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1 Challenging agroecology through the characterization of farming practices' diversity
2 in Mediterranean irrigated areas

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Abstract

21
22 Identifying locally adapted and adopted efficient practices can be a step towards the
23 agroecological transition of irrigated plains of the Southern Mediterranean region. However,
24 these types of practices - often little known - are drowned within a wide range of practices.
25 The objective of this study was, first, to elaborate a method to describe this diversity in a
26 semi-arid irrigated landscape, at both the plot and farm scales; second, to show the main
27 characteristics of these types of crop management; and third, to question their sustainability
28 according to agroecological principles. To do so, this paper focused on Southern
29 Mediterranean irrigated cropping systems as i) studies on management routes are scarce with
30 regard to this region; ii) irrigated landscapes are known for their high level of natural,
31 technical and financial constraints, often favoring more intensive farming practices regarding
32 chemical inputs. A series of semi-directive interviews were conducted in order to assess
33 farmers' management of chili-pepper-based (*Capsicum annuum*) cropping systems, a
34 widespread crop in the Merguellil plain, Central Tunisia. The "Typ-iti" method, combining
35 multivariate analysis, clustering and association rules, was used to characterize the diversity
36 of technical management routes (TMR) of these systems. The environmental sustainability
37 was qualitatively assessed by classifying the clusters of TMRs obtained according to their
38 potential impact on natural resources. Then, these management routes were qualitatively
39 associated to some farm structural indicators, to analyze their diversity at the farm level.
40 These enabled to distinguish a gradient of farming practices and characteristics, respectively
41 at both plot and farm scales relative to environmental impacts. The study showed that some
42 agroecology-compatible TMRs coexisted with conventional TMRs for chili-pepper-based
43 cropping systems. Our method characterized three main groups: i) a group of intensive TMRs
44 regarding chemical input powered especially by tenant farmers, ii) an intermediary group iii)
45 a moderate group powered by land owners. Throughout these main groups, seven types of

46 TMRs were described. These were always comprised of both agroecology and non-
47 agroecology-compatible technical operations. This coexistence of diversely impacting
48 practices challenges agroecology in multiple ways. Fertilization management appeared as a
49 major issue in the study zone, often resulting in high applied doses. These findings could
50 allow actors in charge of agriculture to better focus their action. However, the study did not
51 take into account the outputs of the studied systems, so that their productivity and
52 environmental impacts have not yet been assessed in a quantitative manner. For future
53 studies, the paragon obtained from our analysis are typical cases that could be studied for
54 such a purpose.

55

56 Key words: cropping systems; environmental impact; irrigation; Merguellil plain; Tunisia;
57 typology.

58

59 1 Introduction

60 The Southern Mediterranean region is vulnerable to climatic hazards and at a high risk of
61 severe degradation of both biodiversity and agricultural production, due to the combination of
62 climate change and conventional farming practices (Migliorini et al., 2018; MedECC, 2020).
63 New patterns of action would be required to address these issues simultaneously (Caron et al.,
64 2014), with an acute need to implement new agricultural models combining biodiversity
65 conservation, climate change adaptation and food production. Agroecology, which is the
66 production of significant amounts of food, valorizing ecological processes and ecosystem
67 services and integrating them as essential factors in the improvement of practices (Gliessman,
68 1990; Altieri, 2008. Wezel et al., 2014), with its three pillars i) efficiency increase, ii)
69 substitution of inputs, iii) system redesign or diversification (Hill, 1998; Wezel et al., 2014;
70 Duru et al., 2015; Ci and Ma, 2016), could be a pathway for a more sustainable agriculture in
71 the Southern Mediterranean region (Horlings and Marsden, 2011). Agroecology suggests that
72 actions to achieve this goal must be adapted to each agrosystem and take into account local
73 conditions.

74 Although recent literature is appearing on the subject (for example, de Lattre-Gasquet et al.,
75 2017; Ameur et al., 2020), little is still known on the potential of agroecological concepts to
76 address these issues in this region of the world, in particular within irrigated areas. In the
77 North African irrigated areas, agriculture is strongly based on the use of external productive
78 factors (especially chemical inputs). Efficiency increases and input substitutions could appear
79 as a first step of action towards a more sustainable agriculture. This can start by a widespread
80 adoption of local efficient and environmental-friendly farming practices. In this paper, it is
81 hypothesized that strong social, economic and environmental constraints in irrigated areas
82 (Jamin et al., 2011) might enable a diversity of farming practices. Could more environmental-
83 friendly farming practices arise from this local diversity? In what extent are these practices

84 already present or how can they be developed in Mediterranean irrigated systems? In a first
85 step to answer these questions, the objective of this study was to i) describe the possible
86 diversity of farming practices in a typical North African irrigated area and ii) identify the
87 existence of environmental-friendly management routes, and the types of farmers
88 implementing them. The paper seeks to provide a complete and comprehensive description of
89 existing farming practices at the plot and farm-scale, enhancing their diversity, and putting
90 forward in particular potential agroecological practices, but does not undertake a quantitative
91 evaluation of their agronomic or environmental impacts.

92 Access to irrigation is a recurrent demand of smallholder farmers in North Africa, due to
93 expected productivity and income increases, compared to rainfed systems. Progress has been
94 made in this matter, with the development of individual pumping systems giving access to the
95 aquifers. The number of pumping wells has indeed increased drastically in North Africa,
96 irrigating more than 1.75 million ha in Algeria, Morocco and Tunisia (Leduc et al., 2004;
97 Kuper et al., 2017). The Merguellil plain in Central Tunisia is a typical example. In parallel,
98 public policies sought to encourage water economy and have promoted the development of
99 modern irrigated systems, resulting in a wide adoption of drip irrigation. But through
100 fertigation, the latter also facilitates increased applications of nutrients, at a certain
101 environmental cost due to pollutions (Burkhalter and Gates Timothy, 2005; Poussin et al.,
102 2008; Laib et al., 2018). However, it has been shown that the modern irrigated systems could
103 also enable a better management of nutrients and inputs (Benouniche et al., 2014; Al-Ghobari
104 and Dewidar, 2018; Sandhu et al., 2019).

105 In addition, smallholder farmers such as those in the Merguellil plain, can design
106 environmental-friendly farming practices, more adapted to their local social, economic and
107 environmental conditions, allowing them to achieve their production goals, depending on
108 neither chemical inputs nor pesticides (Altieri, 2008). To achieve this, farmers often combine

109 different strategies as part of a usual household management scheme (Pinto-Correia et al.,
110 2017). Thus, the farmer makes choices through diverse ways of farming. So, it is fair to ask
111 whether diversity is one of the main characteristics of these farming practices at the territorial
112 scale.

113 In this paper, we elaborate a method to describe the diversity of farming practices in the
114 Merguellil plain – a location of multiple researches, characterized by its dynamic and diverse
115 agricultural system (Azizi et al., 2017) – at both the plot and farm scales, by analyzing local
116 practices. This can be achieved by characterizing existing technical management routes
117 (Renaud-Gentié et al., 2014; Salou et al., 2017), noted TMRs, and identifying a gradient
118 between chemically-intensive and more environmental-friendly TMRs.

119 TMRs are the logical and ordered succession of technical operations (TO) aiming to control
120 the environment and obtain a given production (Sébillotte, 1974). So far, investigations that
121 integrate all the TMRs steps to describe existing cropping systems in small-scale household
122 agriculture are scarce (Renaud-Gentié et al., 2014, Czyrnek-Delêtre et al., 2018), even the
123 more in Mediterranean irrigated areas. Multiple studies characterizing farming systems and
124 crop management practices exist (Bellon et al., 2001; Köbrich et al., 2003; Maton et al., 2005;
125 Poussin et al., 2008; Blazy et al., 2009; Ibidhi et al., 2018). These studies used either
126 statistical analysis or participatory and expert-based methods. These methods have limits as
127 they i) only identify the most relevant character of each TMR; and ii) do not describe the
128 logical links between TOs (Renaud-Gentié et al., 2014). For instance, only quantitative data
129 on farming practices were used to describe the diversity of coffee-based agroforestry systems
130 in Costa-Rica (Meylan et al., 2013). Another study, examining the variability of farm
131 structure and farming practices, highlighted both low input and intensive systems, but was
132 limited to the analysis of water and N use, pest and crop residue management (Caballero,
133 2001).

134 The paper, focused on chili-pepper (*Capsicum annuum*) as a cropping system model, proceeds
135 in the following way. First, it develops the approach used to assess farmers' practices. Then, it
136 describes the technical operations, their interconnexions within TMRs, and their (non-
137)agroecological orientation and (non-)association to farm types. Finally, it discusses this
138 diversity of farming practices in the light of co-existing irrigation, pollution and agroecology
139 stakes, and how these conditions challenge the implementation of agroecological practices in
140 Southern Mediterranean irrigated areas.

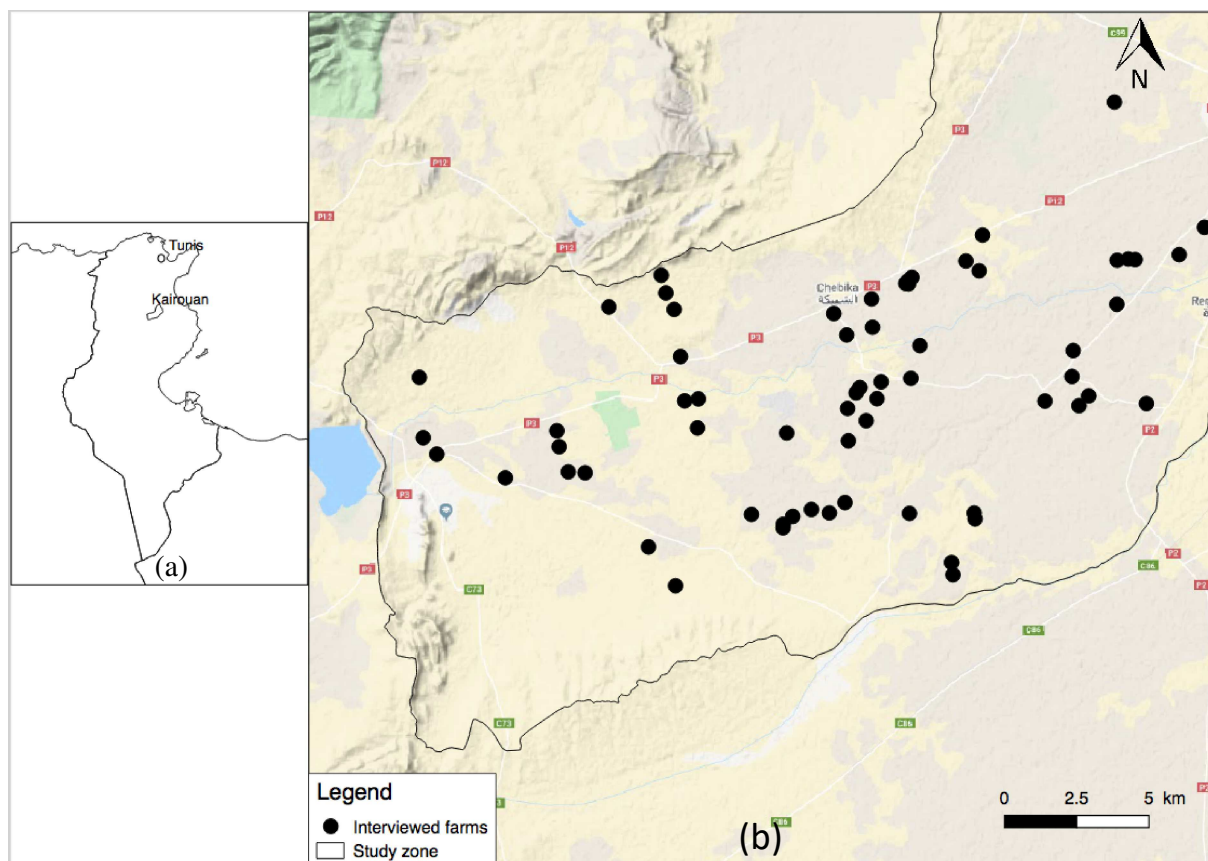
141 2 Materials and methods

142 2.1 Study site

143 The study took place in the downstream plain of the Merguellil catchment in Central Tunisia
144 (Fig. 1). The latter, covering over 700 km², is part of the large and flat Kairouan alluvial plain
145 which extends almost over 3000 km² (Leduc et al., 2007). The climate is semi-arid with 300
146 to 500 mm of total annual rainfall. The downstream plain is almost entirely used for
147 agricultural purposes with a combination of irrigated and, to a lesser extent, non-irrigated
148 agriculture. Most agricultural water withdrawal, consuming 80% of the total extracted water
149 per year (Poussin et al., 2008), takes place in this downstream zone where a very high density
150 of drilling is observed (Massuel et al., 2017).

151 Cropping systems are characterized by a wide variety of crops, including olive groves and
152 fruit orchards, alone or intercropped; watermelon (*Citrullus lanatu*) and melon (*Cucumis*
153 *melo*), tomato (*Solanum lycopersicum*), chili-pepper (*Capsicum annuum*) and other winter and
154 summer vegetables (Poussin et al., 2008; Ameur et al., 2020). Farm structures are also diverse
155 as far as total area, level of equipment and cropping systems are concerned. The agricultural
156 sector is very dynamic, characterized by significant changes in farms' production structures
157 and orientation during the last decade. These changes were stimulated by i) a facilitated water
158 access for initially rainfed farms; ii) the adoption of irrigated horticultural crops for some

159 farmers; iii) the reduction of annual crops, replaced by irrigated olive groves and fruits
160 orchards for others (Azizi et al., 2017). As one of the most widespread crops, present in most
161 of cropping systems, pepper-based cropping systems were used to represent the irrigated
162 horticultural crops in this area.



163 Fig. 1 (a) Location of the case-study site: the Merguellil downstream plain in Central Tunisia;
164 (b) interviewed farms (black dots).
165

166 2.2 Methodological approach

167 In this paper, farming practices include the ways of farming at both plot and farm scales. The
168 TMR (Technical Management Routes) is a succession of TOs (Technical Operations) applied
169 to a chili-pepper plot. A TO refers to an action or a choice performed by the farmer on the
170 plot. Agroecology-compatible TOs or practices refer to TOs compatible with agroecology.
171 (Non)-environmental-friendly TMRs refer to TMRs compatible with agroecology or not.
172 The global approach, allowing to finely characterize the TMRs, give indications on their
173 sustainability and links to farm characteristics, consisted in four successive steps: i) sampling

174 and data collection through field surveys, ii) database and variables construction, including a
 175 characterization of their potential environmental impact (in a qualitative manner), iii)
 176 statistical analysis including data mining, enabling the description of different clusters of
 177 TMRs, and iv) the identification of the types of farms implementing each type TMR. These
 178 steps are described here below in detail and in Fig. 2.

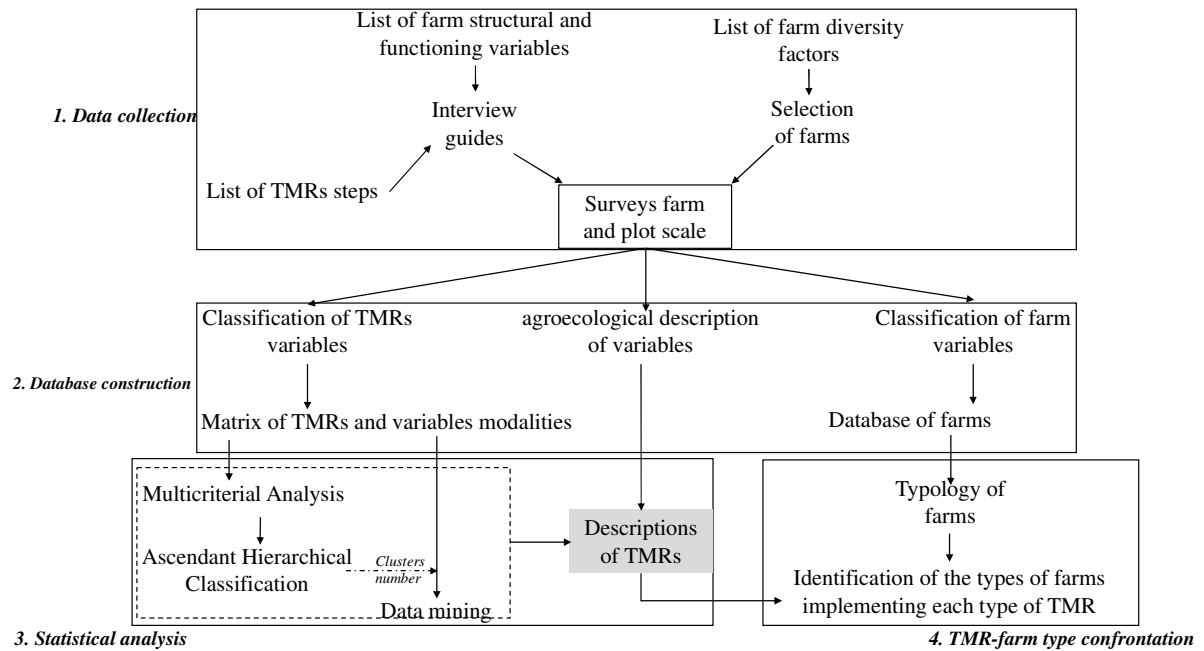


Fig. 2: Methodological approach.

2.2.1 Sampling and data collection

182 Data collection was carried out through semi-directive interviews with farmers in Spring 2018
 183 and was conducted in three phases. First, 65 farms were chosen for their diversity, not only in
 184 their structure (crop types, farm size, land tenure), but also in their localisation throughout the
 185 Merguellil plain. A wide range of farm sizes was covered (1-75 ha). Farm selection was actor-
 186 and expert-based, or by direct observation. Second, a series of semi-directive interviews with
 187 farmers were conducted, in order to apprehend the organization and functioning of the farms.
 188 These interviews concerned not only crop types and successions, but also labor origin (family
 189 or temporary), land tenure (tenants, landlords, sharecroppers), water supply sources

190 (individual drilling, collective network), and crop management (seed origin, chemical
191 fertilizers, plant protection products). This allowed a confrontation of management routes to
192 farms structures. Third, a series of detailed interviews were conducted on the pepper crop
193 farming practices, using the TMR concept applied to both farmers' strategic and operational
194 decisions. The strategic decisions are made at the beginning of the season and concern plot
195 configuration, types of association, choice of crop varieties and planting date, while the
196 operational decisions concern the technical steps of transplantation, tillage, irrigation, pest
197 management, fertilization and harvesting. A list of TOs related to all the steps of a TMR was
198 pre-established through expert-knowledge and was pilot tested with a few farmers.

199 Data acquisition on the TMRs applied to chili-pepper was carried out on 45 plots. To achieve
200 so, a minimum of two interviews of one to two hours with each the farmer was required in
201 order to correctly understand the functioning of the cropping system. Interviews, combined
202 with direct observations, were face-to-face and took place within the farm, with audio record
203 and field notes. When required, additional information were obtained by phone call.

204 2.2.2 Database and variables construction

205 Collected data were transcribed into a table of TMRs, where each TO of the TMR was
206 described by its modalities. The TOs represent the variables used for statistical analyses. The
207 modalities of a TO are the different values it can take. Data were both quantitative and
208 qualitative. The quantitative data were first transformed into qualitative variables, using the
209 “natural occurring division” approach (Husson et al., 2017), based on the analysis of the
210 histograms of the observations, in order to maintain the modalities as observed. Two to four
211 modalities were constructed depending on TOs. To avoid redundant information and
212 characterize the diversity of TMRs, TOs with a single common modality to all farmers were
213 not taken into account in the analyses.

214 2.2.3 Qualitative assessment of the potential environmental impact of farming practices

215 In order to assess the potential environmental sustainability of the TMRs, the modalities of
216 each TO were qualitatively classified according to their potential impact on natural resources,
217 using three levels: TOs with a potentially positive environmental impact (e.g. no pesticide
218 application), TOs potentially harmful (e.g. high value of N input) and TOs with no evident
219 positive nor negative first-order impact (e.g. planting date). TO modalities were classified
220 relative to each other, assuming a gradient of environmental impacts rather than an absolute
221 value. Their attribution into each level was based on described agroecological practices in the
222 literature (Wezel et al., 2014; Ameur et al., 2020), and expertise. A rating was assigned to
223 each TO: +1 for TOs with potentially positive environmental impact (agroecology-
224 compatible), -1 for potentially harmful (non-agroecology-compatible) TOs, 0 for TOs with no
225 evident positive nor negative first-order impact. TOs were classified as harmful or not based
226 its potential contribution to the stages of the ESR (Efficiency increase, Substitution,
227 Redesign) conceptual framework, and criteria presented in Table 1. This scoring was adapted
228 from an approach of scoring farming practices for a qualitative assessment of ecological
229 impacts of cropping systems (Bohanec et al., 2008). After statistical analysis, a total rating
230 was computed by summing up the scores of the TOs significantly linked to each cluster,
231 giving a potential level of environmental impact of the cluster. Four degrees of impact were
232 defined for farming practices: high (non-environmental-friendly), neutral (intermediary),
233 medium low (moderately environmental-friendly), and low (environmental-friendly).

234

235

236

237

238 Table 1: criteria used to classify TOs as 'harmful' or agroecology-compatible. Each TO is
 239 categorized according to the ESR conceptual framework. E= Efficiency increase; S =
 240 Substitution; R = Redesign

TMR steps	TO	ESR	Criteria
Tillage	Weeding / Hoeing	E, S	Reduces energy consumption for seedbed preparation and soil compaction.
Variety choices and crop spatial distribution	Variety	E, S	Increase in pest control, and resistance to water stress. Reduction of fertilizer or pesticide use.
	Planting strategy	-	-
	Association with leguminous	E, S, R	Increase in land productivity. Reduction of pest and disease impact. Improvement of nitrogen content of soils.
	Association with trees	E, S, R	Increase in land productivity. Decrease in nutrient leaching and soil erosion. Diversity of production: wood (timber, firewood), Protection of crops from intense solar radiation and wind.
	Association with cucurbitaceae	E	Increase in land productivity.
Irrigation	Water stress	E	Enhance plant water uptake. Decrease water use.
Pest management Fertilization	Number of pesticide applications	S	Pest pressure control with limited use (or no use) of pesticides.
	Organic fertilization mode	E, S	Reduction of chemical fertilizer use. Reduction of energy consumption for transport when using on-farm manure or from nearby.
	N (kg.ha ⁻¹)	E, S	Reduced fertilizer use increases efficiency. Reduction of risk of ground and surface water contamination.
	P (kg.ha ⁻¹)	E, S	
	K (kg.ha ⁻¹)	E, S	
	Ca (kg.ha ⁻¹)	E, S	
	Mg (kg.ha ⁻¹)	E, S	
	Ternary fertilizer leaf application	E, S	
	Synthetic bio-stimulant use	E, S	Reduction of fertilizer use. Improvement of nutrient availability.
Harvesting	Harvest regularity	-	-
	Crop residue management	E, S, R	Organic matter and nutrient recycling.
	Crop color harvest	-	-

241

242 2.2.4 Statistical analysis using the “Typ-iti” method

243 The "Typ-iti” analytical method (Renaud-Gentié *et al.* 2014) was used to characterize the
 244 diversity of TMRs for pepper cultivation. Combining three different statistical tools, the
 245 former was realized through three phases: i) a multiple correspondence analysis (MCA)
 246 summarizing the relationship between plots and TOs’ modalities ii) an ascending hierarchical
 247 classification (AHC) enabling the grouping of TMRs into separate clusters, within which the
 248 TMRs are relatively similar, finally, iii) a data-mining analysis to generate association rules

249 between modalities (Agrawal et al., 1993). The results of all the statistical analyses are
250 synthesized in a table describing each type of TMR.

251 MCA was first applied to the TO table. Then, using the resulting coordinates of TMRs on the
252 MCA axis, the AHC was performed by the Ward method, to obtain the clusters. The number
253 of clusters, first chosen on the basis of the explained inertia rate, was consolidated through the
254 calculation of the optimal number of clusters using K-Means partitioning. The description of
255 clusters was, first, based on chi² correlation tests. A modality was linked to a cluster if its p-
256 value < 0.05. Second, a TO modality was described as a cluster's character if i) it was present
257 in more than 50% of the cluster's TMRs, or ii) if more than 50% of all TMRs of the dataset
258 were present in the cluster's TMRs in the case of significant p-value.

259 Finally, to have a complete description of TMRs, a data-mining analysis was performed. It
260 consisted in mining association rules, which are combinations of modalities within TOs. This
261 allows to identify additional TOs significantly linked to TMRs and not shown by the previous
262 MCA analysis, because they were not specific to groups. Rules are defined as a succession of
263 TO modalities common to a minimum defined number of TMRs in a same cluster. They were
264 interpreted based on three criteria: the support (S), the confident (C) and the adjusted support,
265 noted S_a (Renaud-Gentié et al., 2014). The support is the frequency of occurrence of a rule. Let
266 us consider A, a succession of k TOs (k > 0), and B another succession of n TOs (n > 0); for
267 A and B, the support of the rule A ⇒ B is computed as follows:

$$268 \quad S(A \Rightarrow B) = P(A \cup B)$$

269 A minimum support S_m was calculated by dividing the number of TMRs in the cluster
270 comprising the lower number of individuals over the total sample size. The confident of the
271 rule A ⇒ B is the percentage of rules containing A and B.

$$272 \quad \text{Confidence}(A \Rightarrow B) = P(B|A)$$

273 The adjusted support is the support relative number of TMRs contained in a cluster.

274 $S_a(A \Rightarrow B) = P(A \cup B) * (\text{total sample size}) * (\text{number of TMRs of the cluster})^{-1}$

275 A rule was considered as linked with a cluster if $S \geq S_m$, $C=1$ and $S_a \geq 0.5$. An S_a of 0.5 meant
276 that 50% of individuals in the cluster should contain the rule.

277 For each cluster, the four longest rules were represented and compared to MCA and AHC
278 descriptions. In addition, the data-mining also describes clusters' similarity and homogeneity,
279 as these increase with number and length of rules. The combined MCA, AHC and data-
280 mining analysis led to a complete description of TMRs for each cluster. These typical TMRs
281 were finally compared to the most representative individual of each cluster, called the
282 paragon, obtained in the clustering phase, to assess in what extend they match with actually
283 existing TMRs.

284 The statistical analyses were performed with the R software (R Core Team, 2019). MCA and
285 data-mining were computed using the FactoMineR (Husson et al., 2020) and Arules (Hornik
286 et al., 2005) packages, respectively.

287 2.2.5 Identifying farm types associated to each cluster

288 This final step consisted in confronting the typical TMRs to farm structural information, in
289 order to qualitatively link the respective TMRs and their potential environmental impact to
290 farm-level characteristics.

291 A contingency table of plots and farm types was obtained, by cross-tabulating the TMRs of
292 each cluster with the characteristics of the farms with which they were associated. The
293 structural data of farms were used to classify them regarding ten criteria, representing farm
294 characteristics, typical of the case-study-site (Azizi et al., 2017; Poussin et al., 2008). These
295 pertained to i) access to water (“individual drilling”, “collective network”), ii) access to land
296 (“direct access” for land owners, “indirect access” for tenants, “indirect & indirect access” for
297 tenants who also owned some land), and iii) types of production (“grain farming”,
298 “cucurbitaceae”, “leguminous”, “arboriculture” and “livestock”).

299 3 Results

300 Results, organized in five sections, first present the various TOs (Technical Operations) found
301 in the study region, then describe the statistical analyses for each specific phase. Stemming
302 from this step-by-step depiction, the overall characteristics of the TMRs (Technical
303 Management Routes) are then presented. Finally, these are analyzed in the light of associated
304 structural farm characteristics.

305 3.1 Technical operations used for statistical analysis

306 Six TMR steps were identified, constituted of one to eight TOs (variables) each (Table 2),
307 resulting in a total of nineteen TOs. Variety type and crop spatial distribution were the
308 strategical choices of the farmer. Tillage, irrigation, pest management, fertilization and
309 harvesting were tactical and operational choices. As far as soil preparation is concerned,
310 farmers had the same practice of ploughing and leveling. Two choices for the varieties were
311 possible, with on the one hand local varieties of chili-pepper, enabling seed reuse, purchased
312 from a nursery or grown on-farm; and on the other hand, hybrid varieties exclusively
313 purchased, yearly, from professional nurseries.

314 In addition, different strategies of planting date and spatial arrangements were observed.
315 Chili-pepper could be associated to leguminous, watermelon or melon and olive groves. Data
316 concerning overall water consumption, unavailable, were not taken into account. Two
317 irrigation strategies were however observed, with the use – or not – of water stress periods,
318 ranging from 10 to 30 days, which « allow good root development », according to farmers.
319 Farmers have access to a wide range of plant protection products, applied on the basis of trade
320 names rather than active substances. As far as fertilization is concerned, nutrient supply was
321 mainly by fertigation. Foliar and soil applications were also common, depending on the
322 strategies and product. Further, the harvest was very dependent on workforce and sale prices.
323 The latter determined the dates and color of fruit at harvest.

324 Table 2: Technical operations (TO), and their defined modalities, used for the MCA and next steps of the study. Each TO has two to four
 325 modalities. NOFA = No Organic Fertilizer Application, SAP = Soil Application before Planting, SAPF = Soil Application before Planting
 326 and Fertigation, SAPP= Soil Application before Ploughing and Planting. Early planting =before April; in-season planting = from April to
 327 May; off-season planting = from June to August. * less than 15 days after planting; ** more than 15 days afetr planting. NA: No answer

TMR steps	TO	Modality 1	Modality 2	Modality 3	Modality 4
Tillage	Weeding / Hoeing	Early*	Late**	No tillage	
Variety choices and crop spatial distribution	Variety	Hybrid	Local		
	Planting strategy	Early planting	Season planting	Off-season planting	Regrowth
	Association with leguminous	No	Association	Relay	
	Association with trees	No tree	Extensive density	Intensive density	
Irrigation	Association with cucurbitaceae	Yes	No		
	Water stress	Yes	No		
Pest management	Number of pesticide applications	0	[1,4]	(4,8)	> 8
	Organic fertilization mode	NOFA	SAP	SAPF	SAPP
Fertilization	N (kg.ha ⁻¹)	(0,50]	(50,100]	(100,150]	(150 -300]
	P (kg.ha ⁻¹)	0	(0,60]	(60,120]	(120 - 200]
	K (kg.ha ⁻¹)	0	(0,20]	(20,40]	(40 - 100]
	Ca (kg.ha ⁻¹)	0	(0,20]	> 20	
	Mg (kg.ha ⁻¹)	0	(0,5]	(5,20]	
	Ternary fertilizer leaf application	Yes	No		
Harvesting	Synthetic bio-stimulant use	Yes	No		
	Harvest regularity	Continue	Stepped		
	Crop residue management	NA or late return	Early return	grazing and restitution	
	Crop color harvest	Green	Red	Green and Red	

328

329 3.2 MCA and clustering

330 The MCA was performed on 45 TMRs, described by the 19 TOs. The total inertia was 1.947,
 331 the two first factorial maps explained 41% of total inertia Results were interpreted on the first
 332 two factorial planes.

333 The two first axes (Fig 4 (a)) opposed intensive treatment and fertilization strategies, which
 334 can be described as conventional, with more moderate strategies. The former was closely
 335 linked to the use of hybrid varieties, high levels of fertilization and phytosanitary treatment on
 336 the left-hand side. On the right-hand side, axis 1 is linked to the use of local varieties and
 337 much more moderate input use. It also highlights weed control strategies, off-season planting
 338 strategies, or preferable fruit color at harvest. The absence of organic fertilization at the
 339 beginning of the cycle is expressed on axis 2. Axes 3 and 4 (Fig 4 (b)) express the use of
 340 ternary fertilizers and the integration of leguminous in the association. They are also
 341 associated with medium to high phytosanitary treatment classes and the highest chemical

342 nitrogen inputs. In addition, axis 4 reflects to some extent early planting strategies, and the
343 harvesting of both red and green fruits.

344 The AHC, resulting in seven clusters was carried out on the coordinates of the individuals on
345 the four dimensions of the MCA and explained 66% of total variability. Fifteen variables
346 contributed to the classification, consisting essentially in: planting strategies, number of
347 pesticide applications, weeding/hoeing, harvest regularity, N, P, K, Ca, and Mg quantities,
348 organic fertigation method, choice of variety, application or not of water stress, association
349 with trees, association with cucurbitaceae, and use of bio-stimulant. The MCA coupled with
350 the AHC results (Table 3) showed an opposition between conventional and chemical input
351 intensive TMRs generally applied to hybrid varieties (cluster 1 and 2) and organic and
352 moderate TMRs associated with local pepper varieties (cluster 5 and 6).

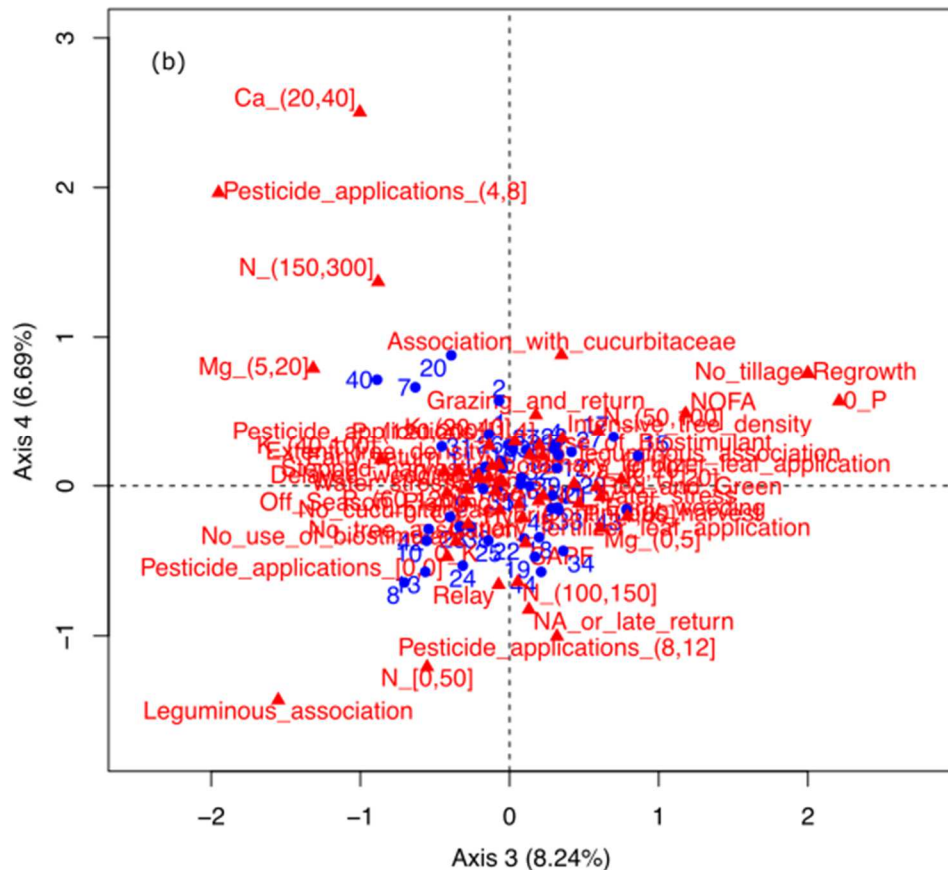
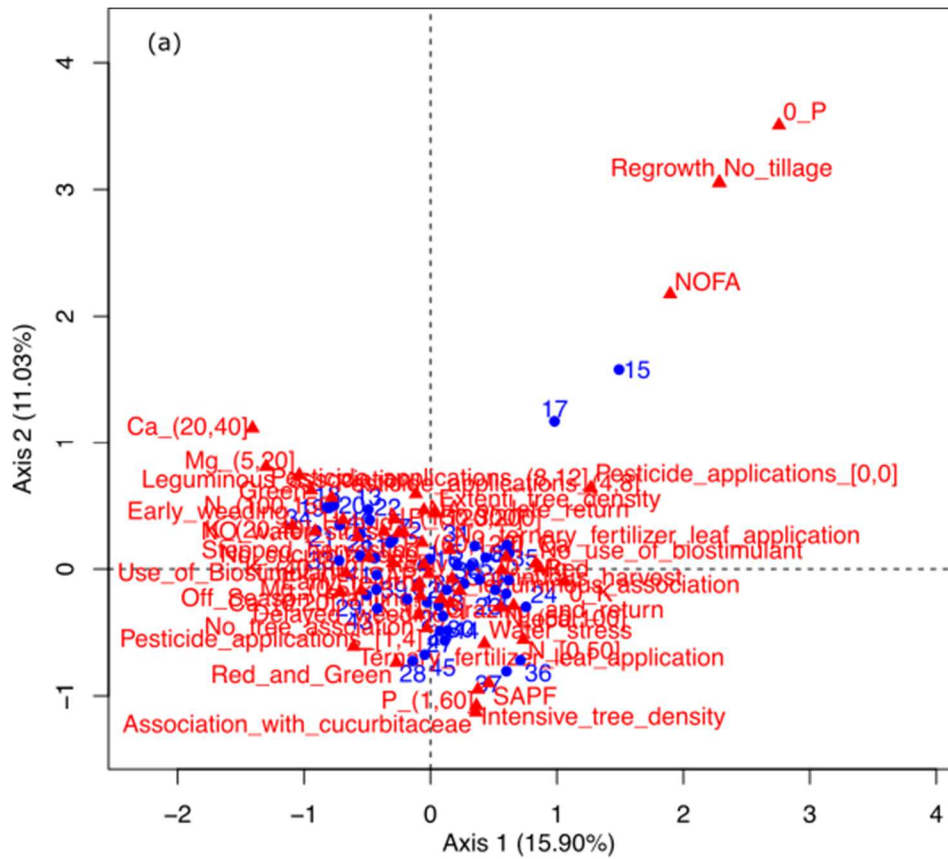
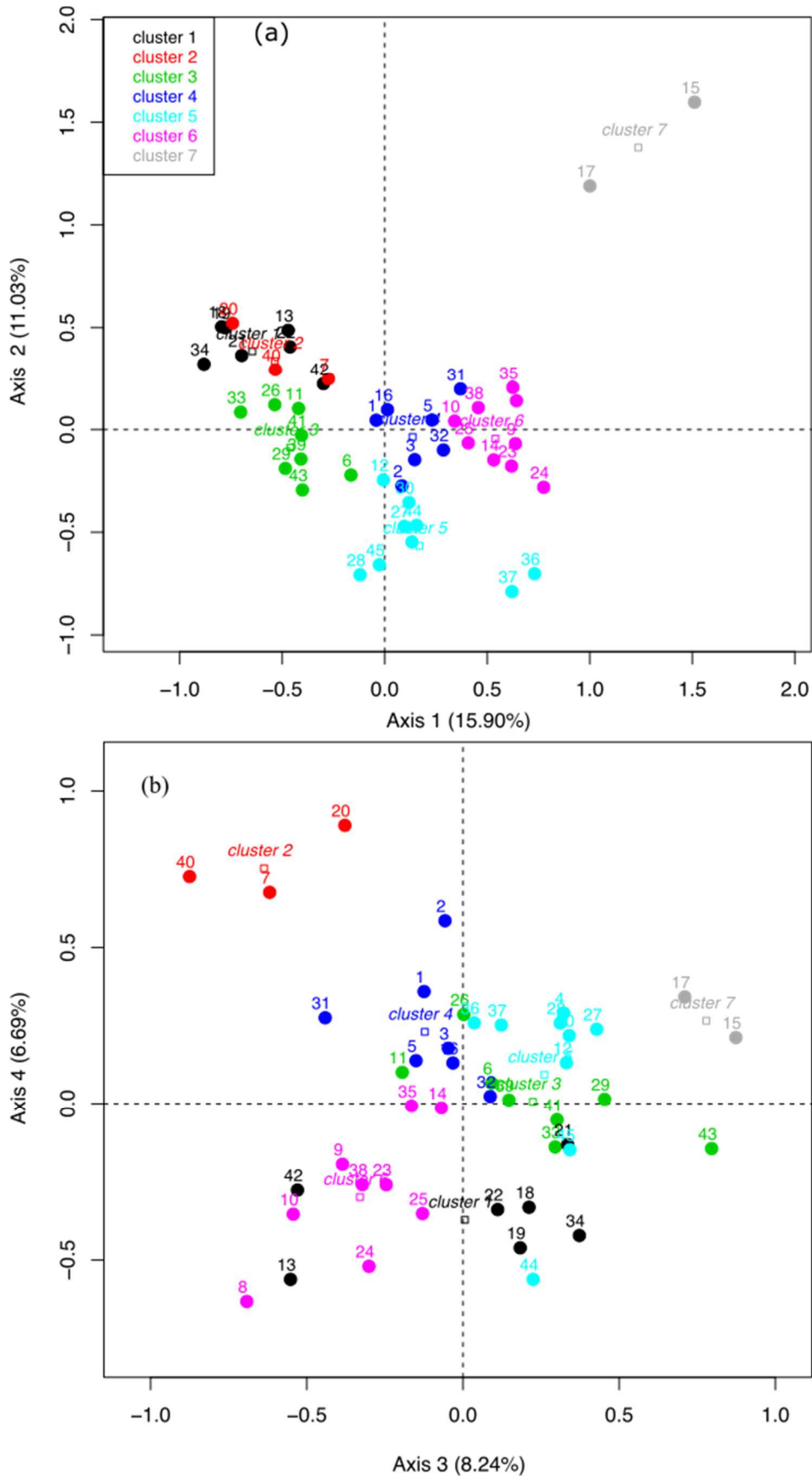


Fig. 3. MCA plot of individuals and variables (TOs) modalities

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Fig. 4: factor map of (a) axis 1 and 2 and (b) axis 3 and 4 with clusters in color. The barycenter of each cluster is represented by a square

360 Clusters 3 and 4 could be assimilated to mixed strategies at an intermediary position between
 361 the systems of clusters 1 and 2 on the one hand, and the moderate and low-input systems of
 362 clusters 5 and 6 on the other hand. Indeed, cluster 3 contains strategies not driven by pesticide
 363 use and N inputs, potentially applied to hybrid varieties. N and P driven TMRs are present in
 364 cluster 4, potentially applied to local varieties.

365 Table 3: Cluster description. Modalities very significantly and significantly linked to the cluster are set in bold
 366 and italic, respectively. NOFA = No Organic Fertilizer Application, SAP = Soil Application before Planting,
 367 SAPF = Soil Application before Planting and Fertigation. Total rating: < 2: low; [2, 6[: neutral; [6, 10[: medium
 368 high; > 10: high.

Cluster name	Cluster (axes of interpretation)	Modality linked	Number of individuals	Total rating
Chemical input intensive and pesticide driven	1 (1-2-4)	Hybrid variety, >8 pesticide applications, 100-150 kgN.ha⁻¹, off-season planting strategies, early weeding, use of synthetic bio-stimulant, no water stress, green fruit harvest.	7	-1
Chemical input intensive and N driven	2 (1-3-4)	5-8 pesticide applications, 150-300 kgN.ha⁻¹, 5-20 kg Mg.ha⁻¹, green fruit harvest, off-season planting.	3	-2
Intermediary strategies	3 (1-3)	Red and green fruit harvest, no tree association, <20 kg Ca.ha⁻¹, SAP.	9	2
N and P driven	4 (4)	<i>150-300 kgN.ha⁻¹, 120-200 kgP.ha⁻¹, red fruit harvest.</i>	7	3
Moderate strategies	5 (2)	SAPF, 1 - 60 kg P.ha⁻¹, association with cucurbitaceae, season planting, water stress application, 1 to 4 pesticide application, 50-100 kgN.ha⁻¹, < 20 kgK.ha⁻¹.	8	9
Very low chemical input strategies	6 (1-3-4)	Local varieties, no pesticide application, no use of K, no use of Ca, no use of Mg, no use bio-stimulant, < 50 kgN.ha⁻¹, red fruit harvest.	9	7
Regrowth strategies	7 (1-2-3)	No pesticide application, no use of P, no tillage, regrowth, NOFA.	2	8

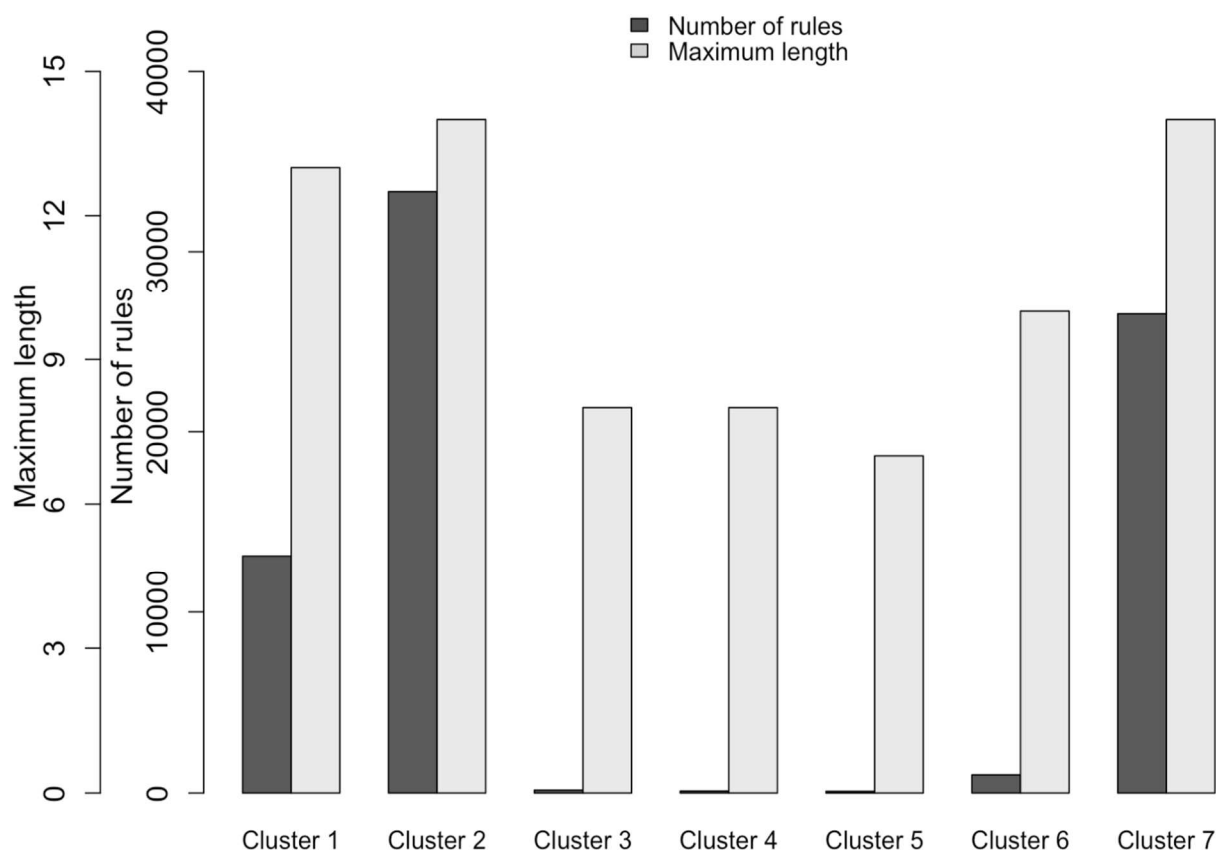
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370 3.3 Association rules and cluster

371 The objective of data mining, which generated the association rules, was to identify additional
 372 TOs linked to TMRs and not identified at previous steps, and to assess cluster homogeneity.
 373 Minimum support S_m was set to 0.044. The results showed that the TMRs in clusters 3, 4 and
 374 5 were much less homogeneous than clusters 1, 2, 7 and to some extent 6. Indeed, Fig. 5
 375 shows a large number of rules for clusters 1, 2, 7. Conversely, clusters 3 to 5 had a low
 376 number of associations. This is supported by the maximum length of rules for clusters 3, 4

377 and 5, which was lower compared to the other clusters. In other words, out of the 19
 378 operations defining a TMR, there are in cluster 5, for instance, a maximum of 7 TOs common
 379 to at least half of the TMRs constituting this cluster, compared to 13 for cluster 1 and 10 for
 380 cluster 6. Additional TOs were identified through this process. These are included in the
 381 complete description of clusters presented in the following section.

382



383
 384 Fig. 5. Number of rules for each cluster and maximum length of rules in clusters.

385 3.4 Description of the seven clusters of TMRs

386 Figure 6 integrates the overall analysis of the results of MCA, ACH and data-mining, and
 387 shows the most representative TMR of each cluster. It shows the TOs linked to each cluster,
 388 used to compute the rating of the degree of agroecology (Table 3).

389 *Cluster 1*, constituted of rather homogeneous individuals, described a TMR using hybrid
 390 varieties, intensive in terms of pesticide applications but moderate in terms of chemical
 391 nitrogen fertilization (100 – 150 kg N.ha⁻¹). Planting is done off-season (July-August), with an

392 early weeding. For this TMR, there is no water stress period in the irrigation calendar,
393 harvesting is often done when the fruits are green. In addition, this cluster is characterized by
394 the use of synthetic bio-stimulants and a late return of crop residues. The cluster 1 had a high
395 potential impact so, these TMRs are considered as non-environmental-friendly.

396 *Cluster 2*, equally homogeneous in nature, consisted in more intensive TMRs with regard to
397 chemical nitrogen fertilization, but moderate in terms of pesticide application. It was
398 characterized by off-season plantation and green fruit harvesting. Further, this cluster had a
399 high potential environmental impact, thus these TMRs are considered as non-environmental-
400 friendly.

401 *Cluster 3* was characterized by chili-pepper cultivation non associated to trees, the use of bio-
402 stimulant, the application of organic fertilizers before planting and the harvest of both red and
403 green fruits. These TMRs were mostly associated with hybrid varieties with a relatively low
404 number of treatments (one to four treatments). They were also characterized by significant Ca
405 and Mg inputs. Cluster 3 was very heterogeneous, particularly with regard to nitrogen
406 fertilization, and is the only cluster not linked to any modality of this variable. This cluster
407 had a neutral potential impact meaning that these TMRs are intermediary between non-
408 environmental-friendly and environmental-friendly TMRs.

409 *Cluster 4* was characterized by very high chemical fertilizer inputs (150 - 300 kg N.ha⁻¹; 120 -
410 200 kg P.ha⁻¹, 40 - 100 kg K.ha⁻¹), and red-fruit harvesting. These TMRs were applied mainly
411 to local varieties with a neutral potential environmental impact. Thus, the TMRs in this cluster
412 are intermediary on the aforementioned agroecological scale.

413 *Cluster 5* described systems with moderate inputs, characterized by the supply of organic
414 fertilizers by fertigation relatively low nitrogen chemical fertilizer inputs (50-100 kg N.ha⁻¹)
415 and a relatively low number of pesticide applications (<4). This cluster essentially
416 corresponded to a TMR involved in local varieties planted in April-May. These almost always

417 i) comprised periods of water stress in the irrigation schedule, and ii) included association of
418 chili-pepper with cucurbitaceae. The TMRs in cluster 5 are moderately environmental-
419 friendly as this cluster had a medium low degree of impact.

420 The TMRs in *cluster 6* were very moderate in terms of chemical inputs, with no use of
421 calcium, magnesium, potassium, nor bio-stimulant fertilizers. Chemical nitrogen inputs were
422 very low (<50kg N.ha⁻¹), and no application of pesticides was observed. However,
423 phosphorus inputs were high (120-200 kg P.ha⁻¹).

424 These TMRs were applied to local varieties with no pest management. Fruits were harvested
425 red. They are moderately environmental-friendly.

426 *Cluster 7* presented an atypical farming practice. Indeed, it described management routes that
427 were part of a two-season growing cycle, during which the residues of the first growth season
428 were cut to initiate a second cycle by regrowth. This cluster 7 which described the second
429 cycle, was characterized by rare interventions of the farmer, with no hoeing nor application of
430 bottom manure at the beginning of the growth cycle. It was also characterized by a total
431 absence of pest management. This cluster included only two individuals and is also
432 considered as moderately environmental-friendly.

433 This thorough description highlights that at the territorial scale, farming practices were very
434 diversified and contrasted. TMRs of cluster 3 and 7 were less common in the dataset. These
435 TMRs contained very particular TOs probably rare at the territorial scale. Note that there was
436 a wide range of alternatives to TMRs of cluster 1 and 2.

437 Further investigation of the potential environmental impact of the TMRs of each cluster
438 suggests that despite this contrast, not one cluster can be seen as environmentally-friendly
439 regarding all aspects of the TOs. Indeed, almost all the clusters were all a combination of of
440 (non)-agroecology-compatible TOs (Fig. 6b), even though some were more moderate than
441 others. For instance, as far as chemical fertilization is concerned, farmers commonly applied

442 high amounts of at least one N, P or K fertilizer. At the same time, all the clusters from 1 to 5
443 were characterized by the use of organic fertilizers, which is an additional supply of fertilizer.
444 Such behavior may be explained by the fact that in most cases, farmers tend to attribute a
445 specific role to each type of fertilizer, then, the amounts applied are defined independently.
446 Further, despite the non-environmental-friendly characters of clusters 1 and 2, they also
447 included some agroecology-compatible TOs. The most frequent, olive grove agroforestry,
448 which offers increased economic benefits, is often undertaken on rented land. This suggests
449 that some farm structural information, such as land tenure, could be linked to specific TMRs.
450

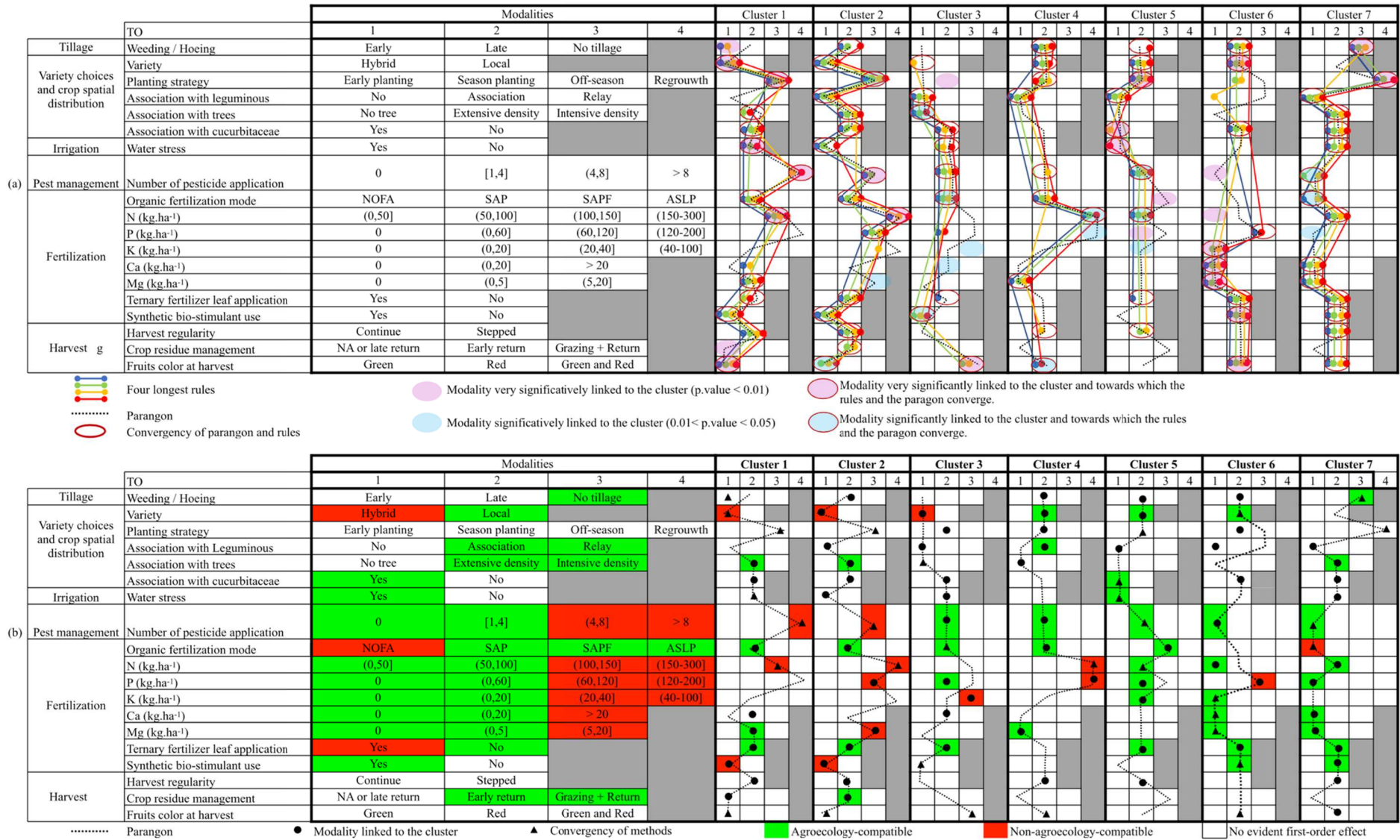


Fig. 6: Description of TMRs. (a) TOs linked to each cluster according to the three MCA, AHC and data-mining steps. (b) Schematic representation of the same results, highlighting the potentially agroecological TOs according to literature.

452 3.5 Identifying farm types associated to each TMR

453 This section describes the key farm structural indicators linkable to each cluster. With the
 454 strong presence of arboriculture in the region and within the sample, Table 4 shows that this
 455 criterion characterizes the majority of farmers of all clusters. The same is true for grain
 456 farming and market garden crops in general. In addition, Table 4 distinguishes farms rather
 457 involved in environmental-friendly TMRs and those implementing non-environmental-
 458 friendly TMRs. Indeed, tenant farmers, oriented towards arboriculture, and vegetable crops of
 459 high added value, in particular cucurbitaceae (watermelon and/or melon), which consume a
 460 lot of water, were typically associated with non-environmental-friendly TMRs of clusters 1
 461 and 2.

462 Table 4: Plots and characteristics of farms: for each cluster, percentage of plots located in
 463 farms having each criterion. UAA: useful agricultural area.

Cluster	1	2	3	4	5	6	7
Sample size	7	3	9	7	8	9	2
UAA (ha)	27.4 ± 25.1	51.3 ± 14.1	29.3 ± 19	15.9 ± 8.5	12.8 ± 11.8	10.3 ± 10.1	17.3 ± 20.9
<i>Access to water</i>							
Individual drilling (%)	86	100	78	71	75	22	50
Collective network (%)	14	0	22	29	25	78	50
<i>Access to land</i>							
Direct (%)	0	0	33	29	38	22	0
Indirect (%)	29	0	11	29	38	33	0
Direct & indirect (%)	71	100	56	43	25	44	100
<i>Production</i>							
Grain farming (%)	71	67	100	86	75	56	50
Cucurbitaceae (%)	100	100	67	86	100	78	100
Arboriculture (%)	85.71	100	100	100	87.5	89	100
Leguminous (%)	43	0	11.11	43	25	78	50
Livestock (%)	57	0	33	71	75	78	100

464

465 Due to high water needs, their access to water is almost exclusively through individual
 466 drilling. The farmers in these two groups seek maximum productivity and therefore tend to
 467 invest heavily in inputs, plant protection products and even land. They generally owned a
 468 piece of land to which rented plots were added. Consequently, their Useful Agricultural Area
 469 (UAA) might be relatively high, compared to other clusters. Since plot renting is often of

470 short duration (1-2 years), they often do not have a long-term land management plan. This is
471 rather the responsibility of the owner. However, tenants pay particular attention to crop
472 history, and generally rent plots that have not been used in the previous crop year.

473 Land owners (“direct access” category) generally adopted TMRs of cluster 3, 4, 5, or 6. They
474 paid special attention to crop rotation. Thus, they were often very diversified in terms of crop
475 cultivation. In most of cases, non-environmental-friendly TMRs (clusters 1 and 2) have
476 relatively low UAA. In addition, TMRs of cluster 6 were more likely associated to farms
477 connected to a collective water network, that further cultivate leguminous or cucurbitaceae
478 associated with livestock. Thus, it might possible to identify farmers adopting TMRs of
479 cluster 6.

480 To sum up, a (non-)environmental-friendly field might be identified, regarding its farmer’s
481 type of access to land. If all or most of the lands are rented and farmer has a large investment
482 capacity, the latter might tend to have a behavior of cluster 1 and 2. If the farmer is a land
483 owner, diversified in production, connected to a collective network with a relatively small
484 UAA, he might have a behavior of cluster 6. It seems more complex to find a typical farm for
485 the clusters 3, 4, 5 and 7, taken individually.

486 4 Discussion

487 This study set out with the aim of thoroughly describing farming practices in a semi-arid
488 Mediterranean irrigated area under multiple constraints, hypothesizing that i) these constraints
489 lead to a diversity of farming strategies and, ii) within this diversity, some interesting
490 environmental-friendly TMRs (Technical Management Routes) adapted to these conditions
491 could emerge. After presenting the advantages and limits of the methodology, the results are
492 discussed relative to these aspects.

493 The methodology employed allowed to describe the diversity of farming practices among a
494 diversity of farms, and we were able to identify some typical farm characteristics linked to

495 some farming practices. The method we used to obtain these results is robust. The statistical
496 tools used were indeed complementary and converged in most of cases. The method of
497 typology, combining hierarchical classification and multivariate analyses, showed the main
498 characteristics of the clusters. The data mining completed the analysis by highlighting
499 additional TOs (Technical Operations) linked to them and their homogeneity. The points of
500 non-convergence could be due to the interpretation criteria. Indeed, TOs present in less than
501 half of the individuals in a cluster, whose weight in relation to the total sample is relatively
502 high, and which are described as group specific TOs by the classical method, were not
503 retained in the interpretation of the results. As these operations are present in less than 50% of
504 the individuals in the group, they are not taken into account in the association rules.

505 Clusters 2 and 7 must be interpreted with caution because of their small size. A limit of the
506 method is the long time required to do interviews. Another important point is that in the North
507 African context, it is difficult to obtain reliable information on certain variables (yield,
508 irrigation doses), in the absence of precise monitoring by the farmer.

509 Further, our findings support the statement that multiple TMRs can exist together in a
510 relatively small territory, with the identification of highly contrasted clusters. It is a way to
511 evaluate the co-existence of farming practices in an area. Our method is intended to be
512 holistic and systemic as it integrated all the TMRs steps described by Wezel et al. (2014).
513 Indeed, five types of management steps can be distinguished to describe a TMR: i) practices
514 addressing crop and variety choices, crop spatial and temporal arrangements and successions;
515 ii) tillage practices; iii) fertilization practices; iv) irrigation practices; and v) weed, pest, and
516 disease management practices (Wezel et al., 2014). Our method also took into account the
517 farmer's operating logics at the farm level, and the interactions between various components
518 of this system. These have not previously been described. Indeed, much work has been done
519 on the diversity of farms (Bellon *et al.*, 2001; Köbrich *et al.*, 2003; Maton *et al.*, 2005;

520 Poussin et al., 2008; Blazy *et al.*, 2009; Azizi *et al.*, 2017; Ibidhi et al., 2018), but very little
521 on the diversity of farming practices (Renaud-Gentié et al., 2014; Czyrnek-Delêtre et al.,
522 2018). These results are based on reliable data obtained after in-depth discussions with
523 farmers. To our knowledge, this study is the first to implement this method on annual crops,
524 confirming its applicability in a wider context than previous studies focused on vineyard.

525 The findings showed that none of the TMRs was thought in an agroecological perspective.
526 Rather, these appear to be a combination of agroecology-(non)-compatible TOs, especially
527 concerning fertilization practices and pesticide uses. Locally, one of the issues that emerges
528 from these findings is that farmers commonly have a problem of fertilization management.

529 Our study highlights the necessity for public policies, to encourage transition toward more
530 environmental-friendly TMRs in opposition to the current tendency. Indeed, in general, it
531 came out of discussion during surveys that TMRs likes those of cluster 1 and 2 are considered
532 to be the “best” and “most productive” by the majority of farmers. The implementation of
533 alternative practices is often due to economic reasons, as these are relatively less expensive.

534 This supports previous findings showing that setting up market gardening (Azizi et al., 2017)
535 and implementing agroecology-compatible practices (Ameur et al., 2020) are driven by the
536 cash flow of the farms and the cost of inputs. Thus, considering the number of tenant-like
537 farm types (mostly powering TMRs likes those of cluster 1 and 2) is increasing since last
538 decade based on additional land rentals and high added value crops (Azizi et al., 2017),
539 environmental-friendly TMRs may be much less prevalent in the future if no action is taken.

540 Furthermore, despite the high value of N inputs in clusters 1 and 2, most values observed in
541 this study remain inferior to the optimum values presented in previous studies. Indeed,
542 previous findings suggest that the optimum value of N fertilization to maximize the
543 profitability of chili-pepper cultivation in drip irrigation was 252 kg N.ha⁻¹ (Hartz et al., 1993)
544 and 227 kg N.ha⁻¹ (Zhang et al., 2010). In contrast, the observed values for P application were

545 largely superior to theoretical requirements, in most of cases. Indeed, the optimum amount of
546 P application for chili-pepper was estimated at 40 kg P.ha⁻¹ by Emongor and Mabe (2012).
547 These are however to be taken with precaution, as pedoclimatic conditions also influence
548 fertilizer requirements. It is important to bear in mind that the practices related to the
549 moderate and low input clusters are not presented as agroecological systems *per se*. However,
550 they contain a lot of single interesting and agroecology-compatible TOs. These results allow
551 us to reassess the paradigm tending to associate irrigated agriculture to intensification and
552 pollution. The findings provide further support for the hypothesis that smallholder farming in
553 irrigated areas may allow the emergence of more environmental-friendly or agroecological
554 farming practices. This study hence challenges research in agroecology in semi-arid irrigated
555 landscapes in the Southern Mediterranean. It confirms the existence of a large range of
556 agroecology-compatible practices at the plot level found by Ameur et al. (2020). Can these
557 form a basis for conceiving locally-adapted, adoptable and more environmental-friendly and
558 viable TMRs? The answer is not straightforward as the interactions among TOs and their
559 relations with the farm-scale strategies are crucial to conceive such TMRs. At least, the high
560 diversity of agroecology-compatible practices found in the region can be a basis towards a
561 large-scale increase of resource-use efficiencies of existing TMRs. Thus, actions can be taken
562 based of these practices to initiate the first steps of the Efficiency-Substitution-Redesign
563 (ESR) process (Hill, 1998) of the agroecological transition. However, combining the
564 agroecology-compatible practices found (such as agroforestry, leguminous integration, use of
565 organic fertilizer etc., reduced pesticide use, use of local varieties, etc.) within new
566 ecological-based TMRs might have social, economic and even agronomic coasts. For
567 instance, agroforestry might generate addition income but reduce cultivated area of green
568 market crops. The use of homemade organic fertilizers can contribute to reduce the
569 production costs but may require increased workload. The use local varieties most resistant to

570 pest attacks can also reduce production but in return, can also lead to lower yields. In
571 addition, resource-use efficiencies highly depend on farmers' irrigation and fertilization
572 strategies which have not been studied in detail. It thus remains to evaluate whether the design
573 of ecological-based TMRs, based on the agroecology-compatible practices found, might be
574 viable on these three axes through an agroecological assessment. More in-depth socio-
575 economic, environmental and agronomic assessments of current and future TMRs, taking into
576 account the whole production systems need to be undertaken.

577 Furthermore, our results support those observed earlier by de Lattre-Gasquet et al. (2017)
578 describing some trends in favor of agroecological uses of land in Tunisia. The findings could
579 allow stakeholders in charge of agriculture to better focus their action, to support smallholder
580 farming through agroecology. Indeed, with such a diversity of farming practices, it is
581 important to differentiate and adapt the support policies. The study can also contribute to a
582 broader field of research on regional diversity of cropping practices. The article defined the
583 key TOs related to each TMR and the types of farms implementing them. On the one hand,
584 the regional representativity of these different chili-pepper TMRs could be more easily
585 obtained by carrying rapid interviews on these key variables on a larger sample. On the other
586 hand, the method could also be applied to the other major regional crops. The findings are
587 also interesting for further research as far as previous studies of modeling or assessment of the
588 environmental impact of the practices in the study zone, did not take into account this
589 diversity (Pradeleix et al., 2012; Massuel et al., 2017; Jouini et al., 2018) or only partly
590 (Pradeleix et al., 2018). Although the study evaluated neither the agronomic nor
591 environmental performances of the TMRs, one simplistic assumption could be that the less
592 environmental-friendly TMRs mostly linked to hybrid varieties lead to higher yields. Indeed,
593 "hybrid varieties are far more productive than local varieties" according to farmers. This
594 statement has been confirmed by additional investigations (Chloé Morel, unpublished report,

2018; Akakpo et al., unpublished data, 2019) showing that in general, yields range from less than 12 T.ha⁻¹ for the chili-pepper local varieties to up to 70 T.ha⁻¹ for hybrid varieties. Hence, cluster 1, 2, and 3, mostly associated to hybrid varieties can be considered as most productive, generating in general, up to 70 T.ha⁻¹. Inversely, cluster 4, 5, 6 and 7 can be considered as much less productive, less than 12 T.ha⁻¹, as these clusters were basically associated to local varieties. However, a mix of (non)-environmental-friendly TMRs were applied to both varieties. So, in terms of agro-environmental performance of the TMRs, one can speculate that high productivity and low environmental impacts can be achieved in systems applying environmental-friendly TMRs to hybrid varieties. Indeed, the current study, based on interviews, could not precisely take into account the outputs of the studied systems, in particular yields. The qualitative assessment of the impact of TMRs and the addition of scores of TOs different in nature and with potentially very different types of impact on the environment are a limit of the study. To have objective and realistic conclusions, this assessment requires precise monitoring of TMRs, in particular of irrigation and fertilization strategies. The paragon is typical cases that could be studied for such a purpose.

5 Conclusion

Returning to the hypothesis formulated at the beginning of this study, we can state that at the territorial scale, farming practices in the Merguelil irrigated plain are very diversified. One of the most significant findings to emerge from this study is that technical management routes of chilli-pepper crop are very contrasted. In a qualitative manner, the findings enable to answer the main question of the study by stating that environmental-friendly technical management routes exist within the conventional agriculture known for this region. Yet, farmers seem to have a common problem of fertilization management and pesticide use. The study challenges research in agroecology in semi-arid irrigated landscapes. It gives a broader hypothesis for further research to reassess paradigms tending to oppose irrigated agriculture to agroecology.

620 Further research might investigate the cumulative environmental impact of the studied TMRs,
621 and their relationship to yield diversity. However, this poses a methodological problem, as it
622 requires costly monitoring often difficult to implement in real and poorly gauged farming
623 conditions.

624

625 Declaration of Competing Interest

626 None

627

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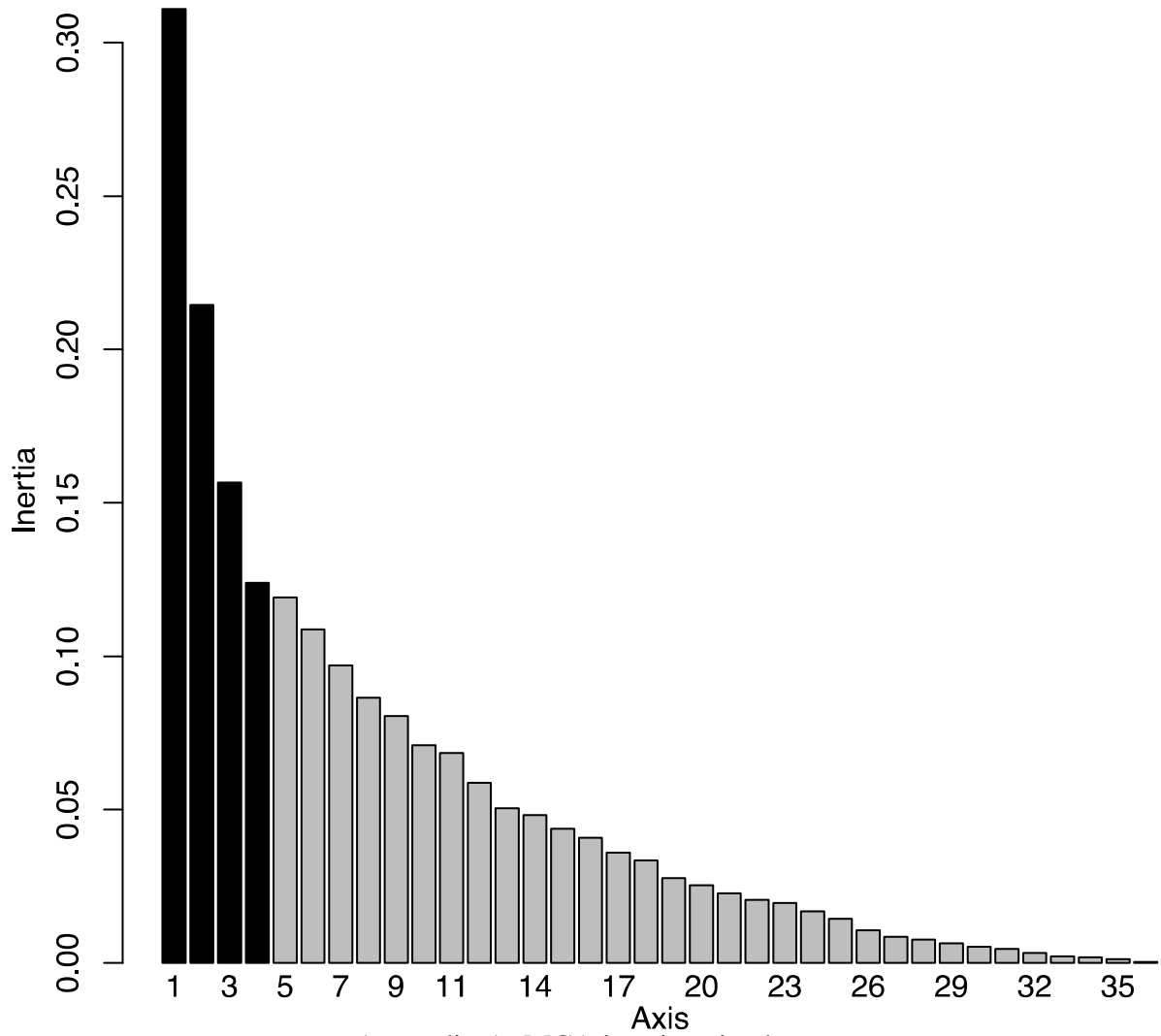
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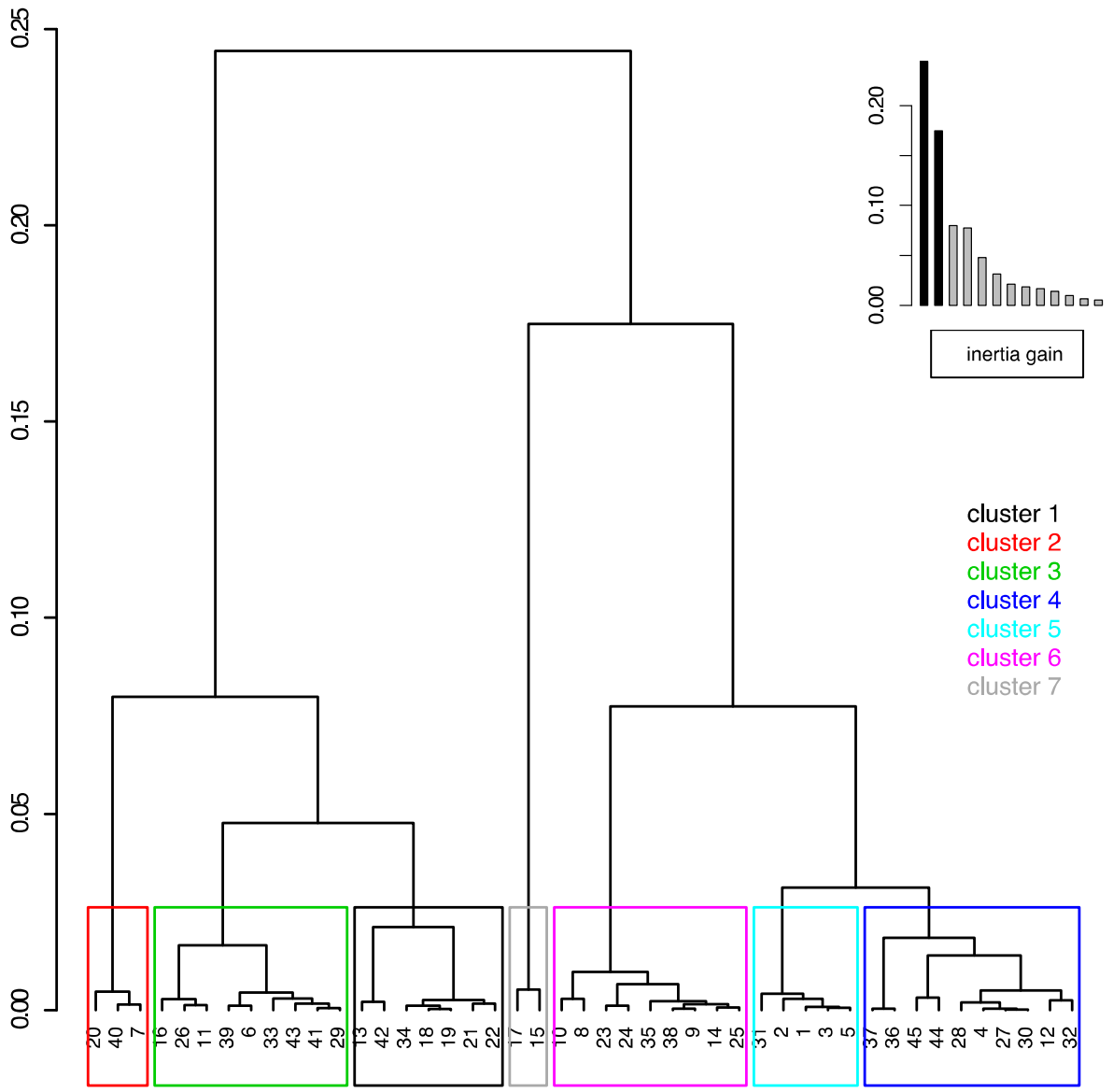
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790 Appendix



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Appendix A: MCA inertia gain chart



Appendix B. AHC tree with TMR clusters and AHC inertia gain chart

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