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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

1 Abstract

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

21 1. Introduction

22 The Mediterranean region is expected to become a hotspot for the impacts of climate change,
23 rendering it particularly vulnerable to related global change (Giorgi and Lionello 2008).

24 Therefore, making agricultural food production systems resilient to climate and market shocks
25 is a major challenge (Rivington et al. 2007). Resilience can be defined as the capacity of a
26 system to buffer shocks while maintaining its structure and functions (Walker et al. 2004). In
27 the case of agricultural systems, resilience can be defined as their capacity to reorganize and
28 maintain interconnected functions and structures that are defined at different temporal and
29 spatial scales (Walker et al. 2004; Souissi et al. 2018). This resilience is context-specific and
30 depends on three main characteristics: threats (e.g., climate change), vulnerability (i.e.,
31 exposure due to agro-ecosystems and farmer characteristics), and reactive capacity (i.e.,
32 capacity of farmers to adapt and recover) (Altieri et al. 2015). This definition puts the farmer at
33 the heart of the assessment and improvement of resilience at field and farm levels.

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

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

42 Second, quantitative approaches are applied to study resilience at the farm scale, often relying
43 on bio-physical components (Reidsma et al. 2010, Souissi et al. 2018), or evolution of capital
44 and financial aspects (Parsonson-Ensor and Saunders 2011). Those studies are often limited in
45 terms of the inclusion of exogeneous factors, drivers (e.g., shocks) and the associated adaptation

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46 strategies, as well as the indicators of assessment (e.g., yield, income, labour), because they rely
47 on modelling tools that are unable to simultaneously integrate multiple effects, and require a
48 large amount of data (e.g., Reidsma et al. 2010; Souissi et al. 2018). In those studies, we have
49 seen few examples of stakeholders' inclusion, and those are at best limited to gathering data
50 and sharing final results. Such research is mainly used to address methodological issues.

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

61 To our knowledge, there is currently a lack of farm-scale approaches capable of placing
62 stakeholders at the heart of resilience analysis. In part, the difficulty of this type of approach
63 arises from the diversity of the stakeholders and their roles, but there is also the issue of
64 researchers' ability to engage them around a specific, unifying tool. Such a tool must be capable
65 of integrating the numerous factors affecting the vulnerability of agricultural systems, such as
66 external factors of price volatility or limited long-term storage capacities (Lejars and Courilleau
67 2014), climate variability, access to irrigation water (Ameur et al. 2017), and land tenure. All
68 of these factors also depend on the type of farms (farm size, irrigated area, type of production)
69 and the farmer's production strategy. Ranking these vulnerabilities, and designing possible

1
2 70 adaptation strategies is a difficult task, which may be particularly suited to local stakeholders
3 themselves, and thus calls for participatory research that can benefit from a simple tool.

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5 72 In the current study, we designed a participatory approach aimed at analyzing the possible
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7 73 futures of a diversity of farm types in a case study in Morocco. Several methods, such as
8
9 74 scenario exercises, have been proposed to study possible futures with stakeholders (e.g.,
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11 75 Delmotte et al. 2017). A scenario is characterized by the description of an initial situation and
12
13 76 the driving forces that induce a specific future (Alcamo and Henrichs 2008). The causes of
14
15 77 change (the drivers) may be any combination of physical or ecological factors (e.g., climate
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17 78 change), or social or economic factors (e.g., political, urban), depending on specific local issues
18
19 79 and contexts. Different scenarios can represent different impacts on agro-ecosystems (cropping
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21 80 systems) and thus different futures with a range of performance at different spatial and temporal
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23 81 scales. An important feature of the scenarios is their internal consistency. Cognitive maps can
24
25 82 be used to guarantee this consistency. A cognitive map is a graphical way of representing
26
27 83 interconnected concepts and is thus intended to graphically represent complex systems. It has
28
29 84 been widely used to elicit mental models (e.g., Mathevet et al. 2011; Gray et al. 2014), for farm
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31 85 design (Gouttenoire et al. 2013) and scenario development (van Vliet et al. 2010). As a flexible
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33 86 and easy-to-understand tool that structures stakeholders' mental models (Gray et al. 2014),
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35 87 cognitive mapping together with written storylines can support collective thinking among
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37 88 stakeholders. Although cognitive mapping has been used to study resilience in enterprises
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39 89 (Branco et al. 2019), urban systems (Olazabal and Pascual 2016), and socio-ecological systems
40
41 90 (Gray et al. 2015), to our knowledge it has never been used to study the resilience of farming
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43 91 systems.

44
45 92 In this study, we mobilized stakeholders and cognitive mapping with two primary objectives:
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47 93 to design possible futures of different farm types (FTs) under a major driver of change, and to
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49 94 qualitatively assess the farms' resilience according to different FTs and their performance.
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95 2. Material and Methods

96 2.1. Study area

97 The Saïss plain covers 2,200 km² including 1,910 km² used for agriculture (Fofack et al. 2015).

98 The plain has fertile soils and benefits from groundwater aquifers (Berriane, 2002). The climate

99 is semi-arid, with rainfall ranging from 207 to 677 mm per year, for an average of 500 mm/year

100 (data 1980-2010). After a series of dry years, the 1980s marked a drastic reduction of rain-fed

101 crops and the development of irrigated agriculture, mainly vegetables (Quarouch et al. 2014).

102 This increase in irrigated crops (e.g., potato, onions, peach orchards, vineyards), which are also

103 associated with a high use of pesticides and chemical fertilizers (Baccar et al. 2018), has led to

104 the overexploitation of the aquifer (Quarouch et al. 2014). In the process, the groundwater level

105 has dropped as much as 60 m at certain points (Agence de bassin hydraulique du Sebou, 2011).

106

107 2.2. Methodological framework

108 The general methodology followed in this work can be divided into three main steps. Each step

109 was aimed at qualifying one element of resilience, corresponding to the three components

110 suggested by Souissi et al. (2018): 1) characteristics and associated performance of the initial

111 system, 2) shock (from a specified cause), and 3) characteristics and associated performance of

112 the future system (equilibrium after the shock).

113 In each step the involvement of local and national stakeholders is a key issue. We interviewed

114 several farmers and local stakeholders in order to achieve the first step's objectives: to

115 characterize the initial situation (baseline) and the associated challenges and to select

116 representative FTs. The objectives of the second step, achieved through a collective workshop,

117 were to describe the structure and the functioning of the representative FTs, identify the drivers

118 of change in each case, and describe how they would adapt to the selected change in the future

119 scenario. In a second collective workshop, the objective of the third step was to assess the
120 performance of representative FTs, both current and future.

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

126 The identification and the involvement of stakeholders to be a part of this study were achieved
127 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

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

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

157 The drivers to be studied were selected by stakeholders during the first collective workshop (6
158 hours). The project's objectives (future projections for 15 years hence, and the resilience of
159 Saïss farming systems) were introduced during this workshop. We then presented (1) a
160 summary of the SWOT analysis carried out during the individual interviews of stakeholders,
161 (2) a summary of farmers current constraints and projects collected during farmers' interviews,
162 and (3) a proposition of representative FTs to be studied during the workshops. After a short
163 discussion on these three diagnostic factors, we presented and illustrated definitions of the
164 terms, resilience and driver. The list of drivers of change (presented without indicating their
165 variation or type of impact, i.e., positive or negative) was based on a literature review and
166 interviews from the first step. This list included labor force, diseases, market access and
167 commercialization options, water resources, land access, prices of inputs, selling prices, and

168 climate changes. This list was finalized by stakeholders who were asked to individually choose,
169 justify and rank up to three drivers for each representative FT. Based on these choices and
170 rankings, the primary driver was selected for each FT in order to study the resilience and
171 changes in farm performance.

172 During this initial workshop, a phase of collective work was also organized, in order to facilitate
173 both knowledge sharing and dialogue. Groups of stakeholders were invited to characterize the
174 current state (structure, performance) of each FT, and the projection for its future state
175 following a shock instigated by the identified driver. This projected state envisions a new
176 equilibrium, once the changes have occurred. The characterizations were formalized using
177 cognitive maps to describe the overall context of the current, or projected FTs: their
178 environment (e.g., market prices, public policies), their resources (e.g., water, labor), their
179 current (or future) structure (e.g., farm size) and functions (e.g., cultivated cropping systems,
180 farm activities) that condition their current or future performance in terms of indicators such as
181 yield, income, and irrigation water use. The “future” state was projected on a 15-year time
182 horizon, suggested by the research team and validated by the stakeholders as coherent (i.e.,
183 close enough to be realistic, and far enough to be creative). This horizon is considered a good
184 compromise between the evolution of socio-economic conditions which are too uncertain to
185 project beyond 15 years, and the effects of climate change which are hardly visible in less than
186 15 years (Souissi et al. 2018).

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

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

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

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

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

Table 2 approximately here

215 The semi-quantification of certain measures of performance was carried out in two steps. First,
216 stakeholders individually chose the three most relevant indicators of performance for each FT.
217 This had two main objectives: 1) familiarize stakeholders with the research team’s definition

218 of performance, and 2) identify the most critical performance indicators (in terms of strength
219 or weakness for each FT). Stakeholders were then divided into groups (2 groups of 6-7 peoples,
220 each group assessing two FTs) to quantify the eight performance indicators for current and
221 future FTs, together with written explanations. A member of each group presented these results
222 at the end of the workshop. The quantification of each indicator ranged between 1 (very
223 low/poor) to 5 (very high/good). During this quantification step, one group of stakeholders was
224 confused about the written explanation of indicator quantification. Therefore, we present the
225 results of their oral restitution, complemented with discussions from both workshops.
226 Resilience of each FT was qualitatively estimated based on those results: (1) the evolution of
227 the most relevant indicator, (2) the number of indicators with no change, and (3) the sum of the
228 differences between the current and future FT for each indicator (expressed as absolute in order
229 to avoid compensations). We thus obtained three indicators of resilience for each FT.

3. Results

3.1. Characterization of the initial situation

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

1 243 threats mainly came from environmental and economic conditions (e.g., overuse of water, and
2 244 market conditions) (see Appendix 2 for details).
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4 245 Although more regional in perspective, the description of agricultural system issues by local
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7 246 stakeholders was mostly consistent with those of the interviewed farmers (step 1); both of these
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9 247 groups emphasized commercialization and lack of workers as important weaknesses (Appendix
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12 248 2). However, it should be noted that concerns about weaknesses in land ownership and yields
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14 249 at the farm scale, emphasized by local stakeholders, were not highlighted by farmers.
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17 250 Conversely, opportunities such as subsidies to increase drop irrigation, increase fruit
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19 251 plantations, and develop farm structures for storage and transformation, were cited by
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21 252 interviewed farmers, but not by the local stakeholders.
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26 254 During the first workshop the research team presented the farm typology, with four FTs
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29 255 differing in their production, size, proportion of irrigated land, labor and livestock (Table 3).
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31 256 Two FTs are seen as intensive with significant mobilization of inputs (especially irrigation
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34 257 water) and some cattle/sheep farming for the market or household consumption of meat or milk
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36 258 (FT1 and FT4). These two FTs were currently considered as the most profitable. FT2
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39 259 corresponded to a typical extensive farm, which produces dry cereals and livestock, particularly
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41 260 sheep, intended for the market. FT2 was considered by local stakeholders as the less profitable.
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44 261 Finally, FT3 corresponded to a moderately intensive mixed farm growing cash crops and raising
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46 262 sheep for the market.
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48 263 # Table 3 approximately here #
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51 264 52 53 265 3.2. Selection of drivers

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56 266 The individual list of drivers developed by local stakeholders in the first workshop was very
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58 267 diverse, within and between FTs (Appendix 3). These drivers were later considered as possible
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268 shocks for testing system resilience. Those most cited were in line with the threats identified in
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2 269 the interviews (Appendix 3): climate change (FT2 and FT3) and decrease in water resources
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4 270 (especially for FT1 and FT4, and to a lesser extent for FT3), along with the weaknesses of
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7 271 commercialization (all) and labor (especially for FT4—the largest—see Table 3). Based on
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10 272 these individual rankings, one main driver was chosen for each FT: climate change was seen as
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12 273 the main driver of change for FT2 and FT3, access to irrigation water was identified for FT1
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14 274 and FT4.

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18 19 276 3.3. Cognitive maps and future farms

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22 277 In order to identify how the chosen drivers would affect the current FTs, the groups of
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24 278 stakeholders built cognitive maps (together with written explanations) of the farm context
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26 279 (explaining their state) for each FT, in both current and future states. The explaining factors
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29 280 differed between FTs, and between current and future states (Figure 1).

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34 282 Farm Type 1 is specialized in marked gardening and generates high income with highly
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36 283 profitable crops (onions and potatoes), but this income varies with input and market prices
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39 284 (Figure 1A). Intensive practices and short rotations have a negative impact on soils (organic
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41 285 matter), and require significant irrigation, which impacts water resources already subject to
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44 286 inefficient management and irregular rainfall. Poor management of water resources is
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46 287 encouraged by the lack of controls on irrigation, government policies that subsidize its
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49 288 extension (irrigation systems can be fully subsidized in some cases), and the negligible cost of
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51 289 water.

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53 290 The shock for FT1 is a decrease in the availability of groundwater irrigation (i.e., a drop in the
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56 291 water table). This shock would involve large changes in the cropping system, with a reduction
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58 292 of intensive market gardening in favor of more extensive practices and less input for crops such
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293 as cereals, legumes, oilseed, and rain-fed trees (olive and fig trees), and the introduction of
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2 294 drought-tolerant varieties (Figure 1B). Direct sowing would be implemented in order to
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5 295 improve conservation of water and organic matter. Farmers could also add value with crop by-
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7 296 products (straw, pulp). Irrigation would decline from 75% of the surface area to only 45% (due
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10 297 to the reduction in market gardening; Table 3). Farmers would have acquired the knowledge
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12 298 needed to control irrigation (inspired by new technologies).
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17 300 Farm Type 2 only grows rainfed cereals which demand few resources (labor, inputs).
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19 301 Government policies providing subsidies for insurance, seeds and equipment have a positive
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21
22 302 impact on these farms. Difficult access to adapted seeds, appropriate phytosanitary products
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24 303 and their high prices have a direct negative impact on their production. The FT2 farms must
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27 304 endure constraints related to storage of agricultural products and commercialization
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29 305 (intermediaries, selling prices, etc.) which can also impact them negatively (Figure 1C).
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32 306 The shock for FT2 is climate change characterized by varying amounts of rainfall
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34 307 (droughts/excessive water) during the year and between years. Climate change would have a
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37 308 direct impact on farms, as grain yields are driven primarily by rainfall. Droughts resulting from
38
39 309 climate change would also have a negative impact on livestock feed (less straw), requiring
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41 310 farms to purchase supplementary feed. Nevertheless, the government might try to maintain
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44 311 livestock production in the region by initiating new policies (livestock and milk subsidies,
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46 312 supplementary feed subsidies). Therefore, two options for FT2 farms were envisioned for the
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48
49 313 future (Figure 1B): (1) specialization towards subsidized livestock, and (2) system
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51 314 diversification with rain-fed arboriculture (arbutus, olive, almond, fig tree) and
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53 315 cereals/legumes/oilseed crop rotations (Table 3). The availability of more efficient
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56 316 phytosanitary treatments and the adoption of new practices (such as direct sowing) would help
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1 317 tackle the challenges of climate change. However, without access to the financing needed to
2 318 transform their system, some farmers might abandon agriculture.

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7 320 # Figure 1 approximately here#

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11 322 Farm Type 3 corresponds to family farming with less access to markets. The government
12 323 strategies seek to overcome related issues: (1) facilitate marketing for farmers (help reduce the
13
14 324 number of intermediaries and find new markets), (2) strengthen production capacity through
15
16 325 collective purchases of materials and organization of shared use), (3) help farmers with
17 326 decision-making (adoption of best practices), and (4) facilitate dialogue between farmers and
18
19 327 members of the agricultural sector, and strengthen professional organizations (Figure 1E).

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21 328 Although the government tries to structure the market with mechanisms such as contracts and
22 329 labelling, the liberalization of agricultural markets has negative consequences for FT3: selling
23
24 330 prices are low and unstable (mainly for market gardening), thus limiting the valorization of
25
26 331 farm products.

27
28 332 In the case of FT3, the shock of climate change (characterized by rising temperatures, a decrease
29 333 and variability in rainfall, a shorter crop cycle and shifting cultivation areas) may affect farms
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31 334 in a number of ways, including a decline in production that would lead to lower revenue (Figure
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33 335 1F). In the projected future state, government policies would have a positive impact by
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35 336 buffering the effects of climate change through a reorientation of strategies (adopting best
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37 337 practices and reducing investment for adverse projects) and the strengthening of the multi-risk
38
39 338 climate insurance system introduced in 2011. Professional organizations could make farmers
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41 339 aware of the consequences of climate change, and enable them to better adapt and gain access
42
43 340 to new technologies (irrigation, mechanization). The main response to climate change would
44
45 341 be the introduction of the rustic tree crops to the current cropping system (Table 3).

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2 343 For FT4, the expansion of irrigated areas has a positive impact on farm income, enabling
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4 344 cultivation of arboreal species that have high added value (Figure 1G). But current policies
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7 345 funding the installation of new boreholes have a direct negative impact on water resources. This
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9 346 policy favors less labor-intensive drip irrigation, leading to a decrease in hired labor, but at the
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11 347 same time, the extension of cultivated land increases the demand for labor. The potential lack
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13 348 of product valorization (refrigerated storage or sorting) has a negative impact on marketing and
14
15 349 subsequently on farmers' income. Thus, the potential benefit of increased production is
16
17 350 countered by lower prices and storage difficulties.

18
19 351 Like FT1, the shock for FT4 is the decline in groundwater resources, leading to a decrease in
20
21 352 irrigated areas and impacting rotations. In the projected future, rustic arboriculture species
22
23 353 (olive, almond) would replace some rosaceous species, and some market gardening areas would
24
25 354 convert to cereals and legumes (Table 3). The sector would experience an evolution in fruit
26
27 355 quality and traceability, and new market policies would be initiated to achieve better
28
29 356 organization of sales and product valorization. Production area would be less extensive (partly
30
31 357 compensated by increased yields through better technical management) but superior in quality:
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33 358 farmers would maintain a good income even if production decreases (Figure 1H).

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35 359
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37 360 All FTs would diversify their crops (Table 3). Some would largely change orientation, such as
38
39 361 FT1 that would reduce the practice market-gardening. FT2 would diversify (legumes,
40
41 362 arboriculture), but remain rainfed. Rainfed legumes and arboriculture would be grown on all
42
43 363 farm types, even on FT4 where the tree cultivation would be divided between rosacea and rustic
44
45 364 species. The irrigated areas would not exceed half of the total agricultural area, and livestock
46
47 365 would not evolve over time.

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367 3.4. Performance of FTs and projected resilience

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2 368 In the second workshop the participants quantitatively assessed the eight types of performance
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4 369 of current and future FTs, as determined with cognitive maps (Figure 1) and associated
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7 370 characterization (Table 3).

8
9 371 FT4 shows the best performance (high yields, high income, landowner, and supported by
10
11 372 government policies) both now and in the future (Figure 2). Family assets is the only indicator
12
13 373 seen as low, because this FT has few livestock. The Political, Irrigation and Marketing
14
15 374 indicators were considered average for the current situation, but they all increased in the future,
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17 375 with improved policy support, better irrigation practices, and better marketing, when compared
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19 376 to the current situation. For this FT4, the participants foresee an improvement in irrigation
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21 377 management, product quality and selling price.

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23
24 378 For FT1 and FT3, only four indicators vary between the current and future situation. For both
25
26 379 types, the four changing indicators tend to reflect declining performance. For FT1, these four
27
28 380 indicators are Land, Family assets, Farmers' income, and Yields. The land indicator is
29
30 381 deteriorating due to land fragmentation. Yield would decrease because of climate change.
31
32 382 Farmers assets and farm income would decrease due to lower yields and less-profitable crops.
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34 383 For FT3, the four indicators are Income, Labor, Irrigation, and Policies. The fall in income
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36 384 would be due to the expected increase in production costs (phytosanitary products, water and
37
38 385 labor). The Labor indicator would decrease because of a decline in the availability of family
39
40 386 labor (rural exodus), generating additional costs for farms.

41
42 387 Fifteen years from now, FT2 (Figure 2), like FT1 and FT3, would anticipate lower performance
43
44 388 than today. Nevertheless, participants expected policies to continue to accompany FT2 through
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46 389 subsidized equipment.

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48 390 The performance indicator judged as the most important/critical remained stable for each FT
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50 391 (boxed performance indicator in Figure 2; Appendix 4), which would argue for their resilience.
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392 Looking at all performance indicators, FT4 is the only type for which they all would increase.
393 It is also the FT with the lowest overall change between current and future performance
394 indicators. Finally, FT1 and FT3 show four stable indicators of performance; FT2 and FT4
395 show three. While all FTs remained the same size (Table 3), most changed their crop strategies,
396 lowered their use of water resources (except for FT2 that is rain-fed only) and increased or
397 maintained hired labor (Table 3).

Figure 2 approximately here

4. Discussion

401 Based on our assessments of resilience, all FTs would be relatively resilient to the main driver
402 of change chosen by stakeholders (either climate change or decrease in availability of
403 irrigation). They would notably adapt to the future through diversification, re-introducing
404 rainfed crops and rustic species (especially among trees). Rainfed legumes would be included
405 in all FTs, contrary to the current situation on most farms. These modifications would be the
406 main adaptation to the increasing scarcity of water, either due to lack of water for irrigation, or
407 to climate change. Several previous studies have highlighted crop diversification as key to
408 improved resilience of farm structure and functions (Reidsma et al. 2009; Baccar et al. 2018).
409 Diversification was seen as a way of spreading the risk and compensating for eventual losses.
410 But the participants of our study saw diversification as being limited to cropping systems, thus
411 excluding both livestock production and off-farm activities. In the first workshop, although feed
412 was highlighted as a possible future issue, the absence of participants or FTs specialized in
413 livestock may have biased the results. In the FTs characterized, the modest number of livestock
414 were seen more as a savings account than as a means of producing regular income (thus
415 differing from the results of Baccar et al. 2018). This perspective was consistent; only one out
416 of the 21 farmers interviewed projected to increase his herd. Off-farm activities, cited by one

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417 farmer, were considered out of the scope by most participants, who felt they could not evaluate
418 the opportunities or impacts, such as labor. By contrast, Lallau and Thibault (2005) highlighted
419 this extra-income as a crucial part of the farmer’s strategy to build farm resilience. This factor
420 would require further study to assess the feasibility and willingness of farmers, as well as the
421 local opportunities for off-farm activities, and their impacts on the farm (e.g. seasonal labor).
422 Farm adaptation in Mediterranean irrigated agriculture inventoried by Harmanny and Malek
423 (2019) included strategies for changes in water management (irrigation techniques), other
424 technological developments (mechanization), and farm production practices (crop choices), but
425 few changes in sustainable resource management (e.g., groundcover to reduce erosion, use of
426 cover crop, etc.) or farm management (e.g., financial and administrative practices). In our study,
427 adaptation through changes in farm production practices was dominant and transversal to all
428 FTs; this is consistent with findings of Harmanny and Malek (2019) who found it to be the most
429 frequent adaptation in the Mediterranean area.
430
431 The only FT showing overall better performance in the future than in the current situation is
432 FT4 (primarily arboreal). This could be due to the multi-variable indicators that were adopted
433 in this study. For instance, while yields would decrease, their quality and price would increase,
434 possibly even leading to higher global income. Although dependent on the current and future
435 state of irrigation, this type of farm is in a better position to adapt due to its initial capital, and
436 the assistance provided by government policies. The government’s agricultural policies were
437 very often cited by the study participants as influencing or conditioning current and possibly
438 future systems and practices. This could be linked to the anticipated renewal of the “Green
439 Morocco Plan”, launched in 2008 with two goals: develop a modern, productivity-oriented
440 agriculture with investors, and ensure solidarity-based support for small farms as a means of
441 alleviating poverty through increased agricultural income (Marzin et al. 2017).

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

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463 In this study we evaluated resilience in a simple way in order to stimulate stakeholders' thinking
464 and knowledge sharing when projecting future farming conditions that anticipate the potential
465 negative effects of climate change (Giorgi and Lionello, 2008). This led to three major limits.
466 The first is the compensation seen in the projected evolution of the various chosen indicators

1 467 of performance. For example, with FT4 the projected decrease in cultivated area would be
2 468 compensated by an increase in yield. Tracking those compensations through storylines in the
3
4 469 cognitive maps allowed us to highlight the differences between current and future states.
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7 470 Second, we distinguished key resilience characteristics related to robustness, adaptability, and
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9 471 transformability (Meuwissen et al. 2019). Our adoption of the scale of FTs was an advantage.
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12 472 It allowed us to distinguish each FT's specific challenges together with the management of a
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14 473 shock characterized by the chosen driver (climate change or water table decrease). Thus,
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17 474 specified and general resilience, as defined by Meuwissen et al. (2019), were combined with
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19 475 future options corresponding to current structures. Third, although the future can be shaped by
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22 476 stress and shocks from interacting social, economic, institutional and environmental factors
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24 477 (Meuwissen et al. 2019), we limited the assessment to one shock. Even though all the adaptation
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26 478 strategies included legumes, adaptation would also depend on other factors such as selling price
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29 479 or changes in the market. Those different types of drivers were cited by local stakeholders and
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32 480 have been highlighted in previous studies concerning the same region (Baccar et al. 2017), but
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34 481 our method was not designed to combine several drivers of change for an overall assessment.
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39 483 Finally, a key point we did not consider is the transition, questioning in detail the adaptive
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41 484 capacities and learning processes of farmers. Adaptation capacities can be assessed using the
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43 485 adaptive capacity index (Swanson et al. 2007) to consider six determinants: economic
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46 486 resources, technology, information and skills, infrastructure, institutions, and equity (Smit et al.
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49 487 2001). Using this index, Grasso and Feola (2012) assessed the adaptive capacity in different
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51 488 areas of the Mediterranean. They concluded that Morocco exhibited a low adaptive capacity,
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53 489 performing poorly on all six determinants when compared to other countries. This differs from
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56 490 the relatively stable performances projected by our study's stakeholders in their assessment of
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58 491 the future, which viewed farmers as being able to adapt. This could be due to the different
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492 performance indicators assessed in Grasso and Feola (2012), but it could also be linked to the
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2 493 scale. Their study was on national scale, whereas we focused on a small region. Our region of
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4 494 study might be less vulnerable than others, such as those close to the sea with salinity issues
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7 495 (Faysse et al. 2014). This highlights the potential effects of both scaling down and focusing on
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10 496 indicators of performance that have specific importance to local stakeholders.

11 12 497 13 14 498 5. Conclusion

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17 499 This study focused on small and medium farms, and participants in the study showed that these
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19 500 farms had the capacity to adapt. This was an expression of strong resilience. However, we did
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21
22 501 not fully examine all dimensions of resilience. To complement our study, it would be useful to
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24 502 make a complete diagnosis of the vulnerabilities, risks, and adaptation capacity. Although all
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26
27 503 these dimensions were present in our methods and results, they were highly integrated and
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29 504 cannot be evaluated as individual components. Another possibility would be to enlarge our
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32 505 study by including large farms. Although their number is limited, they exert significant pressure
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34 506 on (water) resources through intensive agriculture, such as orchard farming or market
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36 507 gardening. Diagnosing the regional resilience would require integrating all types of farms and
37
38
39 508 other sectors, which would implicate a wider arena including livestock experts, and related
40
41 509 industries.

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50
51
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55
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57 515 current and possible future state of agricultural in this highly vulnerable region.

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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	<i>Agricultural school and research</i>	national	0	2	2	2	0	0
	<i>Cooperative</i>	regional	0	2	1	1	0	0
	<i>Private operators</i>	regional	0	5	0	0	0	0
	<i>Producers association</i>	national	0	1	1	1	0	0
		regional	0	4	1	1	0	0
		local	0	1	1	1	0	0
	<i>Public administration (subsidies, statistics)</i>	local	2	2	1	1	2	2
	<i>Public administration - water management</i>	regional	1	1	1	1	0	0
	<i>Public advisory services</i>	regional	2	5	10	5	5	3
		local	0	1	4	1	1	1
	<i>Public popularization service</i>	regional	0	1	1	1	0	0
	<i>Public services for food safety</i>	national	1	1	0	0	0	0
	<i>Research institute</i>	regional	0	1	3	1	4	1
Total external participants			6		26	16	12	7
Internal research team	<i>Agronomy</i>				2	2	2	2
	<i>Economics and public management</i>				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	Indicators of natural, social and financial capital	Soussi et al. 2018
Income: prices of inputs and their variation, products type, price and price variation		
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

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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

Farm type	Current situation					Future situation				
	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	5	75	Family + hired	Bovine: 2-3 Ovine: ~ 5	45 % Market gardening	5	45	Family	Bovine: 2-3 Ovine: ~ 5
	10 % Cereals					55 % Cereals, legumes, arboriculture, oleaginous				
Type 2	100% Cereals	5	0	Family + hired	Bovine: 2-3 Ovine: ~ 10	70% Cereals and legumes	5	0	Family (↓) + hired (↑)	Bovine: 2-3 Ovine: ~ 10
Type 3	50 % Cereals	5	20	Family only	Bovine: 3-4 Ovine: ~ 11	30% rustic arboriculture	5	10	Family + hired	Bovine: 2-3 Ovine: ~ 11
	40% Legumes					50 % Cereals				
Type 4	10% Market gardening	10-15	60	Family + hired	Bovine: 2-10	25% rustic arboriculture	10-15	45	Hired	Bovine: 2-10
	50 % Fruit trees					5% Market gardening				
	35 % Market gardening					50 % arboriculture (25% rustic; 25% <i>Rosaceae</i>)				
	15% Cereals					20% Market gardening				
						30% Cereals and legumes				

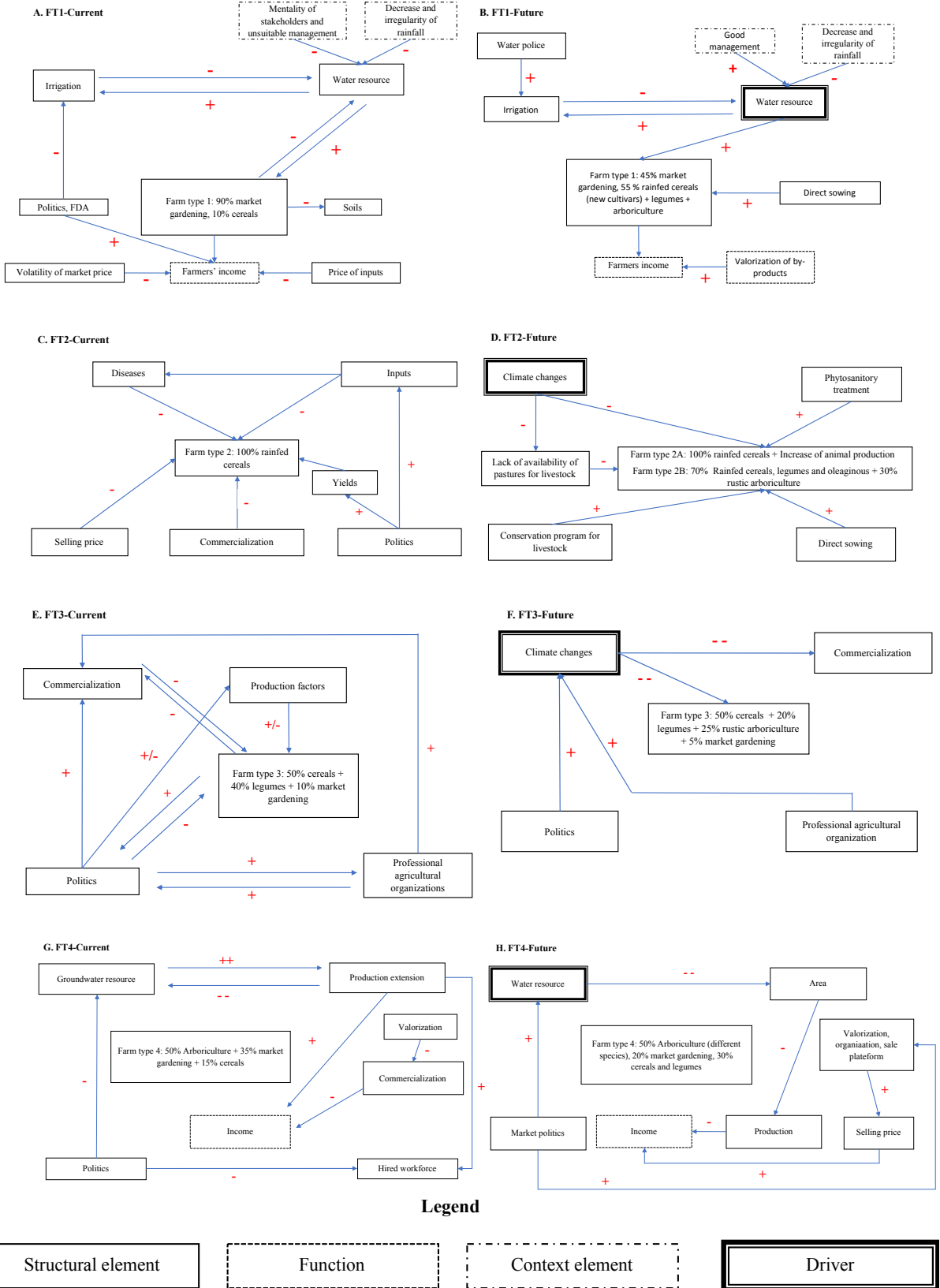
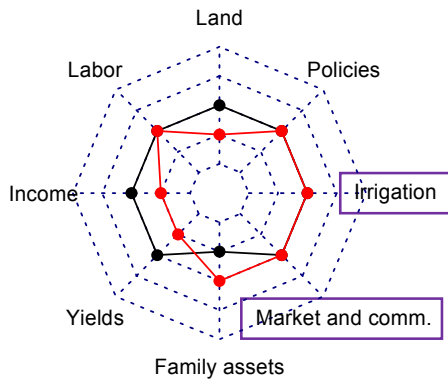


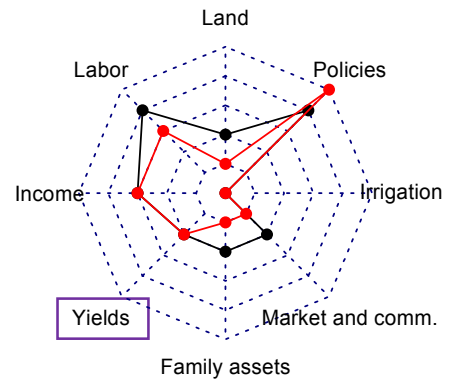
Figure 1. Mental models built by stakeholders for the current (A, C, E, G) and future (B, D, E, H) states of the four farm types (FT1 in A-B, FT2 in C-D, FT3 in E-F, and FT4 in G-H).

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A. Farm Type 1

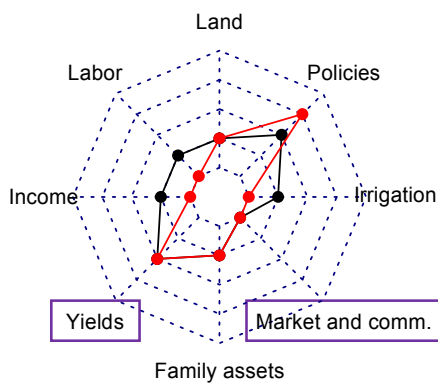


B. Farm Type 2

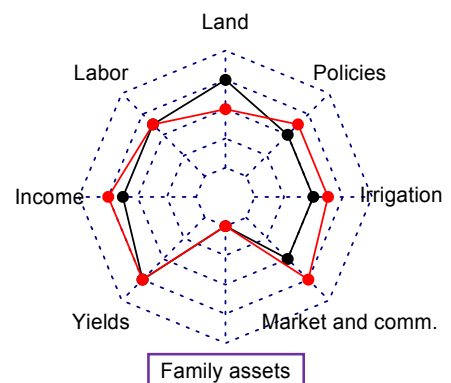


● Current performances
● Future performances

C. Farm Type 3



D. Farm Type 4



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