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Assessing the resilience of farming systems on the Saïss plain, Morocco

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Keywords

Performances; farm types; diversification; climate change; water scarcity; participatory approach

Highlights

- A participatory approach was used to study farm resilience after a shock
- Shocks differed according to farm type, but were all related to water
- Mental models were used with stakeholders to design future farming systems
- Performance was assessed according to eight complementary indicators
- According to stakeholders, all farm types would adapt, suggesting a good resilience

Abstract

The Mediterranean region is expected to be a hot spot for climate change, making the resilience of farming systems a major challenge. Some studies have used quantitative models at the farm scale to analyze the resilience of farming systems but with little involvement of stakeholders. We used a participatory approach with stakeholders on the Saïs plain of Morocco to design possible future states and qualitatively assess the resilience of typical farm types (FTs) experiencing major change. Our approach combined individual interviews of farmers and stakeholders with participatory collective meetings to identify representative FTs and their performance, project their evolutions and future performance in the face of change, and evaluate their resilience. Performance, defined according to literature, interviews and meetings, included different types of capital, income, yields, markets, support of public policies, and water access. Four FTs were considered: highly irrigated market-gardening (FT1), rainfed cereals (FT2), partly irrigated cereal-legumes (FT3), and mostly irrigated fruit-tree/market gardening (FT4). The primary driver for FT2 and FT3 was climate change; for Ft1 and Ft4 it was limiting access to water resources. Stakeholders designed more diversified systems for all FTs in relation to those changes. Rankings of FT performance did not change between current and future states. Performance did not evolve significantly, but FT4 was seen as the most resilient, and FT2 the least. These qualitative results differ somewhat from other studies mobilizing quantitative approaches, but they highlight the potential of local adaptation to limit the impacts of global change on vulnerable agriculture.

1. Introduction

The Mediterranean region is expected to become a hotspot for the impacts of climate change, rendering it particularly vulnerable to related global change (Giorgi and Lionello 2008). Therefore, making agricultural food production systems resilient to climate and market shocks is a major challenge (Rivington et al. 2007). Resilience can be defined as the capacity of a system to buffer shocks while maintaining its structure and functions (Walker et al. 2004). In the case of agricultural systems, resilience can be defined as their capacity to reorganize and maintain interconnected functions and structures that are defined at different temporal and spatial scales (Walker et al. 2004; Souissi et al. 2018). This resilience is context-specific and depends on three main characteristics: threats (e.g., climate change), vulnerability (i.e., exposure due to agro-ecosystems and farmer characteristics), and reactive capacity (i.e., capacity of farmers to adapt and recover) (Altieri et al. 2015). This definition puts the farmer at the heart of the assessment and improvement of resilience at field and farm levels.

In agro-ecosystems, resilience can be assessed at different levels: fields, farms (and connected enterprises), and regions (Peterson et al. 2018). The determination of which level(s) to consider is central to the assessment, because the various farm types will adapt differently (Reidsma et al. 2010).

First, resilience is often assessed at the regional scale without considering farm diversity. Those studies focus on socio-economic aspects, the role of stakeholders and their organizations, and the resilience of the region or sector (e.g., Sinclair et al. 2014). Such approaches are based on surveys and trajectories, typically excluding bio-physical aspects.

Second, quantitative approaches are applied to study resilience at the farm scale, often relying on bio-physical components (Reidsma et al. 2010, Souissi et al. 2018), or evolution of capital and financial aspects (Parsonson-Ensor and Saunders 2011). Those studies are often limited in terms of the inclusion of exogeneous factors, drivers (e.g., shocks) and the associated adaptation strategies, as well as the indicators of assessment (e.g., yield, income, labour), because they rely on modelling tools that are unable to simultaneously integrate multiple effects, and require a large amount of data (e.g., Reidsma et al. 2010; Souissi et al. 2018). In those studies, we have seen few examples of stakeholders' inclusion, and those are at best limited to gathering data and sharing final results. Such research is mainly used to address methodological issues.

Current frameworks for assessing the resilience of farming systems (FS) define FS as large groups of farms that share related challenges such as agro-ecological zoning, type, products, and affected public goods (Meuwissen et al. 2019). This definition can extend beyond a regional scale, creating potential confusion with broader issues of governance and policy. Such frameworks also use a variety of methods to assess indicators (econometrics, modelling, stakeholders' perceptions, etc.), which are data intensive (Meuwissen et al. 2019) and thus can be limited in their applications. Other participatory approaches have been developed to study the adaptation of agricultural systems (e.g., Faysse et al. 2014) but these were limited in their consideration of drivers (climate change) and did not produce a detailed analysis of resilience that takes account of farm diversity at the regional scale.

To our knowledge, there is currently a lack of farm-scale approaches capable of placing stakeholders at the heart of resilience analysis. In part, the difficulty of this type of approach arises from the diversity of the stakeholders and their roles, but there is also the issue of researchers' ability to engage them around a specific, unifying tool. Such a tool must be capable of integrating the numerous factors affecting the vulnerability of agricultural systems, such as external factors of price volatility or limited long-term storage capacities (Lejars and Courilleau 2014), climate variability, access to irrigation water (Ameur et al. 2017), and land tenure. All of these factors also depend on the type of farms (farm size, irrigated area, type of production) and the farmer's production strategy. Ranking these vulnerabilities, and designing possible adaptation strategies is a difficult task, which may be particularly suited to local stakeholders themselves, and thus calls for participatory research that can benefit from a simple tool.

In the current study, we designed a participatory approach aimed at analyzing the possible futures of a diversity of farm types in a case study in Morocco. Several methods, such as scenario exercises, have been proposed to study possible futures with stakeholders (e.g., Delmotte et al. 2017). A scenario is characterized by the description of an initial situation and the driving forces that induce a specific future (Alcamo and Henrichs 2008). The causes of change (the drivers) may be any combination of physical or ecological factors (e.g., climate change), or social or economic factors (e.g., political, urban), depending on specific local issues and contexts. Different scenarios can represent different impacts on agro-ecosystems (cropping systems) and thus different futures with a range of performance at different spatial and temporal scales. An important feature of the scenarios is their internal consistency. Cognitive maps can be used to guarantee this consistency. A cognitive map is a graphical way of representing interconnected concepts and is thus intended to graphically represent complex systems. It has been widely used to elicit mental models (e.g., Mathevet et al. 2011; Gray et al. 2014), for farm design (Gouttenoire et al. 2013) and scenario development (van Vliet et al. 2010). As a flexible and easy-to-understand tool that structures stakeholders' mental models (Gray et al. 2014), cognitive mapping together with written storylines can support collective thinking among stakeholders. Although cognitive mapping has been used to study resilience in enterprises (Branco et al. 2019), urban systems (Olazabal and Pascual 2016), and socio-ecological systems (Gray et al. 2015), to our knowledge it has never been used to study the resilience of farming systems.

In this study, we mobilized stakeholders and cognitive mapping with two primary objectives: to design possible futures of different farm types (FTs) under a major driver of change, and to qualitatively assess the farms' resilience according to different FTs and their performance.

2. Material and Methods

2.1. Study area

The Saïss plain covers 2,200 km^2 including 1,910 km^2 used for agriculture (Fofack et al. 2015). The plain has fertile soils and benefits from groundwater aquifers (Berriane, 2002). The climate is semi-arid, with rainfall ranging from 207 to 677 mm per year, for an average of 500 mm/year (data 1980-2010). After a series of dry years, the 1980s marked a drastic reduction of rain-fed crops and the development of irrigated agriculture, mainly vegetables (Quarouch et al. 2014). This increase in irrigated crops (e.g., potato, onions, peach orchards, vineyards), which are also associated with a high use of pesticides and chemical fertilizers (Baccar et al. 2018), has led to the overexploitation of the aquifer (Quarouch et al. 2014). In the process, the groundwater level has dropped as much as 60 m at certain points (Agence de bassin hydraulique du Sebou, 2011).

2.2. Methodological framework

The general methodology followed in this work can be divided into three main steps. Each step was aimed at qualifying one element of resilience, corresponding to the three components suggested by Souissi et al. (2018): 1) characteristics and associated performance of the initial system, 2) shock (from a specified cause), and 3) characteristics and associated performance of the future system (equilibrium after the shock).

In each step the involvement of local and national stakeholders is a key issue. We interviewed several farmers and local stakeholders in order to achieve the first step's objectives: to characterize the initial situation (baseline) and the associated challenges and to select representative FTs. The objectives of the second step, achieved through a collective workshop, were to describe the structure and the functioning of the representative FTs, identify the drivers of change in each case, and describe how they would adapt to the selected change in the future scenario. In a second collective workshop, the objective of the third step was to assess the performance of representative FTs, both current and future.

The identification and engagement of stakeholders involved in this study built on knowledge from previous local studies (Ameur et al. 2017, Baccar et al. 2017, 2018), associated project partners (INRA-Morocco), and key interviews with individual sources. The goal was to involve stakeholders that had expressed either concerns or courses of action (Appendix 1) on the agricultural systems, as suggested by van den Belt et al. (2010).

The identification and the involvement of stakeholders to be a part of this study were achieved around two principles:

(i) Strong farmer participation, especially in step 1. This was achieved by interviewing 21 farmers characterized as having distinct production objectives and farm structures (access to resources, dominant crops, etc.). The main local challenges were also identified by interviewing actors from extension services, statistics services, and water management (5 interviews in total, each with 2 to 4 actors; Table 1).

(ii) Favor participation of stakeholders with similar or compatible interests (workshops in steps 2 and 3), both among participants in general and between the participants in the two different workshops. Overall, 30 participants from 20 institutions attended the first workshop, and 16 from 11 attended the second (Table 1). These stakeholders were from different types of organizations and levels (from provincial to national). Except for two researchers, all the participants in the second workshop also attended the first. A total of 53 people was involved in the entire process.

Table 1 approximately here

2.2.1. Step 1: Characterization of current situation, including choice of FTs

The diagnosis of the current situation included three categories of information: (1) the general characteristics of the agricultural region; (2) the description of current representative FTs, including available resources and constraints; (3) the different institutions, structures, and people involved in the agricultural development of the Saïs region. These three categories of information were assembled from literature, knowledge among the local research partners, and interviews with farmers and stakeholders. The general characteristics of the local agricultural system were described using SWOT analysis (Strengths, Weaknesses, Opportunities and Threats). The initial selection of representative FTs was based on previous studies in the area. Baccar et al. (2017) interviewed 40 farmers in 2014. El Ansari et al. (2020) interviewed 286 farmers in 2015. A selection of representative farms was updated and completed with interviews, which were also aimed at gathering information on farmers' current constraints and future projects.

2.2.2. Step 2: Selection of drivers of change and characterization of current and future FTs

The drivers to be studied were selected by stakeholders during the first collective workshop (6 hours). The project's objectives (future projections for 15 years hence, and the resilience of Saïss farming systems) were introduced during this workshop. We then presented (1) a summary of the SWOT analysis carried out during the individual interviews of stakeholders, (2) a summary of farmers current constraints and projects collected during farmers' interviews, and (3) a proposition of representative FTs to be studied during the workshops. After a short discussion on these three diagnostic factors, we presented and illustrated definitions of the terms, resilience and driver. The list of drivers of change (presented without indicating their variation or type of impact, i.e., positive or negative) was based on a literature review and interviews from the first step. This list included labor force, diseases, market access and commercialization options, water resources, land access, prices of inputs, selling prices, and climate changes. This list was finalized by stakeholders who were asked to individually choose, justify and rank up to three drivers for each representative FT. Based on these choices and rankings, the primary driver was selected for each FT in order to study the resilience and changes in farm performance.

During this initial workshop, a phase of collective work was also organized, in order to facilitate both knowledge sharing and dialogue. Groups of stakeholders were invited to characterize the current state (structure, performance) of each FT, and the projection for its future state following a shock instigated by the identified driver. This projected state envisions a new equilibrium, once the changes have occurred. The characterizations were formalized using cognitive maps to describe the overall context of the current, or projected FTs: their environment (e.g., market prices, public policies), their resources (e.g., water, labor), their current (or future) structure (e.g., farm size) and functions (e.g., cultivated cropping systems, farm activities) that condition their current or future performance in terms of indicators such as yield, income, and irrigation water use. The "future" state was projected on a 15-year time horizon, suggested by the research team and validated by the stakeholders as coherent (i.e., close enough to be realistic, and far enough to be creative). This horizon is considered a good compromise between the evolution of socio-economic conditions which are too uncertain to project beyond 15 years, and the effects of climate change which are hardly visible in less than 15 years (Souissi et al. 2018).

For each FT, two cognitive maps (CMs) were constructed by groups of stakeholders (4 groups of 5-6 people, each considering one FT): one CM describing its current state, and another CM describing its possible future state according to the driver previously chosen. At the end of the workshop, a member of each group presented both CMs in order to explain the contextual information chosen and the relationships (positive or negative) between context, farm, and performance.

The research team facilitated the construction of CMs in three steps. First, its objects and structure were introduced to all participants, explaining the "boxes" with the use of examples (e.g., market price, environmental policies, etc.) and describing the links between boxes (e.g., positive/negative relationship). Second, one facilitator gave a simple example of a CM for the initial situation of FT1, using only commonly reported elements from the interviews. Third, the three facilitators observed the groups' work and intervened when necessary to clarify the process of CM construction.

2.2.3. Step 3: Semi-quantification of the indicators of FT performance

There were three principal objectives in the second collective workshop (5 hours): (1) to validate the cognitive map results, (2) to detail the description of future FTs according to different elements (crops and their distribution, farm acreage, percentage of irrigated land, family or external workforce, type and number of livestock), and (3) to describe performance of current and future FTs (according to the previously chosen drivers).

The performance indicators to be quantified were selected from the literature (Table 2), with regard to the issues faced by agricultural systems in arid zones. Based on the three pillars of sustainability, it included eight indicators: land, labour, farmer income (Souissi et al. 2018), yields (El Ansari et al. 2020), family assets (Bar et al. 2011), market access and commercialization (Castel et al. 2014), irrigation (El Ansari et al. 2020), and policies (Gameroff and Pommier 2012) (Table 2). This list was consistent with results from farmer and stakeholder interviews (1st step) and the results of the first workshop (2nd step). It was discussed and validated at the beginning of the second workshop.

Table 2 approximately here

The semi-quantification of certain measures of performance was carried out in two steps. First, stakeholders individually chose the three most relevant indicators of performance for each FT. This had two main objectives: 1) familiarize stakeholders with the research team's definition of performance, and 2) identify the most critical performance indicators (in terms of strength or weakness for each FT). Stakeholders were then divided into groups (2 groups of 6-7 peoples, each group assessing two FTs) to quantify the eight performance indicators for current and future FTs, together with written explanations. A member of each group presented these results at the end of the workshop. The quantification of each indicator ranged between 1 (very low/poor) to 5 (very high/good). During this quantification step, one group of stakeholders was confused about the written explanation of indicator quantification. Therefore, we present the results of their oral restitution, complemented with discussions from both workshops.

Resilience of each FT was qualitatively estimated based on those results: (1) the evolution of the most relevant indicator, (2) the number of indicators with no change, and (3) the sum of the differences between the current and future FT for each indicator (expressed as absolute in order to avoid compensations). We thus obtained three indicators of resilience for each FT.

3. Results

3.1. Characterization of the initial situation

Based on the series of interviews, we summarized the characteristics of the initial situation in a SWOT diagram (Appendix 2), which was presented and validated during the first workshop. The descriptions of the agricultural systems by the different local stakeholders highlighted a consensus on the primary issues. The main strengths were related to environmental and social features (e.g. pedo-climatic conditions suitable for a diversity of crops, and qualified workers). The main weaknesses identified were related to social, economic, and technological features (e.g., poor organization between farmers and between administrators, difficulty in commercializing, and difficulty in attaining high yields). For the most part, social arguments ranked at the top. The opportunities highlighted during the interviews were mainly economic and technological (e.g., attractiveness for investors, new markets, and no-till farming); the threats mainly came from environmental and economic conditions (e.g., overuse of water, and market conditions) (see Appendix 2 for details).

Although more regional in perspective, the description of agricultural system issues by local stakeholders was mostly consistent with those of the interviewed farmers (step 1); both of these groups emphasized commercialization and lack of workers as important weaknesses (Appendix 2). However, it should be noted that concerns about weaknesses in land ownership and yields at the farm scale, emphasized by local stakeholders, were not highlighted by farmers. Conversely, opportunities such as subsidies to increase drop irrigation, increase fruit plantations, and develop farm structures for storage and transformation, were cited by interviewed farmers, but not by the local stakeholders.

During the first workshop the research team presented the farm typology, with four FTs differing in their production, size, proportion of irrigated land, labor and livestock (Table 3). Two FTs are seen as intensive with significant mobilization of inputs (especially irrigation water) and some cattle/sheep farming for the market or household consumption of meat or milk (FT1 and FT4). These two FTs were currently considered as the most profitable. FT2 corresponded to a typical extensive farm, which produces dry cereals and livestock, particularly sheep, intended for the market. FT2 was considered by local stakeholders as the less profitable. Finally, FT3 corresponded to a moderately intensive mixed farm growing cash crops and raising sheep for the market.

Table 3 approximately here

3.2.Selection of drivers

The individual list of drivers developed by local stakeholders in the first workshop was very diverse, within and between FTs (Appendix 3). These drivers were later considered as possible shocks for testing system resilience. Those most cited were in line with the threats identified in the interviews (Appendix 3): climate change (FT2 and FT3) and decrease in water resources (especially for FT1 and FT4, and to a lesser extent for FT3), along with the weaknesses of commercialization (all) and labor (especially for FT4—the largest—see Table 3). Based on these individual rankings, one main driver was chosen for each FT: climate change was seen as the main driver of change for FT2 and FT3, access to irrigation water was identified for FT1 and FT4.

3.3. Cognitive maps and future farms

In order to identify how the chosen drivers would affect the current FTs, the groups of stakeholders built cognitive maps (together with written explanations) of the farm context (explaining their state) for each FT, in both current and future states. The explaining factors differed between FTs, and between current and future states (Figure 1).

Farm Type 1 is specialized in marked gardening and generates high income with highly profitable crops (onions and potatoes), but this income varies with input and market prices (Figure 1A). Intensive practices and short rotations have a negative impact on soils (organic matter), and require significant irrigation, which impacts water resources already subject to inefficient management and irregular rainfall. Poor management of water resources is encouraged by the lack of controls on irrigation, government policies that subsidize its extension (irrigation systems can be fully subsidized in some cases), and the negligible cost of water.

The shock for FT1 is a decrease in the availability of groundwater irrigation (i.e., a drop in the water table). This shock would involve large changes in the cropping system, with a reduction of intensive market gardening in favor of more extensive practices and less input for crops such as cereals, legumes, oilseed, and rain-fed trees (olive and fig trees), and the introduction of drought-tolerant varieties (Figure 1B). Direct sowing would be implemented in order to improve conservation of water and organic matter. Farmers could also add value with crop by-products (straw, pulp). Irrigation would decline from 75% of the surface area to only 45% (due to the reduction in market gardening; Table 3). Farmers would have acquired the knowledge needed to control irrigation (inspired by new technologies).

Farm Type 2 only grows rainfed cereals which demand few resources (labor, inputs). Government policies providing subsidies for insurance, seeds and equipment have a positive impact on these farms. Difficult access to adapted seeds, appropriate phytosanitary products and their high prices have a direct negative impact on their production. The FT2 farms must endure constraints related to storage of agricultural products and commercialization (intermediaries, selling prices, etc.) which can also impact them negatively (Figure 1C).

The shock for FT2 is climate change characterized by varying amounts of rainfall (droughts/excessive water) during the year and between years. Climate change would have a direct impact on farms, as grain yields are driven primarily by rainfall. Droughts resulting from climate change would also have a negative impact on livestock feed (less straw), requiring farms to purchase supplementary feed. Nevertheless, the government might try to maintain livestock production in the region by initiating new policies (livestock and milk subsidies, supplementary feed subsidies). Therefore, two options for FT2 farms were envisioned for the future (Figure 1B): (1) specialization towards subsidized livestock, and (2) system diversification with rain-fed arboriculture (arbutus, olive, almond, fig tree) and cereals/legumes/oilseed crop rotations (Table 3). The availability of more efficient phytosanitary treatments and the adoption of new practices (such as direct sowing) would help tackle the challenges of climate change. However, without access to the financing needed to transform their system, some farmers might abandon agriculture.

Figure 1 approximately here#

Farm Type 3 corresponds to family farming with less access to markets. The government strategies seek to overcome related issues: (1) facilitate marketing for farmers (help reduce the number of intermediaries and find new markets), (2) strengthen production capacity through collective purchases of materials and organization of shared use), (3) help farmers with decision-making (adoption of best practices), and (4) facilitate dialogue between farmers and members of the agricultural sector, and strengthen professional organizations (Figure 1E). Although the government tries to structure the market with mechanisms such as contracts and labelling, the liberalization of agricultural markets has negative consequences for FT3: selling prices are low and unstable (mainly for market gardening), thus limiting the valorization of farm products.

In the case of FT3, the shock of climate change (characterized by rising temperatures, a decrease and variability in rainfall, a shorter crop cycle and shifting cultivation areas) may affect farms in a number of ways, including a decline in production that would lead to lower revenue (Figure 1F). In the projected future state, government policies would have a positive impact by buffering the effects of climate change through a reorientation of strategies (adopting best practices and reducing investment for adverse projects) and the strengthening of the multi-risk climate insurance system introduced in 2011. Professional organizations could make farmers aware of the consequences of climate change, and enable them to better adapt and gain access to new technologies (irrigation, mechanization). The main response to climate change would be the introduction of the rustic tree crops to the current cropping system (Table 3).

For FT4, the expansion of irrigated areas has a positive impact on farm income, enabling cultivation of arboreal species that have high added value (Figure 1G). But current policies funding the installation of new boreholes have a direct negative impact on water resources. This policy favors less labor-intensive drip irrigation, leading to a decrease in hired labor, but at the same time, the extension of cultivated land increases the demand for labor. The potential lack of product valorization (refrigerated storage or sorting) has a negative impact on marketing and subsequently on farmers' income. Thus, the potential benefit of increased production is countered by lower prices and storage difficulties.

Like FT1, the shock for FT4 is the decline in groundwater resources, leading to a decrease in irrigated areas and impacting rotations. In the projected future, rustic arboriculture species (olive, almond) would replace some rosaceous species, and some market gardening areas would convert to cereals and legumes (Table 3). The sector would experience an evolution in fruit quality and traceability, and new market policies would be initiated to achieve better organization of sales and product valorization. Production area would be less extensive (partly compensated by increased yields through better technical management) but superior in quality: farmers would maintain a good income even if production decreases (Figure 1H).

All FTs would diversify their crops (Table 3). Some would largely change orientation, such as FT1 that would reduce the practice market-gardening. FT2 would diversify (legumes, arboriculture), but remain rainfed. Rainfed legumes and arboriculture would be grown on all farm types, even on FT4 where the tree cultivation would be divided between rosacea and rustic species. The irrigated areas would not exceed half of the total agricultural area, and livestock would not evolve over time.

3.4. Performance of FTs and projected resilience

In the second workshop the participants quantitatively assessed the eight types of performance of current and future FTs, as determined with cognitive maps (Figure 1) and associated characterization (Table 3).

FT4 shows the best performance (high yields, high income, landowner, and supported by government policies) both now and in the future (Figure 2). Family assets is the only indicator seen as low, because this FT has few livestock. The Political, Irrigation and Marketing indicators were considered average for the current situation, but they all increased in the future, with improved policy support, better irrigation practices, and better marketing, when compared to the current situation. For this FT4, the participants foresee an improvement in irrigation management, product quality and selling price.

For FT1 and FT3, only four indicators vary between the current and future situation. For both types, the four changing indicators tend to reflect declining performance. For FT1, these four indicators are Land, Family assets, Farmers' income, and Yields. The land indicator is deteriorating due to land fragmentation. Yield would decrease because of climate change. Farmers assets and farm income would decrease due to lower yields and less-profitable crops. For FT3, the four indicators are Income, Labor, Irrigation, and Policies. The fall in income would be due to the expected increase in production costs (phytosanitary products, water and labor). The Labor indicator would decrease because of a decline in the availability of family labor (rural exodus), generating additional costs for farms.

Fifteen years from now, FT2 (Figure 2), like FT1 and FT3, would anticipate lower performance than today. Nevertheless, participants expected policies to continue to accompany FT2 through subsidized equipment.

The performance indicator judged as the most important/critical remained stable for each FT (boxed performance indicator in Figure 2; Appendix 4), which would argue for their resilience.

Looking at all performance indicators, FT4 is the only type for which they all would increase. It is also the FT with the lowest overall change between current and future performance indicators. Finally, FT1 and FT3 show four stable indicators of performance; FT2 and FT4 show three. While all FTs remained the same size (Table 3), most changed their crop strategies, lowered their use of water resources (except for FT2 that is rain-fed only) and increased or maintained hired labor (Table 3).

Figure 2 approximately here

4. Discussion

Based on our assessments of resilience, all FTs would be relatively resilient to the main driver of change chosen by stakeholders (either climate change or decrease in availability of irrigation). They would notably adapt to the future through diversification, re-introducing rainfed crops and rustic species (especially among trees). Rainfed legumes would be included in all FTs, contrary to the current situation on most farms. These modifications would be the main adaptation to the increasing scarcity of water, either due to lack of water for irrigation, or to climate change. Several previous studies have highlighted crop diversification as key to improved resilience of farm structure and functions (Reidsma et al. 2009; Baccar et al. 2018). Diversification was seen as a way of spreading the risk and compensating for eventual losses. But the participants of our study saw diversification as being limited to cropping systems, thus excluding both livestock production and off-farm activities. In the first workshop, although feed was highlighted as a possible future issue, the absence of participants or FTs specialized in livestock may have biased the results. In the FTs characterized, the modest number of livestock were seen more as a savings account than as a means of producing regular income (thus differing from the results of Baccar et al. 2018). This perspective was consistent; only one out of the 21 farmers interviewed projected to increase his herd. Off-farm activities, cited by one farmer, were considered out of the scope by most participants, who felt they could not evaluate the opportunities or impacts, such as labor. By contrast, Lallau and Thibault (2005) highlighted this extra-income as a crucial part of the farmer's strategy to build farm resilience. This factor would require further study to assess the feasibility and willingness of farmers, as well as the local opportunities for off-farm activities, and their impacts on the farm (e.g. seasonal labor). Farm adaptation in Mediterranean irrigated agriculture inventoried by Harmanny and Malek (2019) included strategies for changes in water management (irrigation techniques), other technological developments (mechanization), and farm production practices (crop choices), but few changes in sustainable resource management (e.g., groundcover to reduce erosion, use of cover crop, etc.) or farm management (e.g., financial and administrative practices). In our study, adaptation through changes in farm production practices was dominant and transversal to all FTs; this is consistent with findings of Harmanny and Malek (2019) who found it to be the most frequent adaptation in the Mediterranean area.

The only FT showing overall better performance in the future than in the current situation is FT4 (primarily arboreal). This could be due to the multi-variable indicators that were adopted in this study. For instance, while yields would decrease, their quality and price would increase, possibly even leading to higher global income. Although dependent on the current and future state of irrigation, this type of farm is in a better position to adapt due to its initial capital, and the assistance provided by government policies. The government's agricultural policies were very often cited by the study participants as influencing or conditioning current and possibly future systems and practices. This could be linked to the anticipated renewal of the "Green Morocco Plan", launched in 2008 with two goals: develop a modern, productivity-oriented agriculture with investors, and ensure solidarity-based support for small farms as a means of alleviating poverty through increased agricultural income (Marzin et al. 2017).

The construction of cognitive maps did not appear to cause difficulties for the participants, who recognized it as a useful tool to build a systemic vision of the specific context encountered by different FTs, and to highlight differences between the FTs. We did, however, observe that all CMs did not show the same degree of complexity (number of boxes and relationships). This could be due to the diversity of participants in group (e.g. more representatives of professional organizations in the FT3 group). Although the collective construction of a CM did not cause major disagreement, it could represent a bias in the CM comparisons. Overriding this bias could be achieved by pre-determining the group composition, but this would entail two particular difficulties: (1) the uncertainty about who will participate in the workshop, and (2) a top-down approach that might be questioned by some participants and limit creativity. The performance quantification exposed one particular difficulty, when one group was confused during the exercise of ranking the importance of a performance indicator and quantifying it. This issue could have been avoided if the research team had allowed more time between the two exercises and provided more assistance in the group work during this step. Finally, this approach enabled participants to share their perceptions on the current and possible future systems. CMs and their associated storylines highlighted the different contextual aspects characterizing the agricultural systems. The perceptions of the current and future contexts differed somewhat among the participants according to their institution, function, and scale of action. Knowledge sharing in the workshops allowed participants to imagine a broader picture of performance, helping them to anticipate the negative consequences of various drivers of change with respect to specific vulnerabilities of the different FTs.

In this study we evaluated resilience in a simple way in order to stimulate stakeholders' thinking and knowledge sharing when projecting future farming conditions that anticipate the potential negative effects of climate change (Giorgi and Lionello, 2008). This led to three major limits. The first is the compensation seen in the projected evolution of the various chosen indicators of performance. For example, with FT4 the projected decrease in cultivated area would be compensated by an increase in yield. Tracking those compensations through storylines in the cognitive maps allowed us to highlight the differences between current and future states. Second, we distinguished key resilience characteristics related to robustness, adaptability, and transformability (Meuwissen et al. 2019). Our adoption of the scale of FTs was an advantage. It allowed us to distinguish each FT's specific challenges together with the management of a shock characterized by the chosen driver (climate change or water table decrease). Thus, specified and general resilience, as defined by Meuwissen et al. (2019), were combined with future options corresponding to current structures. Third, although the future can be shaped by stress and shocks from interacting social, economic, institutional and environmental factors (Meuwissen et al. 2019), we limited the assessment to one shock. Even though all the adaptation strategies included legumes, adaptation would also depend on other factors such as selling price or changes in the market. Those different types of drivers were cited by local stakeholders and have been highlighted in previous studies concerning the same region (Baccar et al. 2017), but our method was not designed to combine several drivers of change for an overall assessment.

Finally, a key point we did not consider is the transition, questioning in detail the adaptive capacities and learning processes of farmers. Adaptation capacities can be assessed using the adaptive capacity index (Swanson et al. 2007) to consider six determinants: economic resources, technology, information and skills, infrastructure, institutions, and equity (Smit et al. 2001). Using this index, Grasso and Feola (2012) assessed the adaptive capacity in different areas of the Mediterranean. They concluded that Morocco exhibited a low adaptive capacity, performing poorly on all six determinants when compared to other countries. This differs from the relatively stable performances projected by our study's stakeholders in their assessment of the future, which viewed farmers as being able to adapt. This could be due to the different performance indicators assessed in Grasso and Feola (2012), but it could also be linked to the scale. Their study was on national scale, whereas we focused on a small region. Our region of study might be less vulnerable than others, such as those close to the sea with salinity issues (Faysse et al. 2014). This highlights the potential effects of both scaling down and focusing on indicators of performance that have specific importance to local stakeholders.

5. Conclusion

This study focused on small and medium farms, and participants in the study showed that these farms had the capacity to adapt. This was an expression of strong resilience. However, we did not fully examine all dimensions of resilience. To complement our study, it would be useful to make a complete diagnosis of the vulnerabilities, risks, and adaptation capacity. Although all these dimensions were present in our methods and results, they were highly integrated and cannot be evaluated as individual components. Another possibility would be to enlarge our study by including large farms. Although their number is limited, they exert significant pressure on (water) resources through intensive agriculture, such as orchard farming or market gardening. Diagnosing the regional resilience would require integrating all types of farms and other sectors, which would implicate a wider arena including livestock experts, and related industries.

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Table 1. Overview of participants in the interviews and workshops

Participant category		Scale of action	Step 1		Step 2 (Workshop 1)		Step 3 (Workshop 2)	
			Number interviews	Number invitations*	Number participants	Number institutions	Number participants	Number institutions
External participants	*Agricultural school and research*	national	0	2	2	2	0	0
	Cooperative	regional	0	2	1	1	0	0
	Private operators	regional	0	5	0	0	0	0
	Producers association	national	0	1	1	1	0	0
		regional	0	4	1	1	0	0
		local	0	1	1	1	0	0
	Public administration (substidies, statistics)	local	2	2	1	1	2	2
	Public administration - water management	regional	1	1	1	1	0	0
	Public advisory services	regional	2	5	10	5	5	3
		local	0	1	4	1	1	1
	Public popularization service	regional	0	1	1	1	0	0
	Public services for food safety	national	1	1	0	0	0	0
	Research institude	regional	0	1	3	1	4	1
Total external participants			6		26	16	12	7
Internal research team	*Agronomy*				2	2	2	2
	Economics and public management				2	2	2	2
Total internal participants					4	4	4	4
Total			6	27	30	20	16	11

*Involvement was solicited by sending official invitations, followed by individual phone calls.
Res: Research; CC: Crop Collector; Adm: administrations; Adv: Advisors.

Table 2. Type and definition of performance indicators

Indicators of performance	Relevance	Reference
Land: status, size, successor **Labor**: number of employees, price **Income**: prices of inputs and their variation, products type, price and price variation	Indicators of natural, social and financial capital	Soussi et al. 2018
Yields: efficiency of inputs, crop management	Most current agronomical indicator to assess farm performance	El Ansari et al. 2020
Family assets: liquid assets, insurance, livestock (and possibility to sell)	Essential for farm equilibrium	Bar et al. 2011
Market access and commercialization: intermediaries, processing, labels	Cited as highly important factors during interviews (and workshop 1); major constraints according to farmers	Castel et al. 2014
Irrigation: water access, type of irrigation, management	Very important for some farm types; Allows to intensify the agricultural production	El Ansari et al. 2020
Policies: subsidies, minimum salary, export regulations	Agriculture is highly subsidized and supported by the Moroccan government; public support can be seen as favoring resilience	Gameroff and Pommier, 2012

Table 3. Main characteristics of the four current FTs (current situation), based on El Ansari et al. (2020) and Baccar et al. (2017), and the future FTs achieving equilibrium (future situation), as projected by stakeholders during the workshops. UAA: Utilized Agricultural Area; ↓ and ↑ highlights decrease/increase as compared to current situation

	Current situation					Future situation				
Farm type	Main Crops with relative UAA	UAA (ha)	Irrigation (% UAA)	Labour	Livestock	Main Crops with relative UAA	UAA (ha)	Irrigation (% UAA)	Labour	Livestock
Type 1	90 % Market gardening 10 % Cereals	5	75	Family + hired	Bovine: 2-3 Ovine: ~ 5	45 % Market gardening 55 % Cereals, legumes, arboriculure, oleaginous	5	45	Family	Bovine: 2-3 Ovine: ~ 5
Type 2	100% Cereals	5	0	Family + hired	Bovine: 2-3 Ovine: ~ 10	70% Cereals and legumes 30% rustic arboriculture	5	0	Family (↓) + hired (↑)	Bovine: 2-3 Ovine: ~ 10
Type 3	50 % Cereals 40% Legumes 10% Market gardening	5	20	Family only	Bovine: 3-4 Ovine: ~ 11	50 % Cereals 20% Legumes 25% rustic arboriculture 5% Market gardening	5	10	Family + hired	Bovine: 2-3 Ovine: ~ 11
Type 4	50 % Fruit trees 35 % Market gardening 15% Cereals	10-15	60	Family + hired	Bovine: 2-10	50 % arboriculture (25% rustic; 25% *Rosaceae*) 20% Market gardening 30% Cereals and legumes	10-15	45	Hired	Bovine: 2-10

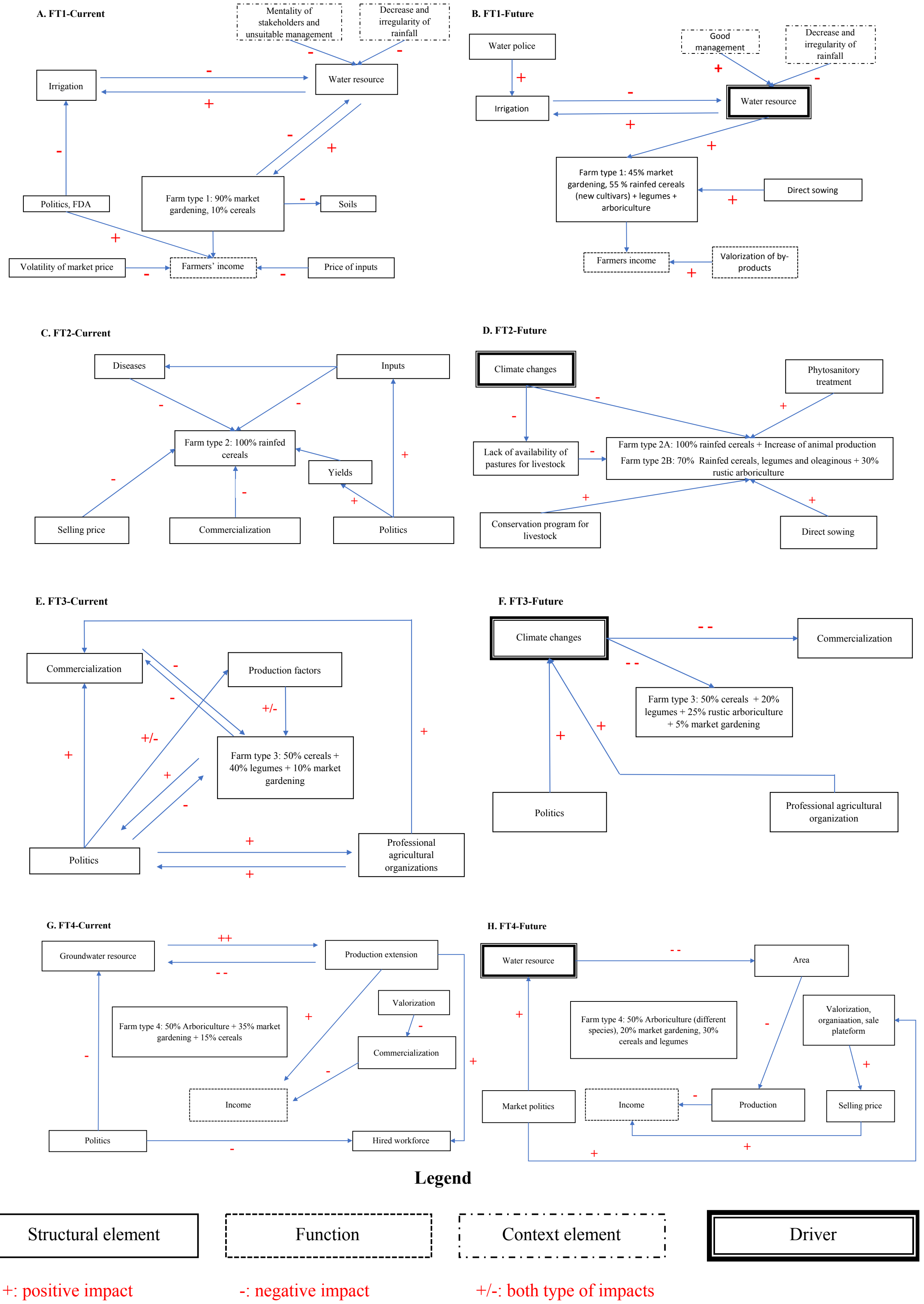

Figure 1. Mental models built by stakeholders for the current (A, C, E, G) and future (B, D, E, H) states of the four farm types (FT1 in A-B, FT2 in C-D, FT3 in E-F, and FT4 in G-H).

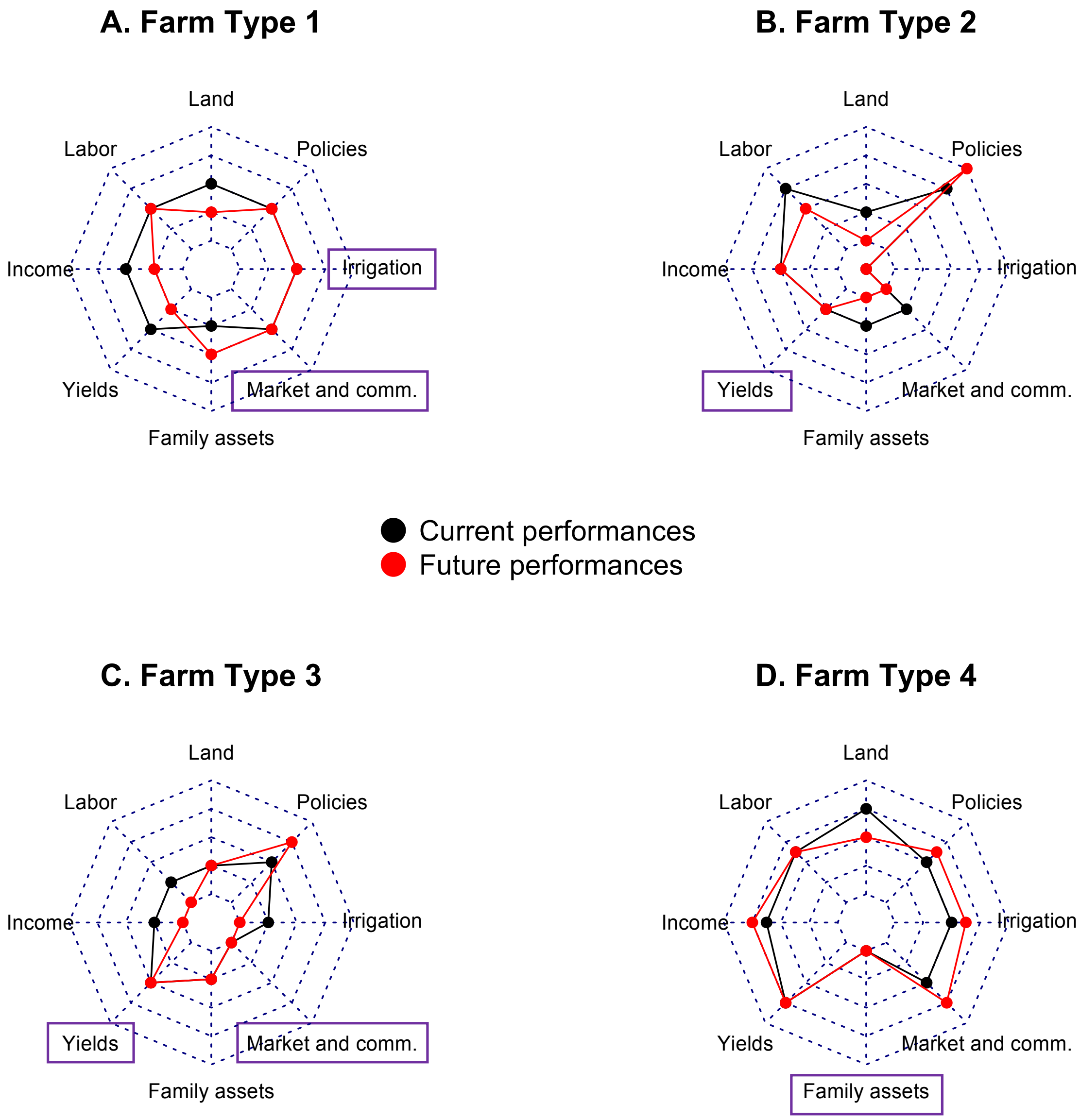

Figure 2. Performance indicators of current (black) and future (red) farm types, as quantified by stakeholders during workshop 2. 0 = very low/poor; 5 = very high/good. Boxed indicators are those identified as the most important by stakeholders during the second workshop (Appendix 4).