and technical indicators of soil quality presents multiple potential benefits. First, their combination can provide complementary information covering knowledge gaps that are not addressed by each type of indicator alone (e.g. indicator plants can add information not addresses by only quantifying soil nutrients, such as overall agroecosystem health, soil salinity or specific nutrient deficiencies), and increase confidence by validating information provided by each type of indicator (e.g. soil fertility status) (Barrios et al., 2006; Bicalho and Peixoto, 2017). Second, their combination can broaden the coverage and feasibility of impact evaluation, making use of one of the types to cover the inherent limitations - i.e. associated costs, accuracy… - of the other (Giordano et al., 2010). Finally, it is expected that involving farmers and researchers in participatory monitoring will contribute to knowledge sharing and learning between stakeholders, trust building and interest to implement sustainable land management practices (Pahl-Wolst, 2007; Young et al., 2013). Combining local and technical indicators is especially relevant to monitor soil quality changes from innovative farming approaches like regenerative agriculture (RA) which promotes a wide diversity of soil restoration practices, such as no tillage and maintenance of green covers, to maximize ecosystem service delivery (Rhodes, 2017), but which impacts have been limitedly addressed or provided contrasting results (Palm et al., 2014). This is all the more relevant in semiarid areas where visible changes may take a long time to occur due to limited water availability for developing soil biological activity, discouraging farmers to adopt or maintain sustainable land management (Chinseu et al., 2018) such as RA.

To help the visibilization of soil quality changes to farmers, Visual Soil Assessment (VSA) tools are a good example of user friendly practical tools that facilitate the collection and systematization of field observations (Shepherd et al., 2008, 2000) and the exchange of information between different stakeholders and levels of expertise. VSA tools aid a straightforward interpretation of the soil quality status based on the visual assessment of soil and plant key performance indicators, fostering farmers′ self-evaluation and self-reflection on individual and community records (Ball et al., 2017). Furthermore, the use of VSA tools can help in the decision-making towards objectives of sustainable management and soil restoration (Ball et al., 2017; Triste et al., 2014) enhancing farmer ownership and community empowerment to adopt and adapt sustainable management (Darnhofer et al., 2008) without the need of continual technical support.

While recognition grows around the relevance of combining local and technical indicators for soil quality assessment, frameworks that facilitate their identification and selection remain scarce. Furthermore, there is no a standardized methodology to assess soil quality so far particularly integrating technical and local indicators for participatory monitoring land management measures between farmers and researchers. Therefore, there is a need for participatory frameworks that help selecting representative indicators that are informative and useful for stakeholders involved, enhancing more comprehensive assessment and efficient implementations of sustainable management practices to maximize the delivery of ecosystem services. Hence, in this paper we present a participatory framework to generate monitoring systems of soil quality based on the identification and selection of local and technical key performance indicators, and co-creation of a VSA tool, for collaborative assessment of RA by farmers and researchers. We present its application with a group of farmers taking part in a large-scale landscape restoration project based on RA in southeastern Spain, in order to: i) evaluate the complementarity of selected local and technical indicators to improve the impact assessment of RA on ecosystem services and, ii) demonstrate the framework suitability to develop monitoring systems that can enlarge the coverage, relevance, and feasibility of RA impact assessments based on indicator complementarity.

With the development and application of this framework we further aim to contribute to enhanced knowledge exchange between farmers and researchers in order to better understand the impacts and effectiveness of RA, and facilitate the large-scale implementation of effective landscape restoration initiatives.

2. Material and Methods

2.1. Study site

The participatory research reported here was conducted in the steppe high plateau of southeast Spain (Figure 1) in close collaboration with 12 organic farmers, all members of the regional agroecology association AlVelAl.

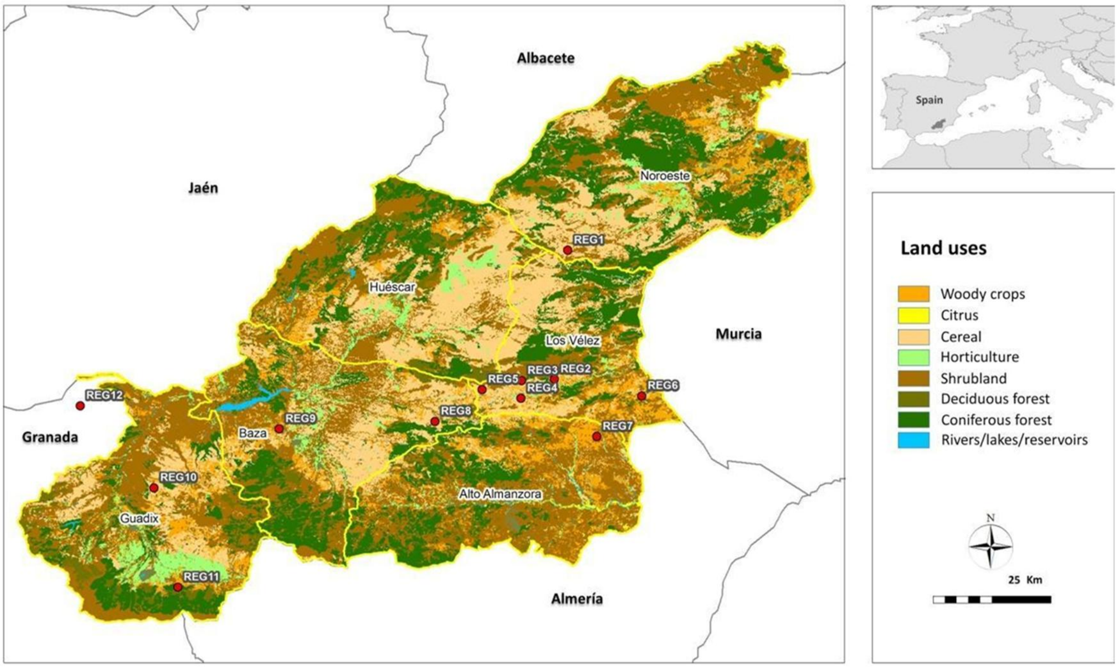

Figure 1 Map of the territory where the AlVelAl association operates. Yellow lines define county borders within the autonomous regions of Andalusia and Murcia, red dots represent the 12 farms involved in the participatory research project.

The semiarid southeast of Spain is one of the European regions most affected by land degradation and desertification processes (Martínez-Valderrama et al., 2016) and represents one of the world´s largest areas for the production of rainfed organic almonds. Since the 1950´s this region has experienced major farm management changes promoted by the green revolution model, leading to the abandonment of soil and water conservation structures (Bellin et al., 2009), a large shift from cereal to woody perennial farming (Cruz Pardo et al, 2010), the near-total disappearance of sheep farming (Aguilar et al., 2015), and the intensification of tilling practices (Clar et al., 2018), resulting in a considerable increase of erosion rates and land degradation (García-Ruiz, 2010). Following the growing awareness of the problems provoked by land degradation, increasing political attention was paid to soil and water conservation measures. However, they have been often fostered through top-down regulations with little acceptance and success amongst farmers (de Graaff et al., 2013; van Leeuwen et al., 2019).

While changes in land use and farming management to more intensive systems lie behind the human causes exacerbating land degradation; torrential rainfall events, highly erodible soils and steep slopes are behind the natural causes. Soils in the steppe high plateau are very diverse, representing more than 11 soil types (FAO WRB), but with shallow Calcisols covering approximately 90% of the territory (Cruz Pardo et al., 2010). The climate is semiarid Mediterranean, with on average 350 mm of annual precipitation concentrated in few rainfall events, wide daily and seasonal thermal amplitudes, and frost periods that usually extend about 6 months, resulting in a mean annual temperature of 13 ºC (Cruz Pardo et al., 2010). These extreme climatic conditions constrain vegetative growth to very narrow periods of time.

Confronted with this panorama, in 2015 local farmers created the agroecology association AlVelAl with the support of regional governments, local businesses, and research institutions, aiming to foster the implementation of regenerative agriculture (RA) to restore vast extensions of degraded land. RA is a farming approach increasingly recognized as a plausible solution to reverse land degradation worldwide (Kassam et al., 2012; Lee et al., 2019; Palm et al., 2014; Pretty N., 1997; Rhodes, 2017). RA focuses on the restoration of soil quality to enhance the delivery of multiple ecosystem services (Rhodes, 2017), promoting various landscape and farm management practices that can be classified under four main principles: 1) minimum soil disturbance, 2) enhance soil fertility, 3) reduce spatio-temporal events of bare soil, and 4) diversify cropping systems with integration of livestock (Elevitch et al., 2018; LaCanne and Lundgren, 2018; Rhodes, 2017). Most common RA practices include reduced and zero tillage, keyline design planting following contour lines, and the addition of organic amendments such as compost, manure, or cover crops, and must be adapted to local contexts to ensure their success (Lahmar et al., 2012; Tittonell et al., 2012).

While promising (de Leijster et al., 2019), RA has not yet been widely adopted by farmers of the steppe high plateau of southeastern Spain, nor in semiarid regions in general. This might be due to the lack of experimental data proving its effectiveness (Lee et al., 2019), the generally slow response of soils to management changes, and insufficient involvement of farmers in monitoring the impacts of RA (Chinseu et al., 2018). Bringing these issues to center stage, we designed the participatory framework to monitor soil quality described here in collaboration with the AlVelAl association and initiated a participatory monitoring project for the assessment of RA impacts between farmers and researchers

2.2. Design and implementation of a framework for participatory monitoring and evaluation of soil quality to support RA adoption

Various frameworks have been developed to facilitate participatory identification and selection of indicators from whose implementation a number of lessons can be taken to enhance the success potential of sustainability projects. Whether they focus on the selection of local indicators (Reed and Dougill, 2002), or include a parallel selection of technical indicators (Barrios et al., 2006; Fraser et al., 2006; Reed et al., 2006), an active participation of land users has been claimed indispensable to develop monitoring systems that can facilitate knowledge exchange and collective learning (Reed, 2008; Stringer et al., 2013).

Previous studies highlighted involvement of land users in the definition of research objectives as a crucial first step to enhance an active involvement of the community in the entire research process (Reed, 2008; Schwilch et al., 2012). Meaningful participation of stakeholders is also considered crucial in the identification, selection and prioritization of indicators. This includes decision making on when and how to assess them, in order to ensure indicator representativeness, relevance and suitability in the study context, and to foster the adoption of indicator-based assessment tools (Bünemann et al., 2018, De Olde et al., 2016).

Nevertheless, involving land users in indicator identification often resulted in remarkably long lists, reflecting their extensive knowledge but complicating a practical use (Fraser et al., 2006). Deriving minimum data sets of key performance indicators is necessary due to resource limitations, to minimize collinearity between indicators and management options (Bünemann et al., 2018) and to make participatory assessments not overly complex. Measurement costs often act as a limiting factor for technical indicators, especially if novel and expensive biological analyses are involved. Regarding local indicators, iterative participatory selection processes, including test application of selected indicators with end users, can help achieving feasible and representative selections (Triste et al., 2014).

There are multiple ways of involving land users in participatory research, from participants´ consultation, to more collaborative and interactive decision making (Lilja and Ashby, 1999; Pretty, 1995). Understanding participatory research as “doing science with people” and participation as an ethical imperative (Cuéllar-Padilla and Calle-Collado, 2011) each situation and phase of the research process may require a different type of stakeholder engagement, depending on a theoretical understanding of the context, process design, management of power dynamics and scalar fit of the process (Reed et al., 2018). Likewise, to achieve desired research goals, different methodologies and techniques from more conventional to more participatory can be used, contributing each approach with unique potentialities to minimize the shortcomings and raise the potentials of each other (Neef, 2008; Neef and Neubert, 2011; Reed et al., 2011; Stringer et al., 2013).

A widely applied framework to integrate local and technical indicators of soil quality was proposed by Barrios et al., (2006). This framework employs workshops integrating a diversity of participatory techniques involving farmers and researchers to help identify, select, and establish links between local and technical indicators and management practices, aiming to improve stakeholder communication and understanding. Inspired by the framework proposed by Barrios et al., (2006) and building on the above mentioned lessons and existing participatory frameworks (Reed and Dougill, 2002; Fraser et al., 2006; Reed et al., 2006), we designed a new participatory framework for the development of a monitoring system of soil quality based on combinations of technical and local key performance indicators adapted to the particularities of the study context (Figure 2). The framework we propose includes various iterative phases for the operationalization of indicators and sharing of results. The framework was designed to facilitate understanding and mutual learning between different stakeholders, making use of participatory techniques to enhance scientific rigor and local relevance (Allen, 2001; Jemberu et al., 2018; Stringer et al., 2013).

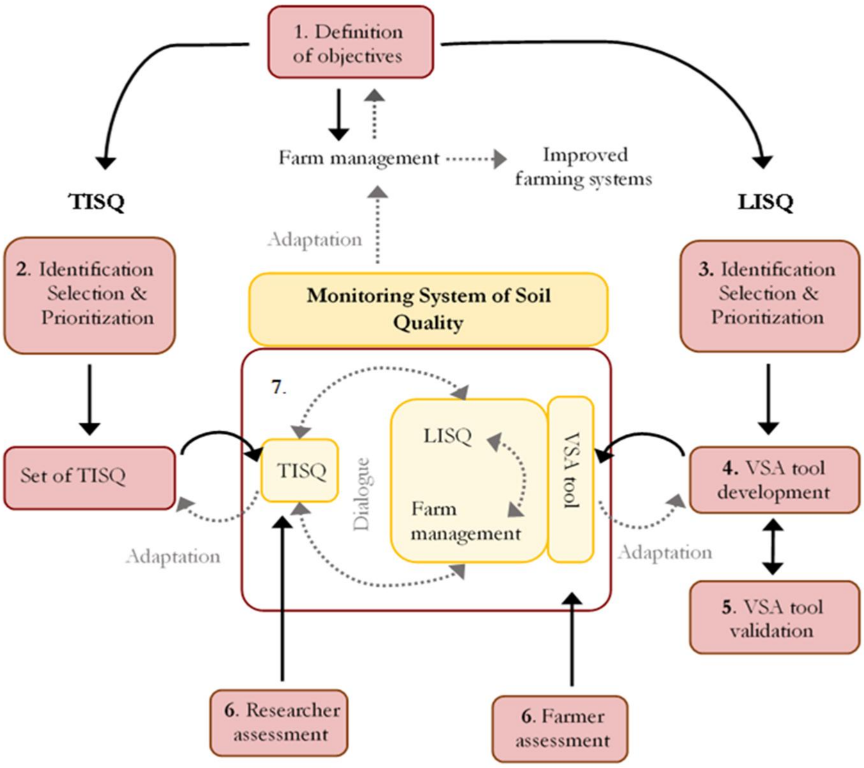

Figure 2 Proposed participatory methodological framework to generate and implement a soil quality monitoring and assessment system between researchers and farmers, where: TISQ: technical indicators of soil quality and, LISQ: local indicators of soil quality. Garnet-red cells identify methodological phases and yellow cells obtained results, black arrows indicate the direction of methodological phases and dashed arrows show adaptation and redesign feedback processes that lead to a new monitoring cycle for the improvement of farming systems.

The proposed participatory framework acts on the premise of active collaboration between farmers and researchers since initial research stages, consisting of seven phases:

Phase 1) Definition of research and monitoring objectives

Phase 2) Identification, selection and prioritization of Technical Indicators of Soil Quality (TISQ)

Phase 3) Identification, selection and prioritization of Local Indicators of Soil Quality (LISQ)

Phase 4) Development of a VSA tool integrating LISQ

Phase 5) Testing and validation of the VSA tool

Phase 6) Monitoring the impacts of RA practices by researchers and farmers based on TISQ and VSA tool results

Phase 7) Exchange of monitoring results between all involved participants, and joint assessment of RA impacts

This paper illustrates the process to develop a monitoring system of soil quality (phases 1 to 5) and evaluates its effectiveness to facilitate a more comprehensive assessment of the impacts of RA on ecosystem services and human well-being than when based on local or technical indicators alone. Phases 6 and 7 consist on a continuous learning and adaptation process that involves intensive data gathering through the operationalization of TISQ and LISQ and the joint discussion of results by farmers and researchers. Hence we decided to report these results in separate publications (Luján et al. 2020; in review).

2.3. Framework operationalization

Phase 1: Definition of research and monitoring objectives

We defined together with board members of the AlVeLAL association, main research and monitoring objectives prior to developing and applying the proposed participatory framework. These main objectives were:

i) Involve farmers in monitoring activities and cover the whole territory of action of AlVelAl association.

ii) Accompany farmers in providing scientific evidence supporting the diversity of RA practices already implemented in the territory.

iii) Develop and apply participatory monitoring tools useful to current and forthcoming farmers for the adoption of RA.

Once agreed on the overarching research and monitoring objectives, the AlVelAl association provided general information about farm location, farm characteristics and RA practices implemented by farmers, which we verified through formal and informal conversations with AlVelAl board members and researchers that previously collaborated with the AlVelAL association. We classified farms according to main RA principles and practices (Table 1) and selected at least one farm from each county to cover most of the spatial variability in environmental and socioeconomic conditions within the AlVelAl territory. We then contacted the farmers to introduce the research project, ask for their willingness to participate and gather further information about farm management. During a subsequent farm visit we jointly selected one regenerative and one nearby conventionally managed parcel to monitor and compare the impacts of RA on soil quality. In total 12 farmers were interested in taking part in the research (Figure 1) and actively participate in monitoring activities on their lands.

Table 1 Classification of farms according to main regenerative principles and practices implemented in the parcel selected for

Farm	Location	Crop	Regenerative principles and practices						
			Minimum soil disturbance			Organic amendments		Reduction of spatial t of bare s	
			Zero tillage	Reduced tillage	Erosion barriers / keyline	Fertilizers (manure/ compost)	Green manure	Green covers (annual)	Green covers (winte
REG 1	Murcia	Pistachios		x		x			x
REG 2	Almeria	Almonds		x	x	x	x		x
REG 3	Almeria	Almonds		x	x	x			x
REG 4	Almeria	Almonds		x	x		x		x
REG5a	Almeria	Almonds	x		x	x		x	
REG5b	Almeria	Almonds			x	x			x
REG 6	Almeria	Almonds		x		x			x
REG 7	Almeria	Almonds		x	x	x			x
REG 8	Granada	Almonds				x			x
REG 9	Granada	Almonds		x	x	x			x
REG10a	Granada	Almonds	x			x		x	
REG10b	Granada	Olives	x			x		x	
REG 11	Granada	Almonds		x	x	x	x		x
REG 12	Granada	Pistachios	x		x		x	x	

Lowercase letters “a” and “b” differentiate two parcels selected for RA monitoring within the same farm

Phase 2: Selection of TISQ

Technical indicators of soil quality were identified based on an extensive literature review of studies assessing the impacts of regenerative management practices on soil quality with special focus on land degradation in semiarid regions. From this review we glean a reduced list of most relevant technical indicators, and their expected response during soil regeneration, based on the following considerations: 1) indicators are sensitive to assess soil quality changes from the different RA practices (table 1) implemented in our study area, 2) include physical, chemical and biological soil properties, and indicators related to crop productivity, 3) are suitable for covering potential changes in soil ecosystem services, 4) there is available data from previous research group long term experiments for allowing comparisons and enhance the understanding of RA impacts on almond agroecosystems,) are useful for farmers and the AlVelAl association to support on-farm management decisions. We further prioritized the indicators to obtain the most cost-effective selection given realistic financial and time resources within conventional research projects.

Phase 3: Selection of LISQ

Local indicators of soil quality were identified by interested farmers from phase 1, in a first participatory workshop held on June 23, 2018. This workshop aimed to achieve 3 main goals: 1) Introduce farmers involved in the participatory research, their practices and experiences with RA, 2) Enhance mutual learning and knowledge exchange, 3) Collectively identify, select and prioritize LIQS to evaluate the impact of regenerative practices. To meet these goals, 5 exercises were performed, each with their own specific objectives, and methods (Table 2). Exercises were interdependent and connected in such a way that the results of each exercise served as input for further elaboration in the consecutive one. The identification of indicators included farmers´ definition of low and high quality categories for each LISQ, the methodology, frequency and timing for their assessment, and the information farmers obtained from them. The workshop took place during 6 morning hours, moderated by two of the scientists leading the research project with experience in facilitating participatory processes.

Table 2 Structure breakdown of Workshop 1

Exercise	**Objectives**	**Techniques**
Presentation of participants and RA experiences	Introduce the participants involved in the participatory research and their experiences with RA, and create a pleasant and relaxed working atmosphere	Work in pairs using cards with guiding prompts and plenary presentation of peers
Linking management practices, soil degradation and regeneration	Encourage group reflection to link conventional and regenerative management practices to different soil properties that can be identified as indicators of soil	Artistic pedagogical installation, individual reflection and plenary

processes, and soil properties	quality. Make a non-oral return of relevant and highlighted aspects that emerged during farm visits prior to workshop 1	discussion
Identification of Local indicators of Soil Quality	Identify local indicators used to distinguish between “high” regenerated and “low” degraded soil qualities	Focus group work with guiding questions, and plenary sharing of outcomes
Identification of information, methodology and time for the assessment of LISQ	Identify key information farmers relate to indicators, find a methodology for a simple and rapid VSA, as well as the most appropriate time to carry it out	Group work and plenary discussion
Ranking of Indicators	Prioritize indicators based on their relevance to attain research objectives and to assess soil quality changes	Individual scoring of indicators with a limited amount of points
Workshop closure and establishment of agreements	Recapitulate about obtained results; establish agreements on research commitments by farmers and researchers; briefly introduce following research steps to keep participants´ engaged	Plenary session and discussion

Phase 4: VSA tool development

We used the outcomes from workshop 1 as input to create a VSA tool based on the selected LISQ and following examples of previously developed VSA tools (Shepherd et al., 2008; Shepherd, 2010). This VSA tool, that we named the ‘*Farmer Manual’* (supplementary material), aims to assist farmers in monitoring and assessing RA at their farms based on the continuous gathering of management data and resulting status of LISQ to help them identify causes and effects.

The *Farmer Manual* was divided in two sections. An introductory Section 1 explains the concept of soil quality, requests a detailed description of farming managements under evaluation, and illustrates how to carry out a representative VSA. Section 2 corresponds to the VSA and includes the set of LISQ identified in workshop 1. Each indicator is briefly introduced in one page providing the information, methodology and timing for its assessment as defined by farmers. The manual includes individual evaluation sheets (Figure 3) consisting in three quality categories - low, medium and high – illustrated by an image, and associated to three different scores - 1, 2, and 3 - respectively. The low and high quality categories were established based on obtained results from workshop 1, whereas the medium quality was established considering a medium gradient in between categories. At the end of section 2 the VSA is summarized in an overall soil quality rating, resulting from the sum of individual indicators scores. The *Farmer Manual* was reviewed by colleague researchers and changes were implemented prior to be presented to farmers.

Phase 5: VSA tool application and validation

A second workshop took place on November 17, 2018 at the farm of a participating farmer, pursuing a twofold objective: 1) Familiarize participants with the *Farmer Manual* by testing it in field conditions, and 2) Revise the *Farmer Manual* and incorporate further improvements. To meet these goals, we designed and performed various exercises (Table 3) in which participant farmers and 2 researchers engaged in during 6 morning hours.

During the workshop farmers applied the *Farmer Manual* to assess the soil quality of two differently managed parcels. After this hands-on experience, farmers revisited the set of LISQ resulting in various modifications and adjustments.

Table 3 Structure breakdown of workshop 2

Exercise	**Objectives**	**Methods**
Participatory research update: Refreshing main aims and process stage	Keep all participants informed on the research project. Introduce the aims of workshop 2	Plenary talk
Presentation of the "Farmer Manual" draft	Present the "Farmer Manual", explain its structure, and explain how to use it; Explain the aim of using the "Farmer Manual" and how to interpret the results obtained from the VSA	Plenary: Description of the farmer Manual structure, and directions on how to use it
Landscape and farm management example	Link natural factors and processes of landscape formation to farm management; show potentialities of soil restoration by learning from and working with nature in given conditions. Value local knowledge and enhance participant's creative thinking	Farm visit guided by the hosting farmer
In field VSA: Applying the *Farmer Manual*	Familiarize participants with the *Farmer Manual*; Validate the feasibility and accuracy of the "Farmer Manual" to evaluate and discern between different soil qualities by applying the VSA in differently managed farm areas	Field visits; farmer presentation of farm management; Work in groups to apply the "Farmer Manual"
Validating the *Farmer Manual*	Validate quality ranks, methodology and timing of measurement of all indicators; receive participants'´ suggestions to improve indicators. Arrive to a group consensus on indicator modifications	Work in groups: Plenary session for consensus agreement
Improving the "Farmer Manual"	Adding suggestions on content, structure and design, to improve the "Farmer Manual". Arrive to a final agreement of a First Version of the "Farmer Manual"	Plenary: brainstorm and negotiation about further improvements
Presentation of results from TISQ	Present TISQ to farmers as the complementary half of LISQ that complete the monitoring system of soil quality; Present and interpret preliminary results of TISQ in relation to conventional and regenerative farm parcels	Plenary: researcher presentation and group discussion
Workshop closure and establishment of agreements	Introduce following participatory monitoring and research steps and next workshop to keep participant engagement	Plenary: Stating stakeholder agreements

At the end of the workshop, TISQ were presented to farmers using common language and making use of cards with graphical representations of each indicator to inform what was assessed and facilitate current and forthcoming understanding and exchange of results. Preliminary results from TISQ of the conventional and regenerative parcels under research were then presented and interpreted together with farmers to give a first insight of management impacts and facilitate knowledge exchange.

3. Results

3.1. Technical indicators of soil quality (TISQ)

After extensive literature review and an iterative selection process by researchers, a set of twenty technical indicators of soil quality was selected considering their scientific relevance for the study context, their feasibility, and financial and time limitations (Table 4). Of the twenty TISQ selected, seventeen related to the soil component; including three physical, eleven chemical, and three biochemical properties (indicators T.1 to T.17). Three indicators were selected to assess crop nutritional status (indicators T.18, T.19 and T.20).

Table 4 Set of selected TISQ, expected response during regeneration of soil quality in the study region, information provided and examples of previous research in which they have been used.

Indicator	Expected response	Information	Study
T.1. Texture	=	Water holding and drainage capacity	*
T.2. Bulk density	-	Soil compaction, water holding and drainage capacity	(Fernández-Ugalde et al., 2009; González-Sánchez et al., 2012; Macci et al., 2012)
T.3. Aggregate stability	+	Resistance to degradation, infiltration capacity	(Álvaro-Fuentes et al., 2008a; Fernández-Ugalde et al., 2009; Garcia-Franco et al., 2015; López-Garrido et al., 2012)
T.4. pH	=/-	Degree of acidity, alkalinity. Plant nutrient availability	(Melero et al., 2009a, 2009b)
T.5. Electric conductivity	=/-	Degree of salinity. Crop productivity	(Melero et al., 2009a, 2009b)
T.6. Total Soil organic carbon	+	Soil fertility and health. Soil structure, water and oxygen holding capacity, aggregate stability, nutrient storage and turnover.	(Almagro et al., 2017; Gong et al., 2013; López-Garrido et al., 2012; Ramos et al., 2011)
T.7. Labile carbon	+	Organic matter quality, nutrient availability and carbon storage	(Álvaro-Fuentes et al., 2008b; Liu et al., 2013; Peregrina et al., 2010; Plaza-Bonilla et al., 2014)
T.8. Recalcitrant carbon	=		
T.9. Total N	+	Soil fertility, plant nutrient availability	(González-Sánchez et al., 2012; Moreno et al., 2006; Ramos et al., 2011, 2010)
T.10. Total P	+		
T.11. Available P	+		
T.12. Available K	+		
T.13. Calcium carbonates	=/-	Plant nutrient availability. Limiting crop iron absorption	(Fernández-Ugalde et al., 2009; Moreno et al., 2006; Murillo et al., 2004)

T.14. Exchangeable cations	+	Soil storage capacity for available plant nutrients, soil fertility	(Mrabet et al., 2012)
T.15. Microbial biomass	+	Element and organic matter cycling, decomposition	(García-Orenes et al., 2010; López-Garrido et al., 2012; Madejón et al., 2009, 2007)
T.16. Microbial respiration	+	Microbial activity, decomposition rates?	(García-Orenes et al., 2010)
T.17. Enzymatic activity	+	Element and organic matter cycling, decomposition, biological population regulation	(García-Orenes et al., 2010; López-Garrido et al., 2012; Macci et al., 2012; Madejón et al., 2009, 2007; Ramos et al., 2011)
T.18. Leaf N	+	Crop nutritional status, growth, flower formation, fruit production, ripening and quality. Crop resistance to pests, droughts and frosts.	(De Leijster et al., 2019; Martínez-Mena et al., 2013)
T.19. Leaf P	+		
T.20. Leaf K	+		

* Static property for soil class classification

Signs indicate the tendency of the indicator response as: increasing (+), decreasing (-) and unchanged (=).

3.2. Local Indicators of Soil Quality (LISQ) and VSA tool

Based on the process of identification, selection, assessment and validation during the two workshops, farmers selected a final set of sixteen LISQ (Table 5); nine indicators related to the soil component (indicators L.1 to L.9), and seven indicators related to agroecosystem and crop components (indicators L.10 to L.16).

During the last validation phase in workshop 2, farmers made a number of adjustments on the candidate indicators, methodology and frequency of measurement. Farmers changed crop production measured through crop yield for the indicators "almond laden & shoot length", and "whole nut & kernel weight" (Table 5). These two indicators were considered easier, more accurate and less time and labor consuming than separately harvesting almond yields in differently managed parcels. Farmers argued that crop yield highly depends on climatic conditions, but *"when soils are fertile and with sufficient humidity, they have the capacity to provide enough nutrients for the almond tree to produce plenty of almonds and long shoots"*. Farmers also included measuring crop production by the quality of the almonds defined by the weight difference between shelled nuts and kernel portions, which depends on the percentage of empty almonds and the size of almond nuts.

During the VSA tool testing, farmers could not find some plant species they initially proposed to assess soil quality such as cotton thistle (*Onopordum acanthium*) and alfalfa (*Medicago sativa*). However, farmers assessed the indicator based on the plant families to which some of the present plants belonged. As a result, farmers proposed to assess indicator plants (L.13) by including main plant families to help interpretation.

While the indicators "pests and diseases" and "wind erosion" were included during the first participatory workshop, farmers decided to drop them from the final set, arguing that "*pests and diseases could be present in both regenerative and conventional farms. Simply, healthy trees in more sustainable farms would be hardly damaged or would get rid of them easier*", and "*although wind erosion can be easily assessed by soil dust accumulation on field edges and the removal of soil from the base of surface stones, it is uncommon and less relevant phenomenon in the territory".*

Regarding indicator scoring, farmers emphasized the need to assign intermediate scores in between quality categories to embrace the complexity and variation seen in the field. Thus, we included and stressed this scoring possibility in Section 1 of the *Farmer Manual* (supplementary material).

Table 5 Set of selected LISQ integrated in the Farmer Manual

Indicator	Scores	Characteristics related to quality ranks	Information
L.1. Structure	1	Hard, pressed and packed soils. Blocky or no visible aggregate	Infiltration capacity
	2	Soils somewhat loose. Medium-sized aggregates	
	3	Loose and spongy. Rounded aggregates of small size	
L.2. Color	1	Pale colors	Organic matter content
	2	Nor pale, neither dark	
	3	Dark colors	
L.3. Smell	1	It does not smell or has a chemical smell	Organic matter content and living soils
	2	It has a faint forest smell	
	3	It has a fresh and deep forest smell	
L.4. Root content	1	Few or no roots and rootlets	Soil structure, degree of soil compaction
	2	Appreciable number of roots and rootlets	
	3	Many roots and rootlets	
L.5. Earthworms	1	Absence of earthworms	Living soils, soil health
	2	A few earthworms present	
	3	Many earthworms present	
L.6. Moisture	1	Dry several days after last rains	Soil protection, porosity, water retention capacity
	2	Slightly moist several days after last rains	
	3	Moist several days after last rains	
L.7. Temperature	1	Up to 5 °C above or below a reference (covered) soil	Buffer capacity to temperature extremes. Soils protected with green covers, stones and mulch. Soil life
	2	Up to 10 °C above or below a reference (covered) soil	
	3	More than 10 °C above or below a reference (covered) soil	
L.8. Protection against erosion	1	Presence of large rills and gullies. Difficult to eliminate after tillage	Degree of soil protection
	2	Presence of few and small rills. Easily filled after tillage	
	3	Absence rills, gullies and visible erosion signs	
L.9. Infiltration capacity	1	Presence of puddles and surface runoff several days after last rain	Texture and structure , tillage practices, design
	2	Puddles disappear some days after the last rain	

	3	Spongy soils and absence of surface puddles after the rain	on contour curves
L.10. Auxiliary fauna: Ladybugs	1	Absence of ladybugs and auxiliary fauna	Environmental health
	2	Few ladybugs and/or other auxiliary fauna	
	3	Abundance of ladybugs and auxiliary fauna	
L.11. Green cover	1	Bare soils or sparse green covers	Fertility, structure, soil seed bank, protection against water runoff and evaporation
	2	Medium percentage of soil covered with low plant diversity	
	3	High percentage of soil densely covered with high plant diversity	
L.12. Green cover color	1	Pale colors and yellowish greens	Soil nutritional status, fertility
	2	Pale greens	
	3	Deep greens	
L.13. Indicator plants	1	Low quality indicators. Absence of leguminous and plant diversity	Soil nutritional status, humidity, structure
	2	Some good quality indicators. Low plant diversity	
	3	High abundance of good quality indicators and leguminous plants. High plant diversity	
L.14. Almond load & shoot length	1	Low laden trees, with no or few shoot growths	Soil fertility and nutrient availability
	2	Half laden trees and lengths of shoot growths below maximum	
	3	Fully laden trees, and with large shoot growths	
L.15. Whole nut & kernel weight	1	Large portion of empty & close nuts. Small caliber kernels	Soil fertility and nutrient availability
	2	Small portion of empty & close nuts. Medium caliber kernels	
	3	Low portion of empty & close nuts. Big caliber kernels	
L.16. Crop vigor: leaf color	1	Pale and yellowish greens	Crop health, soil fertility, crop nutrient deficiencies
	2	Light green colors and with some discoloration signs	
	3	Deep homogeneous greens	

4. Discussion

4.1. Monitoring system of soil quality and influence on ecosystem services delivery

The monitoring system for participatory assessment of soil quality by farmers and researchers presented here is based on the integration of local and scientific knowledge. In this section we examine how local (LISQ) and technical (TISQ) indicators provide complementary information to assess the impacts of RA practices on supporting, regulating, provisioning and cultural ecosystem services relevant for environmental and human well-being (Figure 4).

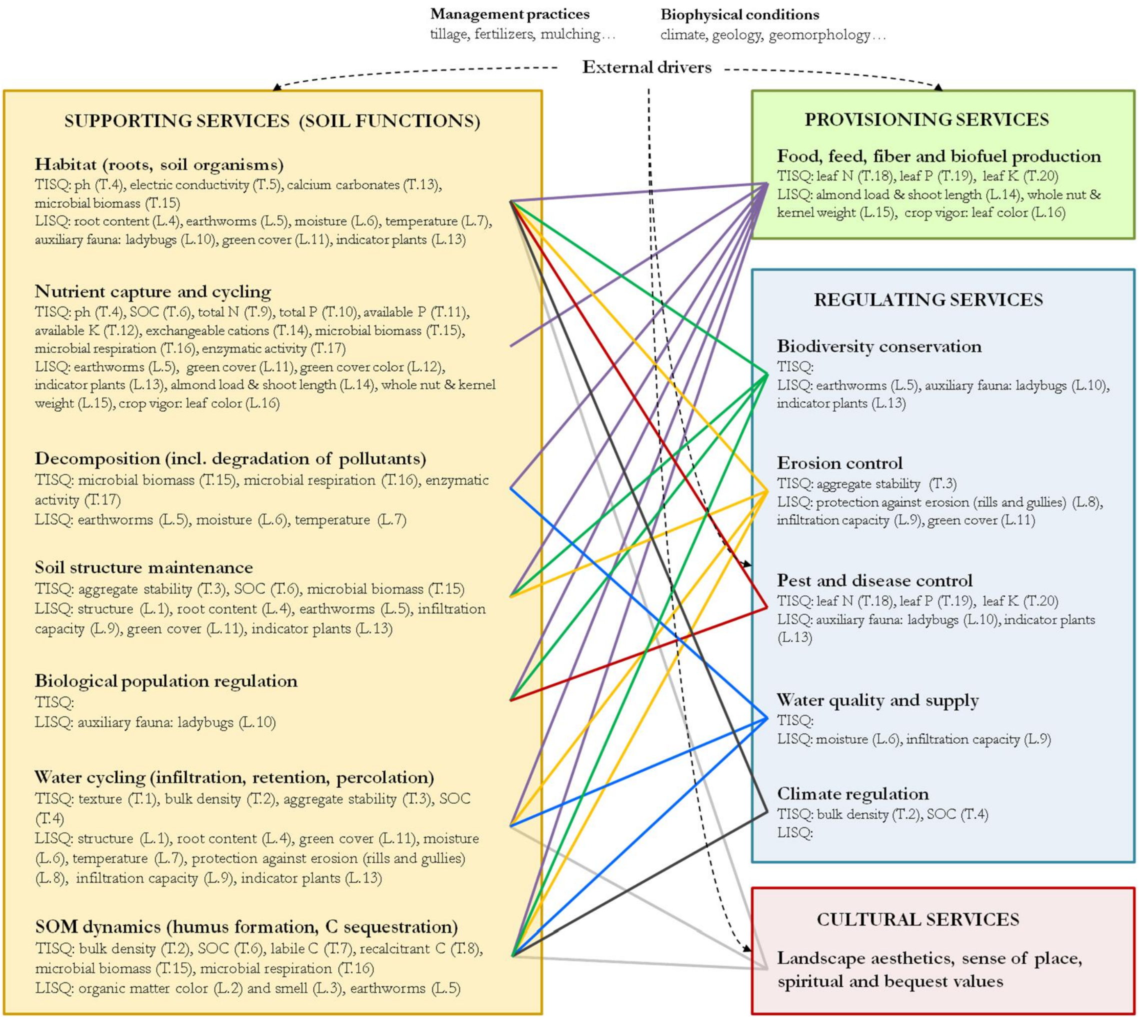

Figure 4 Monitoring system of soil quality consisting of technical (TISQ) and local (LISQ) indicators of soil quality and their relation with supporting, regulating, provisioning and cultural ecosystem services.

• Supporting services

Supporting ecosystem services encompass the processes that support soil formation and include nutrient and water cycling, soil organic matter decomposition and dynamics, biological population regulation, and soil structure and habitat maintenance, thus they are also considered soil functions (see iSQAPER Project). All soil properties are involved in supporting services to some extent and have a great influence on the delivery of other ecosystem services (Adhikari and Hartemink, 2016; Dominati et al., 2010). In agricultural lands, the maintenance of soil fertility can be considered the main supporting service. Soil fertility includes numerous variables; one of the most important is organic matter, which comprises a set of pools involved in several functions within physical, chemical and biological soil processes.

Farmers identified color (L.2) and smell (L.3) as indicators of soil organic matter and soil life. Darker colored soils with deep and fresh forest smell were related to higher quality soils, whereas pale and odorless soils were assigned to degraded soils. From a technical approach, soil organic carbon (T.6) is commonly used as an indicator of organic matter content, since about three fifths of organic matter consists of carbon. The proportions of labile (T.7) and recalcitrant (T.8) carbon pools that compose soil organic carbon also provide important information about soil quality and supporting services (Liu et al., 2013; Plaza-Bonilla et al., 2014). High quality soils are expected to have a larger proportion of labile carbon, that is biologically more active, facilitating nutrient cycling and formation of soil structure. The labile carbon fraction also influences soil life, conditioning the total microbial biomass (T.15) and its activity (T.16), as well as the activity of the enzymatic reactions (T.17) taking part in the mineralization of elements. Consonantly, farmers related soil life and soil health throughout the presence of earthworms (L.5). Earthworms play a major role in organic matter and nutrient cycling, stimulating soil microbial activity, aggregate stability (T.3), soil porosity, water holding capacity and the consequent crop growth (Blouin et al., 2013). In addition, farmers identified soil moisture (L.6) and soil surface temperature (L.7), considering soils of higher quality as those capable to buffer extreme temperatures and maintain soil moisture for longer periods of time, both parameters crucial to sustain soil life and biological activity. Unprotected soil surfaces are more susceptible to sunstroke, water losses, and increased aridity as such conditioning soil life (Maestre et al., 2015).

Farmers identified the percentage of soil covered with vegetation (L.11), their color (L.12), and the type and diversity of plants present (L.13), as indicators providing information on soil fertility, nutrient availability, humidity, and soil structure. Farmers associated delivery of supporting services and high quality soils with those well covered by dark green colored vegetation, high plant diversity and presence of indicators species, such as borage (*Borago officinalis*) , alfalfa (*Medicago sativa*) and vetch (*Vicia sativa*), most of them from the leguminous family. In contrast, they associated lower quality soils with scarce vegetation cover, pale and yellowish colors, and presence of thistles such as field eryngo (*Eryngium campestre*) and tumbleweed (*Salsola kali*). From a technical approach, the indicators pH (T.4), salinity (T.5), total and available nutrients (T.9, T.10, T.11, T.12), and bulk density (T.2) can be conditioning factors influencing the performance of vegetation covers, helping the interpretation of farmers' observations.

Soil structure was considered a relevant indicator for both farmers and researchers in agricultural lands since it links above and belowground soil systems, intervenes in soil nutrient and water cycling and influences multiple soil processes (Ball et al, 2017). Farmers assessed structure (L.1) by direct visual estimation of the size and roundness of aggregates, and by the soil's hardness or sponginess. Additionally, farmers selected the content of roots and rootlets (L.4) and assigned a higher quality category to those soils with abundant roots and rootlets in surface and depth as a sign of good structure. From a technical approach, bulk density (T.2) and aggregate stability (T.3) provide a notion of the soil porosity and can add insights to interpret soil structure.

- **Regulating services**

Regulating ecosystem services include a wide diversity of services that contribute to create stable and healthy environments, resilient to external drivers like climate variability, climate change and extreme weather events (Dominati et al., 2010). Soils have the capacity to control pests and diseases, reduce soil loss by erosion processes, mitigate flood frequency and intensity, and regulate the climate, acting as sinks of GHGs (Adhikari and Hartemink, 2016).

Farmers identified a number of indicators relating soil quality to regulating services and the degree of soil protection against water erosion and water losses through surface runoff and evaporation. The formation of rills, and gullies (L.8) and surface puddles (L.9) were attributed to lower soil qualities, whereas soils with higher quality were classified as spongy and with high infiltration capacity, contributing to the prevention of soil erosion and water loss. Farmers linked soil infiltration capacity (L.9) to soil texture and structure, and identified tillage practices and plantation design as drivers of quality changes affecting regulating services. Similarly, the technical indicators texture (T.1), bulk density (T.2) and aggregate stability (T.3) provide quantitative information on the infiltration capacity of soils and their resistance to runoff generation and soil erosion, information that can support farmers´ observations on RA benefits to increase water retention and soil conservation. While frequent measurement of soil moisture content, runoff, and soil erosion requires set-up of intensive field monitoring programs, total soil organic carbon (T.6) and soil texture (T.1) can provide relevant information of soil water retention capacity and sensitivity to soil loss by erosion.

Farmers identified the percentage of soil covered with vegetation (L.11) not only relevant in relation to soil quality and supporting services, but also as an indicator of soil protection against soil erosion and water losses, attributing a better performance to soils with a dense vegetation cover. Unprotected soils are also more exposed to solar radiation leading to higher temperatures, evaporation and consequent loss of soil moisture affecting water regulation. Soil temperature (L.7) and soil moisture (L.6) served as local indicators identified by farmers and directly linked to soil protection and water regulation.

Furthermore, farmers identified the presence of ladybugs and other auxiliary fauna (L.10) as a sign of environmental health and soil quality. Certainly, soil conditions determine the quality of the agroecosystem habitat, and thereby the type of organisms present (Mader, 2015). In contrast to the direct assessment by farmers focusing on biodiversity observations as indicators of soil health, technical indicators included leaf nutrient contents (T.18, T.19 and T.20). As nutrients influence the formation of resistant vegetative tissues and the quality of flowers and fruits, they provide information about crop resistance to pests and diseases and attraction of natural enemies, helping an early diagnosis on crop pest susceptibility.

- **Provisioning services**

Supporting and regulating services directly relate to the delivery of soil provisioning services. The provisioning of food, fiber, raw materials and physical support integrate this group of services. Arguably, crop production comprises the main provisioning service in agricultural lands and is often considered as one of the principal concerns of farmers.

Farmers selected the joint assessment of almond load and shoot length (L.14), and the relative crop performance in terms of weight and caliber of the almond nuts (L.15) to measure crop production. They related higher crop performance to higher soil quality in terms of fertility, nutrient and water availability. Most soil properties somehow affect crop production as they intervene in the release and availability of nutrients and water. Several technical indicators can serve to support farmers' observations on crop performance. For instance, soil structure, water holding capacity, and nutrient availability condition the provisioning of crop production. In turn, nutrient availability depends on soil texture (T.1), organic carbon (T.6), total exchangeable cations (T.14) and pH (T.4). Moreover, the salinity level of the soil solution is highly correlated to crop growth, and can be quantified by measuring the electric conductivity (T.5).

Farmers also identified leaf color (L.16) as a sign of crop vigor and crop health. Farmers related higher soil quality to trees with deep green leaves, while trees presenting lighter and yellowish green colored leaves were assigned to lower quality soils. Farmers related leaf color to soil fertility and nutrient deficiencies. From a technical point of view, leaf color is also a relevant indicator of the nutritional status of the crop, which can be determined by measuring principal leaf macronutrients (T.18, T.19, and T.20). The lack of any of these nutrients causes different patterns of discoloration. Furthermore, total and available soil nutrients are a good proxy of possible crop element deficits. In calcareous soils with a pH higher than 7.5, such as those commonly found in AlVelAl region, iron precipitates and becomes unavailable for plant uptake, resulting in yellowish and discolored leaves in almond trees as signal of ferric chlorosis. Calcium carbonate (T.13) is the best technical indicator of the chlorosing power of a soil.

- **Cultural services**

Although soil quality can directly or indirectly have a tremendous impact on the provision of cultural services through landscape aesthetics, peoples culture, spirituality, recreation and education opportunities, neither local nor technical indicators were identified to measure these group of services. While these non-material services are generally missing in literature and VSA tools to measure changes in soil quality (Dominati, 2013; Kuria et al., 2019; Omari et al., 2018), cultural services often receive attention as indicators to be strongly affected by landscape restoration (Teixeira et al., 2018). Since assessing the impacts of soil and landscape restoration on cultural ecosystem services requires of specific methodologies, we decided to include them in a separate study.

4.2. Framework suitability

The proposed participatory framework proved suitable to guide the identification of most relevant indicators for supporting, regulating and provisioning ecosystem services affecting farmers' livelihoods. Most local indicators selected by farmers related to the control of soil and water erosion, soil fertility and crop production which are crucial ecosystem services to ensure agroecosystem sustainability in almond farming in Mediterranean drylands (Almagro et al., 2017; Martínez-Mena et al., 2013), and whose optimization of delivery can be supported with the information provided by proposed technical indicators.

Our framework proved suitable to develop a soil quality monitoring system consisting of an integrative minimum set of measurable local and technical indicators. The suitability and feasibility of impact assessment is illustrated by the farmers´ proposed modifications during the VSA validation. The elimination of some indicators, such as wind erosion, or the adaptation of others to embrace the complexity and diversity of agroecosystems, such as including plant families for the assessment of indicator plants, evidence that involving farmers in the decision making of indicator identification, selection and validation is crucial to ensure monitoring suitability and feasibility. When this step is not considered, involving farmers in the identification of indicators has resulted in very long lists that cannot be tested because of lack of data, time, budget and socio-political constraints (Fraser et al., 2006).

The assessment of soil erosion and crop production provide a good example to illustrate the enlarged coverage and feasibility of impact assessment when counting with both types of indicators. The quantitative assessment of these indicators commonly entail a large deployment of economic, material and labor resources, often unavailable in scientific studies. While providing less insight into the exact responsible processes than provided by detailed scientific studies, monitoring local indicators such as the presence of rills and gullies (Milgroom et al, 2006), or crop vigor, allow for a cost effective evaluation of the delivery of these services with relatively little effort. Farmers´ selected indicators also provide practical solutions for variables that are often difficult to measure otherwise. For example, it is often difficult to relate soil fertility directly with crop yield due to the difficulty of measurement of annual crop production and its high dependence on annual climatic conditions (e.g. late frosts and hail storms). Farmers´ decision to estimate crop production by tree visual performance provides a pragmatic solution and shows their deep understanding of the interrelations between agroecosystem management, functioning, and the biophysical conditions of the study context. This reinforces the importance of their involvement to ensure the relevance and practicality of indicators.

In the light of the foregoing, the application of our framework shows that farmers and researchers, through their different approaches, selected local and technical indicators that, when combined, provided a more feasible, relevant and comprehensive assessment of soil quality than either of them alone. However, the adequacy of soil quality indicators to evaluate the impacts of the RA practices used by the participating farmers can only be verified once indicators are applied and discussed (Phases 6 and 7 of the framework). Although the design and application of our framework was developed to encourage farmer adoption of RA practices through participatory monitoring and to minimize dependency on technical support; new needs and demands may emerge along the research process, leading to include, expand, reduce or modify selected indicators. Thus, this soil quality monitoring system is intended to act as a continuous adaptive tool that requires regular interaction between participating farmers and researchers.

5. Conclusions

There is increasing awareness amongst researchers, policy makers and land users that we need participatory monitoring and evaluation systems that support the identification of effective solutions and foster their adoption to deal with the enormous challenges posed by land degradation. The participatory framework developed in this research can guide the identification and selection of technical and local indicators of soil quality to obtain relevant monitoring systems and user friendly VSA tools adapted to local contexts. Monitoring systems of soil quality including local and technical indicators offer the opportunity for scientists and farmers to jointly embark on a monitoring process enhancing knowledge exchange and mutual learning, to help implementing regenerative management practices that optimize the provisioning of soil ecosystem services. Our results show that the combination of local and technical indicators of soil quality can help to better understand the impacts of regenerative agriculture on soil quality restoration and related ecosystem services than when only local or technical indicators are used. Technical indicators often provide detailed insight into the reasons behind land degradation or restoration, while most local indicators related more directly to the benefits of RA for a range of ecosystem services and human well-being. The combination of this information is crucial to support farmers´ implementation and adoption of RA practices in the face of the lack of empirical data and contrasting scientific results on its effectiveness, and to help farmers see the multiple impacts of their efforts, even long before they find a possible positive effect on their crop yields.

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References

Almagro, M., Garcia-Franco, N., Martínez-Mena, M., 2017. The potential of reducing tillage frequency and incorporating plant residues as a strategy for climate change mitigation in semiarid Mediterranean agroecosystems. Agric. Ecosyst. Environ. 246, 210–220. https://doi.org/10.1016/j.agee.2017.05.016

Álvaro-Fuentes, J., Arrúe, J.L., Gracia, R., López, M. V., 2008a. Tillage and cropping intensification effects on soil aggregation: Temporal dynamics and controlling factors under semiarid conditions. Geoderma 145, 390–396. https://doi.org/10.1016/j.geoderma.2008.04.005

Álvaro-Fuentes, J., López, M. V., Cantero-Martinez, C., Arrúe, J.L., 2008b. Tillage effects on soil organic carbon fractions in Mediterranean dryland agroecosystems. Soil Sci. Soc. Am. J. 72, 541. https://doi.org/10.2136/sssaj2007.0164

Cuéllar-Padilla, M., Calle-Collado, Á., 2011. Can we find solutions with people? Participatory action research with small organic producers in Andalusia. J. Rural Stud. 27, 372–383. https://doi.org/10.1016/j.jrurstud.2011.08.004

De Leijster, V., Santos, M.J., Wassen, M.J., Ramos-Font, M.E., Robles, A.B., Díaz, M., Staal, M., Verweij, P.A., 2019. Agroecological management improves ecosystem services in almond orchards within one year. Ecosyst. Serv. 38, 100948. https://doi.org/10.1016/j.ecoser.2019.100948

Fernández-Ugalde, O., Virto, I., Bescansa, P., Imaz, M.J., Enrique, A., Karlen, D.L., 2009. No-tillage improvement of soil physical quality in calcareous, degradation-prone, semiarid soils. Soil Tillage Res. 106, 29–35. https://doi.org/10.1016/j.still.2009.09.012

Garcia-Franco, N., Albaladejo, J., Almagro, M., Martínez-Mena, M., 2015. Beneficial effects of reduced tillage and green manure on soil aggregation and stabilization of organic carbon in a Mediterranean agroecosystem. Soil Tillage Res. 153, 66–75. https://doi.org/10.1016/j.still.2015.05.010

García-Orenes, F., Guerrero, C., Roldán, A., Mataix-Solera, J., Cerdà, A., Campoy, M., Zornoza, R., Bárcenas, G., Caravaca, F., 2010. Soil microbial biomass and activity under different agricultural management systems in a semiarid Mediterranean agroecosystem. Soil Tillage Res. 109, 110–115. https://doi.org/10.1016/j.still.2010.05.005

Gong, X., Liu, Y., Li, Q., Wei, X., Guo, X., Niu, D., Zhang, W., Zhang, J., Zhang, L., 2013.

Sub-tropic degraded red soil restoration: Is soil organic carbon build-up limited by nutrients supply. For. Ecol. Manage. 300, 77–87. https://doi.org/10.1016/j.foreco.2012.12.002

González-Sánchez, E.J., Ordóñez-Fernández, R., Carbonell-Bojollo, R., Veroz-González, O., Gil-Ribes, J.A., 2012. Meta-analysis on atmospheric carbon capture in Spain through the use of conservation agriculture. Soil Tillage Res. 122, 52–60. https://doi.org/10.1016/j.still.2012.03.001

Liu, E., Yan, C., Mei, X., Zhang, Y., Fan, T., 2013. Long-Term Effect of Manure and Fertilizer on Soil Organic Carbon Pools in Dryland Farming in Northwest China. PLoS One 8. https://doi.org/10.1371/journal.pone.0056536

López-Garrido, R., Deurer, M., Madejón, E., Murillo, J.M., Moreno, F., 2012. Tillage influence on biophysical soil properties: The example of a long-term tillage experiment under Mediterranean rainfed conditions in South Spain. Soil Tillage Res. 118, 52–60. https://doi.org/10.1016/j.still.2011.10.013

Macci, C., Doni, S., Peruzzi, E., Masciandaro, G., Mennone, C., Ceccanti, B., 2012. Almond tree and organic fertilization for soil quality improvement in southern Italy. J. Environ. Manage. 95, S215–S222. https://doi.org/10.1016/j.jenvman.2010.10.050

Madejón, E., Moreno, F., Murillo, J.M., Pelegrín, F., 2007. Soil biochemical response to long-term conservation tillage under semi-arid Mediterranean conditions. Soil Tillage Res. 94, 346–352. https://doi.org/10.1016/j.still.2006.08.010

Madejón, E., Murillo, J.M., Moreno, F., López, M. V., Arrue, J.L., Alvaro-Fuentes, J., Cantero, C., 2009. Effect of long-term conservation tillage on soil biochemical properties in Mediterranean Spanish areas. Soil Tillage Res. 105, 55–62. https://doi.org/10.1016/j.still.2009.05.007

Mader, P., 2015. Soil Fertility and Biodiversity in Organic Farming Author(s): Paul Mäder, Andreas Fließbach, David Dubois, Lucie Gunst, Padruot Fried and Urs Niggli Source: 296, 1694–1697.

Martínez-Mena, M., Garcia-Franco, N., Almagro, M., Ruiz-Navarro, A., Albaladejo, J., de Aguilar, J.M., Gonzalez, D., Querejeta, J.I., 2013. Decreased foliar nitrogen and crop yield in organic rainfed almond trees during transition from reduced tillage to no-tillage in a dryland farming system. Eur. J. Agron. 49, 149–157. https://doi.org/10.1016/j.eja.2013.04.006

Melero, S., López-Garrido, R., Madejón, E., Murillo, J.M., Vanderlinden, K., Ordóñez, R., Moreno, F., 2009a. Long-term effects of conservation tillage on organic fractions in two soils in southwest of Spain. Agric. Ecosyst. Environ. 133, 68–74. https://doi.org/10.1016/j.agee.2009.05.004

Melero, S., López-Garrido, R., Murillo, J.M., Moreno, F., 2009b. Conservation tillage: Short- and long-term effects on soil carbon fractions and enzymatic activities under Mediterranean conditions. Soil Tillage Res. 104, 292–298. https://doi.org/10.1016/j.still.2009.04.001

Milgroom, J., 2006. Erosion en Olivar Ecológico: Manual de Campo.

Moreno, F., Murillo, J.M., Pelegrín, F., Girón, I.F., 2006. Long-term impact of conservation tillage on stratification ratio of soil organic carbon and loss of total and active CaCO3. Soil Tillage Res. 85, 86–93. https://doi.org/10.1016/j.still.2004.12.001

Mrabet, R., Moussadek, R., Fadlaoui, A., van Ranst, E., 2012. Conservation agriculture in dry areas of Morocco. F. Crop. Res. 132, 84–94. https://doi.org/10.1016/j.fcr.2011.11.017

Murillo, J.M., Moreno, F., Girón, I.F., Oblitas, M.I., 2004. Conservation tillage: long term effect on soil and crops under rainfed conditions in South-West Spain (Western Andalusia). Spanish J. Agric. Res. 2, 35. https://doi.org/10.5424/sjar/2004021-58

Neef, A., 2008. Integrating participatory elements into conventional research projects: Measuring the costs and benefits. Dev. Pract. 18, 576–589. https://doi.org/10.1080/09614520802181632

Neef, A., Neubert, D., 2011. Stakeholder participation in agricultural research projects: A conceptual framework for reflection and decision-making. Agric. Human Values 28, 179–194. https://doi.org/10.1007/s10460-010-9272-z

Palm, C., Blanco-Canqui, H., DeClerck, F., Gatere, L., Grace, P., 2014. Conservation agriculture and ecosystem services: An overview. Agric. Ecosyst. Environ. 187, 87–105. https://doi.org/10.1016/j.agee.2013.10.010

Peregrina, F., Larrieta, C., Ibáñez, S., García-Escudero, E., 2010. Labile organic matter, aggregates, and stratification ratios in a semiarid vineyard with cover crops. Soil Sci. Soc. Am. J. 74, 2120–2130. https://doi.org/10.2136/sssaj2010.0081

Plaza-Bonilla, D., Álvaro-Fuentes, J., Cantero-Martínez, C., 2014. Identifying soil organic carbon fractions sensitive to agricultural management practices. Soil Tillage Res. 139, 19–22. https://doi.org/10.1016/j.still.2014.01.006

Ramos, M.E., Benítez, E., García, P.A., Robles, A.B., 2010. Cover crops under different managements vs. frequent tillage in almond orchards in semiarid conditions: Effects on soil quality. Appl. Soil Ecol. 44, 6–14. https://doi.org/10.1016/j.apsoil.2009.08.005

Ramos, M.E., Robles, A.B., Sánchez-Navarro, A., González-Rebollar, J.L., 2011. Soil responses to different management practices in rainfed orchards in semiarid environments. Soil Tillage Res. 112, 85–91. https://doi.org/10.1016/j.still.2010.11.007

Reed, M.S., 2008. Stakeholder participation for environmental management: A literature review. Biol. Conserv. 141, 2417–2431. https://doi.org/10.1016/J.BIOCON.2008.07.014

Reed, M.S., Fazey, I., Stringer, L.C., Akhtar-Schuster, M., Begni, G., Bigas, H., Brehm, S., Briggs, J., Bryce, R., Buckmaster, S., Chanda, R., Davies, J., Diez, E., Essahli, W., Evely, A., Geeson, N., Hartmann, I., Holden, J., Hubacek, K., Ioris, A.A.R., Kruger, B., Laureano, P., Phillipson, J., Prell, C., Quinn, C.H., Reeves, A.D., Seely, M., Thomas, R., Van der Werff Ten Bosch, M.J., Vergust, P., Wagner, L., 2011. Knowledge management for land degradation monitoring and assessment: an analysis of contemporary thinking. L. Degrad. Dev. DOI: 10.10, 1–16.

Robinson, D.A., Hockley, N., Dominati, E., Lebron, I., Scow, K.M., Reynolds, B., Emmett, B.A., Keith, A.M., de Jonge, L.W., Schjønning, P., Moldrup, P., Jones, S.B., Tuller, M., 2012. Natural Capital, Ecosystem Services, and Soil Change: Why Soil Science Must Embrace an Ecosystems Approach. Vadose Zo. J. 11, 0. https://doi.org/10.2136/vzj2011.0051

Schwilch, G., Bernet, L., Fleskens, L., Giannakis, E., Leventon, J., Mills, J., Short, C., Stolte, J., Delden, H. Van, Mara, T., Verzandvoort, S., 2016. Operationalizing ecosystem services for the mitigation of soil threats : A proposed framework. Ecol. Indic. 67, 586–597. https://doi.org/10.1016/j.ecolind.2016.03.016

Schwilch, G., Lemann, T., Berglund, Ö., Camarotto, C., Cerdà, A., Daliakopolus, I.N., Kohnová, S., Krzeminska, D., Marañón, T., Valente, S., Van Delden, H., van der Akker, J., Verzandvoort, S., Vrînceanu, N.O., Zoumides, C., Hessel, R., 2018. Assessing Impacts of Soil Management Measures on Ecosystem Services. Sustainability. https://doi.org/10.3390/su10124416

Shepherd, G., Ross, C., Basher, L., Saggar, S., 2000. Visual Soil Assessment - Volume 2: Soil management guidelines for cropping and pastoral grazing on flat to rolling country.

Shepherd, G., Stagnari, F., Pisante, M., Benites, J., 2008. VISUAL SOIL ASSESSMENT. Field guides. Annual crops. Olive orchards. Orchards. Vineyards. Wheat.

Stringer, L.C., Fleskens, L., Reed, M.S., de Vente, J., Zengin, M., 2013. Participatory Evaluation of Monitoring and Modeling of Sustainable Land Management Technologies in Areas Prone to Land Degradation. Environ. Manage. 54, 1022–1042. https://doi.org/10.1007/s00267-013-0126-5