The dynamic of crop-livestock systems in the Mediterranean and future prospective at local level: A comparative analysis for South and North Mediterranean systems

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Abstract

Mediterranean livestock farming systems have evolved to adapt to current and future pressures, including strong demographic growth and urbanization in the coastal zone, greater competition for land and water, and a big shift in the hinterland where farming activities are hardly maintained. We aim to explore future pathways for integrated crop-livestock systems in South and North Mediterranean countries to identify potential sustainable increases in efficiency and adaptability of resource utilization. The research was conducted in three countries, Egypt, France and Morocco, through case studies in a gradient of socio-ecological contexts, from favourable (plains and irrigated lands) to harsher ones (mountains, rain-fed areas). We mobilized farm surveys and monitoring, open-ended interviews, databases and previous studies. Based on a transversal analysis at the local level, we identified two main trends and five archetypical systems: (1) a centrifugal trend of specialization, towards cash crops or dairy herds in favourable areas, and pastoral system for meat production in harsher environments, and (2) a centripetal trend of diversification based on mixed crop-livestock systems in irrigation areas and agro-pastoral livestock-crop systems in intermediate rain-fed areas. The analysis showed an overwhelming antagonism between social vulnerability and ecological efficiency. Crop and livestock integration reduced the risk of biodiversity loss and low environmental efficiency observed in specialized systems, but mixed systems were more socially vulnerable. Those results call for dedicated rural development policies that favor the diversification as a lever of sustainable development but taking into account the land fragmentation and developing higher value added products chains. Taking advantage of spatial mobility abilities of livestock farming at the regional level, promoting collective actions must be encouraged to allow a wider range of livestock farmers in the hinterlands to live from their activities.

Keywords: adaptive capacity; development pathways; efficiency; livestock systems; Mediterranean

1. Introduction

Over the last several decades, the Mediterranean agriculture systems have faced increasing pressures that include strong demographic growth, urbanization, increasing demand for animal products (especially in southern regions), a demand for safer animal products, and high competition for land and water. In this context, pressure on biomass to feed animals raises many challenges and sometimes competition in the trade-offs of the use of resources (land, water, and nutrients) that can affect the sustainable development of these systems (Dixon et al., 2010). Meanwhile, the synergies between cropping and livestock husbandry offer many opportunities for a sustainable increase in production, notably by raising productivity and improving resource use efficiency for both households and territories (Herrero, 2010). For example, Sraïri *et al.* (2011) showed that feeding system and agricultural practices improve water use efficiency in the crop-livestock systems in Morocco. Livestock activities are also recognized for their multiple roles in reducing vulnerability in fragile environments (Ashley, 1999; Alary *et al.*, 2015; 2018) and their roles in diversification and intensification (Duteurtre and Faye, 2009). However, the main recent scientific assessments (IAASTD, 2009; IPCC, 2007) provide evidence of the difficulties of capturing the complex biological, social, and economic dynamics of the challenges likely to confront future crop and livestock production and their integration.

All over the world and especially in the Mediterranean basin, livestock farming systems have experienced important changes due to the extension of irrigation schemes and the social and political changes that have affected livestock management (settlement, mobility, and transhumance), land tenure and land use, and the sustainability of whole production systems. Although the South Mediterranean countries show an increasing demand for animal products that is linked to the demographic growth and emergence of a medium social class, North Mediterranean countries are experiencing a stagnating consumption of animal products of local origin (especially sheep meat). Over the last two decades, the

North Mediterranean trends have been more driven by the public agricultural policies at the production level and, more recently, by the new environmental preoccupations embedded in the new supports (e.g., European agro-environmental measurements - AEM -).These trends endanger ecological equilibrium and socio-economic viability in these zones: the intensification in the South raises the question of the sustainable use of natural resources (soil and water), and the agricultural decline trend in the North threatens landscapes, biodiversity, and the social life in its hinterlands.

Finally, important cultural food changes linked to urban expansion and new life conditions are observed, as is increasing demand for "safe" and "ecological" or even organic products. These dynamics constitute new opportunities for agro-ecological systems in the Mediterranean zone, with potential pathways for livestock development. More generally, livestock has always played an important role in adding value to the resources in these environments, but high competition in animal products at the international level reduces profitability, while land access and comparative valorisation prospects at the regional level threaten the social and environmental sustainability of these systems and their future. This highlights future challenges concerning the efficiency of these systems and their contribution to food security.

In this direction, one of the key elements for developing a sustainable crop-livestock system is to promote intensification methods to produce more food using less land, water, and other resources (Matson *et al.*, 1997). This concept that integrates ecological and economic efficiency was highlighted at Earth Summit 1992 by the World Business Council for Sustainable Development (WBCSD), as reviewed by Camarero *et al.* (2013). OECD (2000) has called eco-efficiency the efficiency with which ecological resources are used to meet human needs. It is approached by a ratio of an output (i.e., the value of products and services produced) divided by the input used (that measure the environmental pressures). This ratio can be assessed at different scales, from the firm to a sector, or even a local economy. From the end of the 2000s, the concept of ecological intensification focused more on sustainable processes in agriculture. Ecological intensification is achieved by considering the functioning and dynamic of ecosystems, the

76 profitability and feasibility of technical options, and the social and technical viability of the new practices
77 in liaison with the social and environmental system (CIRAD, 2010). This integrates the interactions
78 between the actors, their activities, the environment and society. However, farm systems in the
79 Mediterranean are diverse in their links with the socio-ecological environments. The Mediterranean
80 livestock farming systems need therefore to adapt multiple and complex changes related to the recent
81 history of the area and the predicted events in the near future (climate change, urbanization). This led us to
82 pay special attention to the third pillar of sustainability, i.e., social sustainability, and address it, crossing
83 ecological intensification with more integrative concepts: adaptive capacity and vulnerability. .
84 The overall objective of the paper is to increase the understanding of consistencies of crop-
85 livestock integration systems in three Mediterranean contexts (Egypt, France and Morocco) using
86 databases and published data. The final goal is to help farmers, local communities, researchers and
87 decision-markers in planning for Mediterranean livestock and designing priorities, rules, and policies that
88 could better deal with the socio-environmental issues linked to demographic and land pressure, increasing
89 demand and strong international competition.
90
91 **2. Methodology and materials**
92
93 Understanding the consistencies of crop-livestock integration systems in three Mediterranean
94 contexts (Egypt, France and Morocco) necessitated gathering and integrating information regarding the
95 socio-economic environment and the agronomic practices along with the available resources in each
96 location. However, each country is diverse. As a first step, we identified geographical and social locations
97 that reflect that diversity, from the agro-pastoral zones to the more intensified zones (Figure 1). This
98 identification was based on the expert knowledge of the research teams in each country, supported by a
99 review of the literature. This preliminary study allowed selecting different case studies in each country. In
100 the south of France, the gradient expanded from the mountainous hinterlands of the region of Provence

101 Alpes-Côte d'Azur (PACA) to the plains and Piedmonts of the coastal zones in the Languedoc and
102 Roussillon regions that knew significant changes in links with the development of irrigation in the 1970s,
103 the demographic pressures, the tourism development and the agricultural policies (Figure 1a). In Egypt, we
104 selected a transect from the agro-pastoral systems of the North West Coastal zone to the New Reclaimed
105 Lands (NRLs) in the western part of the Delta (Figure 2b). These NRLs are part of the national Egyptian
106 strategy to increase agricultural production to enhance its food security. In Morocco, we opted for a long
107 transect from the south side of Haut-Atlas (pastoral mobility) to the plain of Gharb (drip irrigation
108 associated with maize silage and fodder production) (Figure 2c). Due to the characteristics of each country,
109 the transects ranged from semi-arid or mountain systems in the less favourable zones to irrigation systems
110 in the more favourable zones.

111

112 [INSERT FIGURE 1]

113

114 Data collection methods were based on several field and multiscale approaches, including the agrarian
115 diagnosis at the territorial level (France, Morocco), bi-monthly or seasonal follow-ups at the livestock
116 system level (Morocco, Egypt), and family farm surveys to identify livestock changes in the family's story
117 and its environment (Egypt). We used qualitative and quantitative data collection systems based on semi-
118 structured questionnaires, guided interviews, or open discussions in participatory approaches (Table 1).

119

120 [Insert Table 1]

121

122 The analysis of the systems aimed at producing and integrating the technical, economic, and environmental
123 parameters to assess the economic and environmental efficiency of integrated crop-livestock system along
124 the defined geographical transect of intensification. This assessment has mobilized different methods and
125 tools. For Morocco and Egypt, a series of indicators related to family (labour constraints, per capita

126 income), feed system (feed availability, feed autonomy), crop-livestock interaction (N management) and
127 animal performances (milk production, animal transactions, expenses related to animal production) have
128 been estimated based on declarative farm surveys. They resulted from the annual follow-up of 14 farmers
129 in the plain of Gharb (Morocco) and a farm survey (175 farms) in West Delta (Egypt). In France, we used
130 previous studies of sheep farms in the Mediterranean area (Bataille *et al.*, 2016) to assess the services
131 provided at the territorial level by a combination of specialized of mixed crop-livestock types (Lurette et
132 al., 2017).

133 The evaluation of eco-efficiency has been crossed with the concepts of adaptive capacity based on
134 the trajectory of change (McAllister *et al.*, 2006; Ploeg, 1994) and the concept of vulnerability based on
135 the livelihood framework (Ellis, 2000). In the approach of adaptive capacity of a system by McAllister *et*
136 *al.* (2006), the questions of the future of the systems are based more on their ability to co-evolve the
137 different components of the system than to control the dynamics of each component. Ploeg (1994)
138 underscores the importance of assessing the livestock activities in their capacities to change with the local
139 perceptions and expectations of the population on these activities. This approach favours an analysis of the
140 collective capacities to contribute to a project that itself evolves dynamically, i.e., the collective capacity
141 for innovation and diversity of systems and contribution of socio-technical networks (Darre, 1999; Ploeg,
142 2004; Renting and Ploeg, 2011). However, we suppose that this capacity is combined with the tangible and
143 intangible assets of each individual in the collective that will influence its capacity to act collectively. For
144 that, we used Ellis' (2000) livelihood framework. Based on these hypotheses and a literature review, we
145 have selected eight major drivers of a farming system's strengths or weaknesses that may impact the
146 pathways towards sustainability (presented in Table 2).

147

148 [Insert table 2]

149

Finally, from the three case studies, we identified major farming systems, based on to the main trends of specialization—diversification towards crop or livestock activities. Then, from the various previous results at farm or territorial levels, we synthetized the strengths and weaknesses of those farming systems towards sustainability.

3. Results

3.1. From complex realities towards a typology of farming systems

To understand the whole system, we elaborated a typology of the modalities of crop-livestock integration in each case study. Six farm types have been identified and described in the New Reclaimed Lands of West Delta (Egypt) according to a gradient of specialization or diversification and a gradient of capital assets (mainly based on land access) (Alary *et al.*, 2016a). This classification identified two main trends of specialization or diversification according to the educational level of the family's head. On the one hand, we identify the groups of 'graduated' farmers; these two groups have accessed to five feddans (around 2 ha as 1 feddan = 0.42 ha) of land according to the Moubarak settlement scheme set up in the 1980s, and they followed a specialization path towards establishing tree plantation. In the other hand, the groups of traditional farmers have maintained, integrated and diversified crop-livestock systems, as compared to the old lands of the Nile Valley and Delta. In the traditional groups, we can identify different groups according to cultivated land size, from the smallest ones with only one ha land and one to two dairy animals to largest ones with around 5 to 10 ha and 15 to 20 dairy animals in the sample.

In the French Mediterranean region, livestock is a specialized activity at the farm and territorial scale. In the mountainous region of PACA, we estimated that only 6% of the farmland of livestock farms

were not directly dedicated to forage cropping or grazing, and two-thirds of these are cereal crops, among which a large part is devoted to livestock feeding. This specialization is illustrated by an agrarian diagnostic at the local level based on open-ended interviews and mapping analysis of agricultural census data (Prud'hon, 2016). Raising livestock, especially sheep farming, is the main activity in the hinterlands, taking advantages of summer pasture availability and relying of a mix of forage and cereal crops in the upper valley for sheep and cattle farming. This specialization of wide areas is historically based on exclusions promoted by the opportunity for extensions of high-value productions (vineyards, orchards in lowlands). Extension of irrigation infrastructure on a large scale (cereals and orchards in large valleys), chemical farming that reduces interest for crop-livestock integration over the last 50 years, and specific financial support for livestock in mountain areas have reinforced this. However, this spatial trend of spatial dissociation for farming activities is actually being questioned, and we can notice some inflexions. We can observe new agreements between specialized livestock farmers and crop farmers for extending organic farming, agreements sometimes favoured by new incentives of European policies. This led to new opportunities to reintroduce livestock in specialized cropping systems thanks to regional livestock mobility.

In the Gharb Plain (Morocco), based on different weights of livestock in the farming systems, and considering particularly income generation, land occupation and work time mobilization, we identified three types of farms: the livestock-oriented farms towards dairy production, the market horticultural-oriented farms, and the traditional mixed crop-livestock farms.

The specific approach of the farming systems and the various roles of livestock in each location reveal contrasting situations between North and South Mediterranean countries regarding the angle of approach (farm to regional approach) and between case studies regarding the indicators of differentiation. While specialization processes are dominant in France, we observe two different factors of differentiation of mixed crop-livestock systems in the south countries. Land access and land availability are the more

199 constraining factors in Egypt that affects the livestock dynamics and the farming systems, although labour
200 productivity becomes a critical trending factor of the systems in Morocco.
201
202 *3.2. Efficiency and sustainability evaluation at the farm and territorial level*
203
204 As mentioned in the methods section, the eco-efficiency assessment analysis of the systems has
205 been based on technical, economic, and environmental parameters calculated in each case study. Even if
206 the indicators are not identical for the three case studies, they allowed characterizing the global efficiency
207 and outcome of crop-livestock integration for each case study.
208 In Morocco, the results show clearly the weight of the feed availability constraints, especially in
209 the dry season, with a hard daily routine for dairy activities (Table 3). Due to constraints related to feed
210 availability, the feed costs reach around 66% and 75% of the milk price, respectively, in rainy and dry
211 seasons. The hard daily routine in the livestock systems is not compensated by high yield or market price;
212 this explains low labour productivity (two times less than in crop and crop-livestock systems). However, in
213 this approach, we neglect the non-economic roles like organic fertilization and the role of livestock in
214 terms of diversification and risk management (Sraïri *et al.,* 2014; Sraïri and Ghabiyel, 2017).
215
216 [Insert tables 3]
217
218 In Egypt, a set of technical economic and environmental parameters has been estimated for the six
219 farm types (Table 4). The table shows clearly, for all farm types, the significant contribution of organic
220 manure in nitrogen management, representing around 46% of the total nitrogen input in 2013/14.
221 However, this organic matter aims mainly to constitute the soil subtract in these desert lands for
222 cultivation. As soon as the soil became productive, we observed a reduction or abandonment of livestock
223 in the farm systems, especially in the tree specialized systems (G5 and G6). This category continued to

224 enrich the soil with poultry droppings purchased from semi-intensive poultry farms. This tree
225 specialization served as a model for traditional farms that converted progressively part of their land to
226 plantations in 2014 as a strategy of market diversification. The biomass constitution and preservation are
227 key-factors of the sustainability of this system in desert environments. Contrariwise, the economic
228 parameters revealed a contrasting profile of roles of livestock according to the farm specialization or
229 degree of diversification. Firstly, the large mixed system oriented to dairy (G4) generated the highest
230 economic outcome per family workforce or per land unit, followed by the tree specialization system. These
231 tree systems were not yet stable in the zone due to recent planting, which explained the limited fruit yield
232 for new planters. However, these economic indicators reveal the social and economic vulnerability of
233 integrated small-scale systems compared to specialized ones.
234
235 [Insert Table 4]
236
237 In France, analyses of agrarian dynamics at the local level showed that the productivity of labour
238 and land were also two major drivers explaining the specialization of the farms towards crops or towards
239 livestock (Thomas, 2014; Aubron *et al.,* 2016). The main stake concerned environmental issues about the
240 use of rangelands and maintenance of open landscapes in the hinterlands. We analysed the services
241 provided by the farms in an area of the *Préalpes*, combining crop or livestock specialized farms and mixed
242 farms. We modelled scenarios with a complete specialization of farms (abandonment of livestock in mixed
243 farms) or diversification (livestock activities in crop-specialized farms). We showed (Lurette *et al.,* 2017)
244 that the current situation maximized the number of farms in the territory. On the one hand, crop
245 specialization decreased the total number of workers (-18%), with a slight increase of the income per
246 worker (+3%), and led to an abandonment of 50% of the rangelands used in the current situation. On the
247 other hand, the diversification with livestock enabled maintaining the amount of cereal production,
248 increased meat production (+24%) and use of rangelands (+44%). The current trade-offs enabled

maximizing the number of farms and workers with a good level of the average income per worker (rural vitality), but at the expense of the use of rangelands (environmental issues). This analysis showed the interest in a diversity of farms in a territory, but also the difficulty to maximize all the services in a bundle (Dumont *et al.,* 2017).

3.3. Assessment of the adaptive capacity to changes based on social arrangements

Despite this trend of apparent dissociation of crop and livestock activities at the farm level, especially for cash crops and dairy specialized systems, a dynamic of relationships between specialized farms and mixed crop-livestock farms can be identified at various spatial scales in the three countries. Specialized crop farms provide opportunities to access to feed resources (mainly crop by-products, such as cereal straw, bran, stubble and weeds from fruit tree plots) for livestock farms, and the livestock farms provide opportunities to valorise biomass and products available on crop farms. The mobility of herds is a key factor to reconnecting crops and livestock. This analysis was mainly developed in the less favourable zones in each case study.

For example, in France, sheep farming in the Mediterranean areas previously relied on forage resources combined from contrasted components of the landscape (*Sylva, Saltus* and *Ager*), and mixed farming was the pivot. We identified new trends in crop-livestock integration mostly based on relationships between farmers, sometimes spatially distant. Crop and livestock integration is now at stake at the territory level to increase feed autonomy, efficiency in resource consumption and adaptation to global change. Collective action is an effective tool to reinforce integration. This research relied on comprehensive interviews with stakeholders to identify socio-technical networks, involvement of livestock farmers in crop-livestock integration initiatives, and consequences on livestock farms and practices. A multitude of actors involved in these initiatives (local policy-makers, environmental and/or inhabitant associations, landowners) had to gather with livestock and crop farmers, thus underscoring the importance

274 of negotiations. From these collective interviews, we identified three ways to foster crop-livestock
275 integration at the territorial level: *i*) vicinity grazing on cash crop fields based on traditional neighbourhood
276 relationship; *ii*) distant winter grazing based on bilateral agreements between livestock farmers and
277 vineyard growers; and *iii*) distant forage cropping on vineyard wasteland in suburban plains (Mohamed
278 M., 2015).
279 The cross analysis of these spatial organizations with the social arrangements allowed defining the
280 different roles of social, spatial and temporal coordination in the systems' adaptive process along an agro-
281 ecological gradient of integration (Table 5).
282
283 [Insert table 5]
284
285 In the Haut-Atlas (Morocco), the analysis of the territorial system based on the characterization of
286 the transhumance systems and the interactions of the different systems (pastoral, agro-pastoral, oasis
287 systems) linked with the spatial and social organization reveals the specific roles formerly defined by the
288 users in territorial resource management. The results show clearly that the viability of the pastoral system
289 has reached its limits due to ecological constraints. Farmers have become obliged to leave their territory
290 during winter because of lack of resources due to pastoral pressure. This individual regulation is possible
291 for medium and large flocks, but difficult for small herders. Moreover, this alternative is fragile and starts
292 to provoke social conflicts with neighbouring territories. In this context, collective regulation of
293 pastureland access appears to be a condition to maintain the social territorial unity (mainly between small
294 and large flocks) and ecological resources. This requires new forms of regulation, known as co-viability,
295 that are legitimized at the local level (Barrière, 2008).
296 Extensive studies in the rain-fed area of the west part of the Delta (Egypt) confirmed the
297 importance of flock mobility for large and medium-size farms to adapt to resource constraints. Interviews
298 with the Bedouin breeders around the settlement zone of Tiba allowed drawing of the herd mobility paths

299 in the zone and estimating the nitrogen supply based on the herd size and the duration of grazing. This
300 contribution ranged from 6% to 25%, depending on the village or grazing zone in 2014/2015. This can
301 explain the lower N intake (chemical and organic) used by crops in this zone (especially for G5).

302 These three case studies show common factors of adaptability of livestock farms based on the
303 territorial exploration of resources through mobility. However, this adaptive capacity concerned mainly
304 large and medium-size farms that have the social capital to manage mobility for their flocks and extend
305 flock size and, as a result, increase labour productivity. Mobility clearly is a strong attribute of
306 Mediterranean systems regarding adaptation (see Ocak, 2016).

307 A strong discrimination may be operated between, (*i*) on the one hand, livestock farmers who may
308 base the future of their farms on this option related with special assets (social capital and networks due to
309 historical background of the families or tribes) that enable them to move as well as public policies
310 incentives; and (*ii*) on the other hand, livestock farmers who may not foster mobility but on local
311 enrolment, activating diversification (tree plantation, vegetable, agro tourism) or plural activities while
312 they do not benefit in mobility assets and initiate another scope for their activity. At the regional level, it
313 appears that to avoid exclusion and maintain availability of contrasted pathways that guarantee diversity,
314 regulations must be implemented that will reinforce the collective resilience.

315

316 **4. Attempt of prospective for future livestock systems in Mediterranean**

317

318 From the three country case studies, we can identify five common farming systems (FS) pathways
319 in these Mediterranean contexts. First, we observe three trends of specialization of farming systems due
320 mainly to policy incentives and infrastructure development. The first trend concerns the development of
321 high-value cash crop-specialized systems in the favourable zones, mainly irrigation zones. This
322 specialization is largely driven by labour productivity and social valorisation linked with the educational
323 level or aspirations in terms of living conditions. This trend extends in all the plains of the coastal line in

the south of France and Morocco and in the recent NRL in Egypt. It has also been encouraged by regional and national policies of rural development in France and in Morocco based on irrigation development and agrarian reform in Egypt in favour of graduates and private entrepreneurs. The second trend is dairy specialized system which is developing in the favourable zones of Morocco and Egypt. This specialization concerns mainly large dairy farms and some smallholder farms that have been boosted, and sometimes structured, by the milk agro-industrial sector through a secured farm gate milk price and regular sales of calves. The third and last trend is related to meat specialized systems in vulnerable zones like the mountainous areas in France or the arid and semi-arid zones in Morocco or Egypt. This specialization depends on the capacity to increase resource access by mobility, thanks to an extended social network.

In this common trend of specialization, we can easily differentiate the 'modern' or 'capitalist' specialization towards the high-value crops or dairy products driven by the national or multinational firms (the so-called modern sector), from the specialization towards meat production in the vulnerable zones mainly driven by individual capital assets.

Furthermore, we can identify two trends of maintenance of the diversification. This concerns two types of farms: (i) The mixed crop-livestock systems in which crop activities are the main source of income and (ii) The mixed livestock-crop systems in which livestock is the main source of income. If the first type constitutes the majority of farming systems in the NRL and in the irrigated zones of Morocco, it is no longer present in the south of France, limited in the interstice between the plains and the mountains. The second type oriented to livestock represents the majority of integrated systems in the rain-fed zone, also called agro-pastoral system due to the maintenance of short seasonal mobility during the favourable climatic years.

From these different development pathways, we can represent the dynamic of farming systems in the area by two main trends: a centrifugal trend of specialization that is the strongest in France and a centripetal trend of diversification that is most widespread in Egypt and Morocco (Figure 2).

349

350 [Insert Figure 2]

351

352 Table 6 gives a brief overview of the weight of the types of farming systems in the studied zones.
353 This table highlights the main differences of trends between South and North Mediterranean contexts, but
354 it shows also the more recent developments of crop or livestock specialized systems in the South
355 Mediterranean, driven by agricultural policies oriented to intensification and modernization, and the agro-
356 industrial development over the last two decades. The two studied zones in the south are emblematic of
357 this trend through the Green Morocco Plan (Plan Maroc Vert -PMV-) in Morocco and the settlement
358 program in the New Reclaimed lands of Egypt, with the installation and specialization of medium-size
359 farms.

360

361 [Insert table 6]

362

363 The comparison of eco-efficiency in the three-country case study was based on three main
364 synthetic indicators: 1) nitrogen use efficiency for environmental assessment, 2) the economic
365 vulnerability based on the diversification of income sources, and 3) the labour productivity that reflects the
366 technical and economic performances (Table 7). If the farming system with a livestock component is more
367 environmentally efficient due to the organic matter supply, the main difference of the systems is between
368 economic vulnerability and labour productivity. If the mixed systems are more resilient to economic or
369 market shocks, they are less attractive in terms of yearly gains. The mixed or specialized livestock systems
370 in the rain-fed areas are the most dependent on climatic events that can affect the economic vulnerability
371 of mixed farming systems and labour productivity of specialized farming systems.

372

373 [Insert Table 7]

374

375 Using the two frameworks for adaptive capacity and vulnerability, we have identified the five
376 farming systems according to eight major drivers of strengths or weaknesses in terms of sustainability.
377 Table 8 shows the different strengths between irrigated and non-irrigated systems: if the irrigated systems
378 have been supported by national territorial development policies that include road infrastructure, the
379 livestock specialized systems in the rain-fed zone resulted from social coordination. In between, without
380 social coordination actions or policy support, the mixed systems—the environmentally friendly systems—
381 are the most vulnerable. This approach showed the high correlations of strengths and weaknesses for all
382 the farming systems between policy support, land and resource access and market access. This supports the
383 idea of the decisive influence of the policy development on the present specialization of the systems based
384 on land assets.

385

386 [Insert Table 8]

387

388 **5. Discussion**

389 Our main hypothesis of this transversal research work was that the integration of crop-livestock
390 activities, at the farm or regional level, is a pillar of sustainability of the farming system mainly in terms of
391 environmental efficiency. However, in the South Mediterranean, the integrated crop-livestock systems
392 remain the only option for small-scale farms in rain-fed and irrigated zones due to limited assets, either
393 land or market access, and given their overwhelming number of workers. The weak access to market
394 constitutes a major handicap for new settlers in the recently reclaimed lands of Egypt located more than
395 100 km from large cities such as Cairo and Alexandria. The integrated crop-livestock systems, however,
396 still ensure the survival of many families and workers, particularly in contexts of significant risks, like
397 prices volatility and climate hazards. In fact, in the South Mediterranean context, where irrigation water

398 may not be sufficient to cover all crop needs, in case of acute drought, livestock remains the only source of
399 income to cover farmers' expenses and the main security in case of major social events (like marriages,
400 funerals, hospitalizations). In addition, livestock in many situations adds value to rainfall, with almost no
401 effect on groundwater depletion (Sraïri *et al.,* 2016), in contrast many summer crops that have a huge
402 effect on the sustainability of ground water resources (Ameur *et al.,* 2017).

403 In the three countries, the compared labour productivity of crop and livestock activities explained
404 the specialization trends towards cash crops such as vineyards, tree plantations, and market gardening in
405 favourable areas like irrigation plains. Over the last two decades, this farm specialization has led to a
406 territorial specialization in France: livestock disappeared in coastal plains and valleys, and cash crops were
407 no longer present in the hinterlands. In Egypt and Morocco, mixed systems still exist in irrigation areas, in
408 combination with specialized crop farms. In those mixed systems, labour is a key factor in terms of
409 quantity, routine tasks and remuneration. At the family level, the diversion of youth from agricultural
410 activities, given its limited attractiveness due its limited revenues, can be a threat to viability; however, it is
411 not a recent phenomenon in Morocco (Bencherifa, 1993; Lubbock and Borquia, 1998). Furthermore,
412 recently, we may find new arrangements, notably the remuneration of family work or new social
413 arrangements such as farm associations and work sharing between farms to keep interest in agriculture
414 (Bencherifa, 1993). However, this may weaken the whole system in the long term, whenever the
415 equilibrium between social demands and the existing resources might collapse due to the end of state
416 technical support for farmers and the emergence of new needs such as better education services for the
417 children (Sraïri, 2005). In Egypt, we observed the highest profits of livestock activity for medium-size and
418 large farms while small mixed crop-livestock systems registered the higher return by capital invested in
419 livestock. This reflects the multiple roles of livestock in farm assets.

420 In the mixed farm systems, as in Egypt and Morocco, or in specialized livestock farms relying
421 partially on fodder and grains provided by cropland in France, the crops provided most of the feed
422 resources to herds or supply resources to get through harsh seasons. The results obtained in the three

423 countries stressed also the crucial function of livestock biomass preservation in the Mediterranean context,
424 through the role of manure to improve the stock of organic matter of the soil. Using manure was a way to
425 maintain soil fertility and reduce the use of mineral fertilizers. Thus, the crop-livestock integration,
426 through feeding and manure management, decreases external inputs. Nevertheless, the practices of crop-
427 livestock integration, especially manure management, created a heavy workload. Even in farms managing
428 both crops and livestock, those activities could be not integrated, or in a one-way path only, with any
429 recycling.

430 Previous research showed that increased demographic pressure and cropping intensity favoured the
431 degree of integration of crop-livestock activities (Boserup, 1965; Ruthenberg, 1980; Pingali *et al.,* 1987).
432 This process was fostered with market access, diffusion of technology packages, or the presence of cash
433 crops in the cropping pattern (McIntire *et al.,* 1992). This process is still on-going in the south
434 Mediterranean countries. However, our results show that these systems,while ecologically most efficient,
435 are also socially deeply vulnerable. They are maintained in Morocco and Egypt "by default" and as
436 protection from uncertainties and risks, supported by social solidarities that substitute for lack of dedicated
437 policies. This antagonism between social vulnerability and ecological efficiency should be a major
438 consideration for rural development policies in the south to avoid the disappearance of such systems that
439 we may notice in many areas in northern Mediterranean countries.

440 Consequently, for the future, limiting micro-regional specialization processes through by
441 maintaining a diversity of systems, both crop-oriented and livestock-oriented, is at stake. This relies on
442 special supports to reduce competition between these systems, reinforcing the ability of livestock systems
443 to be perennial and reducing the common trends observed of substitution of livestock systems (mainly
444 oriented for meat production) by enlargement of crop oriented systems. This requires dedicated actions
445 confronting local feeding systems. This could rely on special incentives and development of territorial
446 food projects. Special environmental rules would reintroduce diversity in cropland occupation such as
447 reintroducing legumes in cultural successions is another way to foster a mix within farming systems. While

448 we may notice that specialization at a micro-regional level results in loss of environmental efficiency for
449 areas devoted to crop systems, taking advantage of the spatial mobility abilities of livestock farming in the
450 Mediterranean is an another option to reinforce crop-livestock integration at the regional level. This
451 mobility has been traditionally operated by medium to large-size farmers (Lasseur et al, 2016). However,
452 promoting collective actions allowing a wider range of livestock farmers in the hinterlands to participate
453 should reinforce sustainability for vulnerable livestock farmers and those with limited animal wealthwhile
454 extending cropping areas. These collective actions should involve a wide array of stakeholders.

455 Nowadays, the adaptive capacity in the Mediterranean area is strongly based on regional
456 integration and diversification. These processes involve different configurations at the time and spatial
457 levels according to the agro-ecological gradient (from rain-fed to irrigated zone) but also the regional
458 policy of territory development.

459 This research has also developed a series of indicators to approach the efficiency of crop/livestock
460 systems according to a gradient of intensification and using tools ranging from livelihood and micro-
461 economic tools (for economic and social assessment) to environmental tools like network analysis. Beyond
462 these data sources and tools, the transversal analysis highlights that livestock at the interface between land
463 management (local) and livelihood diversification (family) plays a vital role in the current rural
464 sustainability, although its future will depend on the societal challenges and policy orientation between
465 employment, food security and resources management. Moreover, the function of livestock in biomass
466 management appears crucial for the medium- and long- term resilience of Mediterranean agrarian systems.
467

468 **6. Conclusion**

469

470 For small ruminant systems (sheep and goat) that are dominant in the rain-fed and mountainous
471 areas of the Mediterranean, we observed an increasing flexibility of medium and large flock systems based
472 on spatial and temporal mobility. This geographical and social expansion went hand in hand with a certain

473 level of specialization. The permanence of small flock systems in the South Mediterranean countries was
474 observed, where the pillar of viability depended on the diversification of farm outputs. In the irrigation
475 areas, we found more contrasted situations between the locations according to the social and political
476 environment. The irrigated systems in the Mediterranean zones tended to specialize in high remunerative
477 crops like orchards or market gardening in the south of France or plain of Gharb in Morocco or specialized
478 fruit production in the West Delta of Egypt. Only farms with small-irrigation land area (which constituted
479 the majority in the South countries) maintained a crop-livestock diversification to secure not only their
480 source of income, but also their family's food supply and savings.

481 Facing this trend of specialization with detected environmental (and economic) risks and the
482 maintenance of a mass of small mixed crop-livestock systems (not necessarily viable, notably in terms of
483 transmissibility and reproducibility), collective regulations appear as a key-driven solution, and incentives
484 to increase resilience of the whole system should rely on maintaining contrasted pathways for farms and
485 diversity management.

486 This study shows that different pathways of development can be proposed according to policy
487 priorities or farmers' expectations. In the rain-fed areas, the results highlight that the local (territorial)
488 perception of development is often far removed from the spatial dynamics of livestock that generally
489 favour a diversity of livelihoods at the landscape level. In this context, mobility driven by agro-ecological
490 conditions and stakeholders' networks constitutes a powerful adaptive strategy in the face of climate
491 change. Nevertheless, these networks have also favoured agricultural development (mainly through
492 irrigation in PACA or Wadi development with orchards in rain-fed Egypt). Consequently, a new integrated
493 livestock-crop model based on local fodder and concentrates is needed. This shows the capacity of
494 livestock activities to reach new agricultural areas adapting to land pressure, but also to respond to
495 emerging food demand with new lifestyles. The permanence, yet adaptability, of livestock confirm its role
496 as a security net in this type of harsh environment. In the irrigated areas, particularly in large scale
497 irrigation schemes, we observe the development of dairy or crop-specialized systems, encouraged by

498 regional and national policies of rural development, but with a loss of environmental efficiency. This
499 model could be improved by taking advantage of the spatial mobility abilities of livestock farming in the
500 Mediterranean to reinforce crop/livestock integration at the regional level. This will certainly also improve
501 the value addition to several resources like rainfall and surface irrigation water (small dams, springs) at a
502 time when severe regulation should be devoted to groundwater resources to avoid amplifying rural exodus.
503

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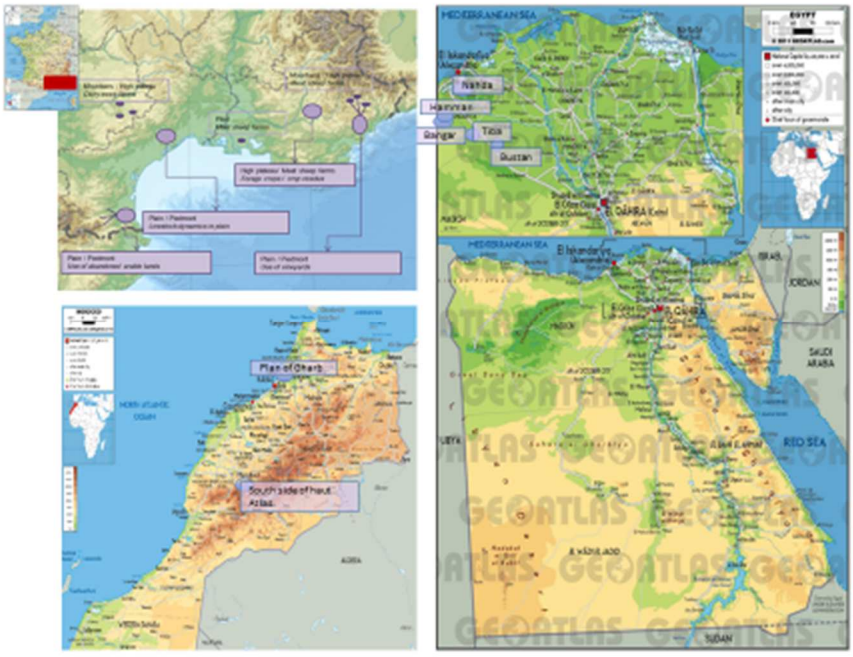

Figure 1. Geographical location of the selected case studies in the three countries. (a) *(up left)* in South of France; (b) (*at right*) the five locations in the Western Desert of the Nile Delta (Source: @geoatlas.com); (c) (*down left*) from the Plain of Gharb to the South side of the haut Atlas (Source: @geoatlas.com)

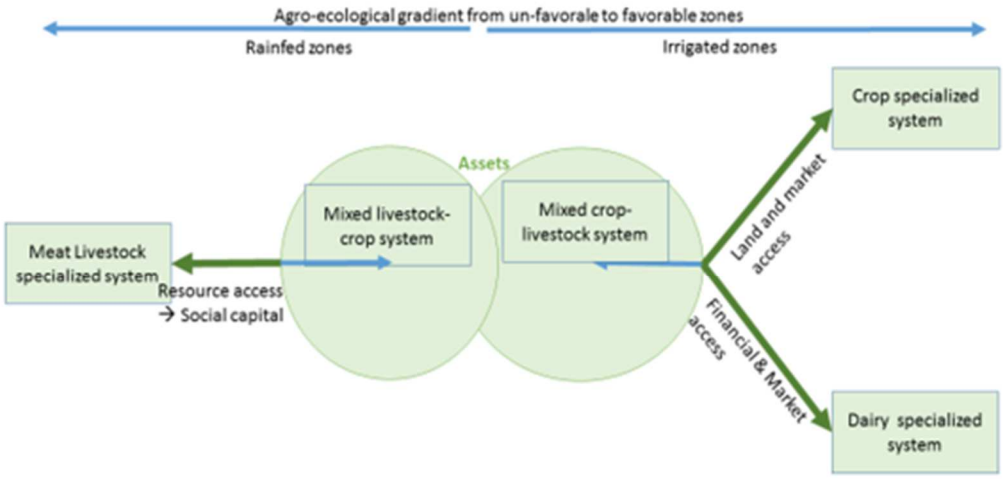

Figure 2. A descriptive approach of five Farming Systems in opposite trends towards specialization or diversification, in contrasted socio-ecological contexts en Mediterranean, from case studies in Egypt, France and Morocco

Table 1. Materials collected in the three Mediterranean countries

Country	Approach	Sample	Main variables
Egypt	Farm survey with semi structure questionnaire (175 family farms with less than 10 ha of arable land)	175 farms	Narrative approach ('Récit de vie'), Socio-economic living conditions, Land tenure and crop land allocation, Livestock and animal products' management
	Bi-Monthly Crop-livestock monitoring with questionnaire (based on the Laser toolkit, http://livtools.cirad.fr/)	20 farms	Crop management, feeding systems, livestock products (milk & meat, live animals)
Morocco	Annual follow up	5 farms	Understanding the relationship between the feeding characteristics of the herd and milk yield and the setbacks recorded in milk production
	Farm survey on livestock system	19 farms	Milk production costs (input/output) (late winter 2013/14; late spring 2014)
	Follow up of work management	14 farms	Using the 'Work Balance' method to assess tasks duration, the split of work between family members and hired off farm workers, and measuring the generated income
France	Agrarian diagnosis, comprehensive analysis of crop livestock integration schemes	Opened interviews with actors and farmers	Mobility, use of rangeland and grassland, land management, typology 'à dire d'acteur', perception (Aesthetic value of landscape, cultural identity)

Table 2: Eight major drivers of farming systems' strengths or weaknesses in terms of sustainability

Drivers	Some sources	Hypothesis	Variables used
Agro-ecological context (relief, soil)	Mac Allister et al. 2006; Ploeg, 1994**;** Cecchi et al., 2010; Seligman and Perevolotsky, 1994; Berkes, 2007 ; Lavorel, 1999; Blondel, 2006.	The diversity reinforces the adaptive capacity to natural and social chocks.	Soil quality; landscapes diversity, level of biodiversity based on agrarian system approach;
Drought risk	Séré and Steinfeld (1996) ; Turner, 2000; Swinton, 1988; Berkes, 2007; Brooks 2006	Many long-enduring societies have developed adaptations to deal with drought incidence.	Variability of annual rainfall; % of dry matter from pastures; herd mobility; annual forages and purchased feeds based on farm survey and monitoring
Water access	Ellis and Mdoe, 2003	Water supply (accessibility and quality) conditions the agricultural activities and defines ways crop and livestock interact within farming activities	Water supply for agriculture based on farm survey;
Market access (opportunity)	Ridaura, 2005 ; Cecchi et al, 2010 ; Ellis and Mdoe, 2003; Eakin, 2005; Turner et Williams, 2002 ;	The adaptive capacity depends on the role and functioning of rural markets (access and distance to market, price negotiation system, debt negotiation)	Localization and infrastructure of markets based on agrarian system approach and interviews
Land/resources	Fraser and Stringer. 2009; Ellis, 2000; Ellis and Mdoe, 2003	Redefine crop livestock integration is a way to comfort access to forage as land access and land tenure are critical for livestock farmers	Land access; location/quality of land, land tenure based on farm survey and narrative approach
Policy support	Agder and Vincent, 2005; Turner and Williams, 2002; Scoones, 1994;	Institutional stability; The public policies affected the de-stocking during drought events, causing the depletion of natural resources due to overgrazing	Feed or grain subsidies; credit access; agro-environmental measurement based on literature review
Collective action/social coordination	Berkes et al., 2003; Folke et al, 2005; Turner II, 2010, Ellis and Mdoe, 2003; Berkes, 2007; Olsson et al., 2004 ; Ploeg, 2004	The social dimension of adaptive co-management of ecosystems and landscapes, referred to as "systems of adaptive governance", are strongly based on "bridging organizations", and then their social capacities to deal with permanent uncertainties, perturbations.	Social network; ways of communication and infrastructure (road, electricity,..); extension and social service (proximity, number of visits); formal and informal institutions based on farm survey and interview
Solidarity	Ellis and Mdoe, 2003; Alary et al, 2016b; Eakin, 2005; Chambers, 2006; Dougill et al 2010	The solidarity is a factor reinforcing family net safety	Distance between actors, frequency of contacts; network, membership of groups, relationships of trust, access to wider institutions of society; ability to move animals;

Table 3: Type of work and family work productivity in three farm types in the plain of Gharb, Morocco (14 farms in 2014)

FS	Livestock system	Horticultural system	Mixed Crop-Livestock system
Sample size	6	3	5
Arable land (ha)	9	28.3	43.7
Main cash crops	Maize, sugar beet	Potato, watermelon, sugar beet, sunflower, rice	Cereal, peanut, bean, rice
Livestock Units (LU)	11.4	8.9	16.9
Fodder area/Total land (%)	47	12	10
Family members involved in work	3.2	3.7	3
Routine work (days)	673.2	491.5	524.7
Seasonal work on crops (days)	136.1	930.4	271.9
Work autonomy (%)	75	62	45
Income generated per LU (€)	997	536	496
Income per ha of crops (€)	554	1052	1058
Total livestock income (€/year)	11362	4769	8391
Total crop income (€/year)	2646	26258	41598
Livestock income/total income (%)	81	15	17
Labor productivity (€/month/family worker)	365	699	1389

* 1 LU equivalent 1 UGB

Table 4. Parameters of economic and environmental efficiency for the six farm types in the New Reclaimed Lands of West Delta (Egypt) according to a gradient of specialization and diversification (175 farms)

Farming system	(G1)	(G2)	(G3)	(G4)	(G5)	(G6)
No of dairy heads (heads)	2-3	3-6	5-6	17-18	--	2-3
Area (feddan)	2.5	2.5	6.7	14.7	6.8	6.4
Tree area (%/total area)	7	13	10	22	64	51
Dairy specialization (%/total animal products)	33	27	35	40	2	29
Organic matter (%/total N supply)	40	42	30	40	48	33
Feed efficiency (feed cost in €/liter)	0.43	0.57	0.46	0.34	--	0.61
Total net income/workforce (€/year/full time unit)	100	476	397	903	788	603
Total net income/land unit (€/feddan/year)	110	258	195	374	103	151
Total net income/capita/year (€)	37	97	126	343	183	171

Legend : (G1) Small C&L system; (G2) Small C&L system oriented to crops; (G3) medium C&L systems; (G4) Large C&L oriented to livestock; (G5) Tree-specialized systems; (G6) C&L systems oriented to trees

Table 5. Adaptive capacities of livestock systems based on three coordination models to access feed resources from cultivated land (South of France)

Models	Vicinity grazing	Distant grazing	Distant forage cropping Plain /Mountain
Types of relations	Neighbor	Inter-individual	Multi-actors
Mode of coordination	Proximity	Mutual agreement	Collective action
Temporal coordination	++	+++	+++
Spatial coordination	+	++	+++
Social coordination	+++	+++	+++

Table 6. Importance of the five farming systems in three Mediterranean countries, based on expert knowledge

	Crop-Specialized system	Dairy specialized systems	Mixed crop-livestock system	Mixed livestock-crop system	Meat specialized systems
Agro-ecological conditions	Very favorable	Favorable	Intermediary	Rain-fed	Rain-fed
Importance of farming systems in each Mediterranean countries (in number of farms)					
South of France	+++	0	0	+	+++
Morocco	++	+	+++	+++	++
Egypt	++(fruit trees)	+	+++	+++	+

Legend: the weight (+++/++/+/0) estimated according to opened interviews among key-resource persons in each case study; 0 meaning the quasi-absence of the system.

Table 7. Eco-efficiency evaluation of five farming systems in three Mediterranean countries

	Crop-Specialized system	Dairy specialized systems	Mixed crop-livestock system	Mixed livestock-crop system	Meat specialized systems
Gradient	Very favorable	Favorable	Intermediary	Rain-fed	Rain-fed
Nitrogen use efficiency	-	+	+	+	+
Economic vulnerability	-	-	+	+/-	-
Labor productivity	+	+	-	-	+/-

Legend: (+) meaning positive value indicators for the farming system in all case studies; (-) meaning negative or low value indicators for the farming system in all case studies; (+/-) meaning the two trends (positive and negative/low values) for the farming system according to the case study.

Table 8. Strengths and weaknesses of five farming systems at the farm and territorial level in three Mediterranean countries, according to eight major drivers

	Crop-Specialized system	Dairy specialized systems	Mixed crop-livestock system	Mixed livestock-crop	Meat specialized systems
Agro-ecological context (relief, soil)	+++	+++	++	--	---
Drought risk	+++	+++	+	---	-
Water access	+++	+++	-	---	-
Market access (opportunity)	++	+++	---	---	++
Land/resources	+++	+++	---	--	++
Policy support	+++	+++	---	--	++
Collective action/social coordination	++	--	---	-	+++
Solidarity→ net safety	-	+	++	++	++