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1 **Long-term maintenance of grasslands on dairy farms is associated with redesign and**
2 **hybridisation of practices, motivated by farmers' perceptions**

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8

9 **Abstract:**

10 Despite a constant decline in grassland areas between the 1970s and 2010 at the regional and
11 national scale in France, in particular on lowlands, grasslands have been maintained locally.
12 This raises questions about long-term changes on the farms involved in these dynamics,
13 particularly with regard to the relation between the evolution of the role of grasslands in
14 production processes, and farmers' perceptions of fodder systems within production systems.
15 Our research concerned three peri-urban cantons in Brittany, where we examined grassland
16 practices over the long term and farmers' perceptions of grasslands in a sample of 15 farms
17 within the area where grasslands were maintained. First, we modelled pathways of the place
18 and roles of grasslands on farms, based on criteria of quantitative presence, management, and
19 valorisation. Second, we characterised the farmers' perceptions of grasslands and the fodder
20 system. We then performed combined analysis of these pathways and perceptions. The
21 maintenance of grasslands was found in a diversity of pathways in which grasslands were
22 used to a medium and large extent in the fodder systems. These changes occurred either
23 through a complete redesign of the fodder system or through hybridisation of practices aimed
24 at obtaining dairy systems that were more intensive yet more agri-ecological. The pathways

25 that gave a new place to grasslands in the fodder system were related to farmers' perceptions
26 marked by a fading opposition between grasslands and maize farming. They attributed
27 additional value – in terms of animal welfare, economics, or agronomy – to grasslands in a
28 mixed maize/grassland fodder system.

29 **Keywords:**

30 grasslands, livestock farming systems, longitudinal study, pathway typology

31

32 **1. Introduction**

33 Grasslands constitute a multifunctional agronomic object that meets multiple challenges faced
34 by agriculture today (Gibon, 2005). Research initiated during the 2000s (Hervieu, 2002)
35 shows that they are beneficial with regard to both zootechnical and economic aspects at the
36 farm scale (Alard *et al.*, 2002; Garambois and Devienne, 2012; McCarthy *et al.*, 2007) and,
37 more broadly, to environmental externalities (Allard *et al.*, 2007; An *et al.*, 2017; Hopkins and
38 Holz, 2006). Yet the modernisation and intensification of agriculture led to a decrease in
39 grassland areas of almost 25% from 1960-2005, due to transformations in production models
40 and the feeding of ruminants (Huyghe, 2009). This reduction in grasslands, particularly
41 permanent grasslands, is found in France and, more broadly, in many other European
42 countries. It mainly concerns grassland livestock farming areas where intensive breeding
43 systems have developed (Huyghe, 2005; Huyghe *et al.*, 2014). Yet despite this decrease,
44 notably in the 2000s, there are still areas where grasslands have been maintained (Couvreur *et*
45 *al.*, 2016) and where it is possible to produce fodder crops other than grassland. This raises
46 questions about why they have been maintained at the farm scale, and thus they constitute
47 situations of particular interest. A typical case is an area composed of three cantons around
48 the city of Rennes (Brittany, France), where grassland areas remained stable from 2000-2010

49 even though they decreased everywhere else in Brittany. The region around Rennes has an
50 agrarian landscape whose main features are predominantly intensive dairy production;
51 pedoclimatic conditions that allow farmers to grow other fodder crops and cereals; and a high
52 level of urbanisation which could limit the movement of animals and farm vehicles, thus
53 limiting grazing and crops that require significant mechanised intervention. Petit *et al.* (2017)
54 argue that the high density of dairy farms and the diversity of dairy-product chains (including
55 organic farming and those based on grazing), combined with new social values among local
56 consumers regarding farming systems and agricultural production models, may however
57 actually have been mechanisms favouring the evolution of practices through grassland
58 maintenance. Yet, because its scale was based on a regional approach, this study could not
59 identify reasons for grassland maintenance over the long term at the farm scale, nor explain
60 why farmers maintain or increase grasslands on their farms. Thus, we decided to analyse the
61 maintenance of grasslands at the farm scale.

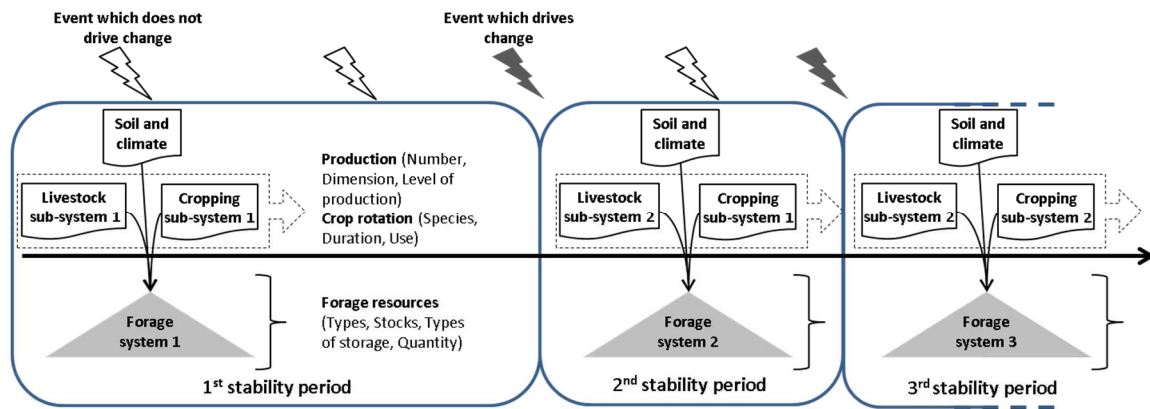
62 A wide diversity of livestock management practices exists at the farm scale, resulting from
63 farmers' choices of production orientation. Boisdon *et al.* (2016) have shown, with regard to
64 grasslands, that with similar environmental potential, grazing techniques may differ,
65 depending on the production choices. The maintenance of grasslands is therefore likely tied to
66 the main scale of decision making behind their establishment: the farm (Brunschwig *et al.*,
67 2006; Girard *et al.*, 2001; Gueringer *et al.*, 2009; Thenail *et al.*, 2009) Accordingly, the place
68 of grasslands at the farm scale is determined by the roles that farmers give them in the
69 execution of their production strategy, and by the perceptions that they have of grassland uses:
70 (i) feasibility with regard to structural dimensions (land-related, field-related, labour); (ii)
71 roles in the fodder system (fodder stores, search for flexibility and/or security); (iii) roles in
72 feeding animals (zootechnical value of fodder); and (iv) roles in the cropping system to obtain
73 agronomic (crop rotation) or environmental (water quality in a catchment) benefits. Therefore,

74 to understand reasons for the maintenance of grasslands at the farm scale, our research
75 focuses on the transformations of grassland practices in the long term, related to farmers'
76 understanding of grasslands. To study changes in grassland surface areas and their uses at the
77 farm scale, we used a combination of analysis frameworks for farm pathways over the long
78 term (Ickowicz *et al.*, 2010) and research on the management of grazing systems (Duru and
79 Hubert, 2003). To identify farmers' perceptions of grasslands considered to be determinant
80 factors in grassland use, we applied a sociological framework based on analysis of farmers'
81 statements to highlight the meaning that they ascribe to their practices.

82 **2. Materials and methods**

83 **2.1. Initial definitions**

84 We define a pathway as the path followed by one or more farms over time (Figure 1). A
85 pathway is a sequence of stability periods (StabP) and events that may modify the operation
86 of the production system (Moulin *et al.*, 2008). The production system is defined as the
87 relation between a farm's cropping sub-system (Sebillotte, 1990) and livestock sub-system
88 (Landais, 1992). An event may consist of recovery of land or production rights, modification
89 of a sub-system, transformation of the work group, change in the management of animal
90 feeding, membership in a quality supply chain, etc. An event can be minor if it does not result
91 in a transformation of the system, or major if it causes a change in the goals of the production
92 system and/or its organisation. A StabP constitutes a state during which the production system
93 does not undergo major changes, although minor changes may occur.



94

95 **Figure 1. Conceptual organisation of a farm and its changes over time (adapted from Keating and McCown, 2001;**
 96 **Moulin *et al.*, 2008)**

97 **2.2. Methodological approach**

98 To collect data to characterise farm pathways and farmers' perceptions of grasslands, the
 99 method was divided into three steps:

- 100 1. Collecting data to select a sample of dairy farms representative of the region based
 101 on farm (i) structural characteristics and (ii) production pathways according to Petit
 102 *et al.* (2017) (see section 2.3). These data were collected using an initial survey
 103 (Appendix 1) (Petit *et al.*, 2016).
- 104 2. Characterising the place and roles of grasslands at the farm scale for each StabP.
 105 Based on the StabP previously identified, we performed a survey to objectify
 106 grassland uses (Appendix 2). The method used to cluster data is described in section
 107 2.4. Using the StabPs as a basic unit, we built pathways by grouping the StabPs of
 108 each farm chronologically (see section 3.1.2).
- 109 3. Characterising farmers' perceptions of the fodder system in relation to their social
 110 and professional network. A qualitative survey was performed (Appendix 3). The
 111 method used to analyse farmers' statements is described in section 2.5.

2.3. Farms surveyed

According to Petit *et al.* (2017), to be selected, a farm had to have the following:

- dairy production as its main sub-system from the beginning
- a farm manager with at least 15 years of farm management experience, because grassland management evolves over the long term
- ability to represent the diversity of dairy production systems and their production pathways based on the following variables: utilised agricultural area (UAA), dimensions of the dairy sub-system, presence of an additional animal sub-system (none, herbivore, granivore), and the intensification of dairy production per livestock unit (LU) and per hectare

Fifteen farms were selected. They followed a variety of production pathways based on major changes that had occurred in the past (Petit *et al.*, 2016) (Table 1). For each farm, StabPs were identified based on major changes in variables and indicators: (i) farm dimensions (UAA and Annual Workforce Units); (ii) production objectives in production sub-systems (number of animals, types of crops) and supply chains; and (iii) technical management of livestock farming through breeds and production levels per animal, and of animal nutrition through the planning of fodder crops and the feeding schedule.

Three production pathways were identified: dairy specialisation, characterised by ceasing to operate other animal sub-systems (n=4); stability with dairy-crop sub-systems, sometimes with a second animal sub-system (n=7); and diversification of dairy-crop sub-systems with other animal sub-systems (granivores, beef cattle) (n=4).

133 **Table 1. Characterisation of the production pathways of the farms studied**

Variables used for the representativeness of the farm sample (according to Petit <i>et al.</i> , 2017)							Illustrative variables	
Farm	UAA (2015)	Fodder area / UAA (% 2015)	Grassland area / UAA (% 2015)	Area / Annual Workforce Unit	Milk produced (kg/year) (2015)	Production pathway	Establishment date of the farmer on the farm	Age of farmer
1	55	95	95	55	251 000	Dairy specialisation	1996	49
2	90	56	33	60	363 000	Stable dairy-crop system with a second animal sub-system	1998	43
3	69	58	37	35	310 000	Stable dairy-crop sub-system with a second animal sub-system	1990	50
4	64	67	49	64	250 000	Stable dairy-crop sub-system with a second animal sub-system	1995	43
5	42	76	55	42	235 000	Diversification of dairy-crop sub-systems with other animal sub-systems	1991	50
6	123	66	37	62	600 000	Dairy specialisation	1994	45
7	60	58	42	60	none; 57 suckler cows	Diversification of dairy -crop sub-systems with other animal sub-systems	1986	53
8	209	66	39	70	344 000	Diversification of dairy-crop sub-systems with other animal sub-systems	1999	42
9	58	76	52	19	330 000	Stable dairy-crop sub-system with a second animal sub-system	1998	40
10	144	65	40	41	650 000	Dairy specialisation	1996	49
11	62	84	73	21	270 000	Diversification of dairy-crop sub-systems with other animal sub-systems	1996	51
12	57	72	47	29	310 000	Stable dairy-crop sub-system with a second animal sub-system	1983	54
13	80	81	71	40	400 000	Stable dairy-crop sub-system with a second animal sub-system	1993	41
14	40	70	70	40	176 000	Stable dairy-crop sub-system with a second animal sub-system	1990	46
15	61	93	93	24	263 000	Dairy specialisation	1991	50

134 UAA: utilised agricultural area; AWU: Annual Workforce Unit

135 2.4. Grassland practices pathways

136 2.4.1. Grassland practices data

137 Farmers were interviewed to characterise the types of grassland use for each StabP identified
 138 (Appendix 1). The interview, called ‘grassland practices’, addressed the types and uses of
 139 grasslands for each StabP previously identified through descriptive data on the types of
 140 grasslands, their management, their use, grazing, advice and innovation regarding grasslands,
 141 and the roles of grasslands other than for feeding cattle (Appendix 2). This allowed us to
 142 compile a database of quantitative and qualitative variables directly resulting from the survey
 143 or created later. These variables describe the quantitative role of grasslands on the farm, their
 144 uses, and the agronomic and environmental roles resulting from the practices developed.

145 The quantitative variables produced by the studies are UAA, fodder area (FA), ruminant
146 animal population, total stores of fodder dry matter (DM), quantity of DM per type of fodder
147 stored, types of rotation, number of rotations with grassland, areas dedicated to rotations.
148 These were used to calculate additional quantitative variables (Table 3). Two indicators
149 (scores) evaluating agronomic and environmental roles of grasslands were created (Tables
150 Table 4 and Table 5). Qualitative variables, whose classes originated in the answers expressed
151 during the interviews, were also created:

- 152 • diversity of grasslands, defined as the number of different botanical compositions (e.g.
153 pure grass, grass-legume mixture, pure legume) of temporary grasslands (TG): 1: 1 type;
154 2: 2-3 types; 3: > 3 types
- 155 • diversity of uses, defined as the number of pairs of different grassland botanical
156 compositions (TG and permanent grasslands) and type of grassland storage (hay, haylage,
157 silage, dehydrated) 1: ≤ 2 pairs; 2: 3-4 pairs; 3: > 4 pairs
- 158 • management of grazing, defined by the use of the energetic and protein potential of
159 grasslands: 1: free-range grazing for all animals; 2: rotational grazing for 3-4 days of dairy
160 cows (DC) / free range for other animals; 3: strip grazing / free range for other animals; 4:
161 strip grazing / rotational grazing for other animals
- 162 • quality of fodder, defined by the feed value of the fodder (Table 2). It considers the
163 influence of botanical composition (pure grass, grass-legume mixture, pure legume) and
164 harvesting method of the grassland on the potential energy and protein contents of the
165 grass fodder (lactation fodder units (LFU, 1,700 kcal) per fill unit, i.e., the amount of
166 digestible protein in the intestine per LFU). We classified the grass fodder types produced
167 in the area into 3 categories by comparing them to the most similar fodder types found in
168 INRA's feed tables (INRA, 2010): (1) low nutritional value (< 0.85 LFU/fill unit and < 90
169 g of digestible protein/LFU); (2) unbalanced foddors (> 0.85 LFU/fill unit and < 90 g of

170 digestible protein/LFU or < 0.85 LFU/fill unit and > 100 g of digestible protein/LFU); and
171 (3) high nutritional value (> 0.85 LFU/fill unit and > 100 g of digestible protein/LFU)

172 **Table 2. Classification of the nutritional value of fodder types according to botanical composition and harvesting**
173 **method**

Fodder type	Pure grass	Grass-legume mixture	Pure legume
Hay	3	2	2
Silage	2	2	1
Dehydrated	3	3	2

174

- 175 • use of permanent grasslands, defined by their role in the system: 1: none; 2: free-range
176 grazing for animals with low nutritional requirements + hay; 3: rotational grazing for
177 animals with low needs + DC on rare occasions + hay; 4: rotational grazing for animals
178 with low needs + DC occasionally + hay + grass-fed beef cattle
- 179 • grazing pressure, defined as the accessible grassland area per DC: 1: ≤30 ares; 2: 30-60
180 ares; 3: >60 ares

181 **Table 3. Description of the variables created to analyse pathways of grassland practices**

Criterion	Indicator	Classes
Percentage of grassland in UAA	= ha of productive grasslands / ha UAA (%)	
Percentage of grasslands in the FA	= ha of productive grasslands / ha FA (%)	
Stocking rate on grasslands	= LU / ha of grasslands	
Rotations that include grasslands	= number of crop rotations with grasslands / total rotations (%)	
Nitrogen fertilisation autonomy	= percentage of grass-legume mixture in the grassland area (%)	
Place of grasslands in rotations	= area in rotations that include grasslands / UAA (%)	
Percentage of grassland in fodder store	= quantity of DM from grasslands stored / total quantity of DM in stores (%)	
Percentage of dehydrated legumes produced in stores	= quantity of DM from dehydrated legumes stored / total quantity of DM in stores (%)	
Diversity of botanical composition of grasslands	= number of different grasslands in the cropping plan	1, 2, 3
Diversity of grassland uses (other than grazing)	= number of pairs of different botanical compositions of grasslands × type of grassland storage (hay, haylage, silage, dehydrated) (sum of the types of stores made from each type of grassland)	1, 2, 3
Quality of fodder	= management of the quality of fodder for storage	1, 2, 3
Use of permanent grassland	= ways to use permanent grassland	1, 2, 3, 4
Area available per dairy cow	= grassland surface area provided / number of grazing DC (ares/DC)	1, 2, 3
Grazing management	= type of grazing management for animals	1, 2, 3, 4
Agronomic indicator	agronomic benefit of grasslands, a f() of duration weighted by area	See Table 4
Environmental indicator	environmental benefit of grasslands, a f() of duration weighted by area	See Table 5

182 UAA: utilised agricultural area, FA: fodder area, LU: livestock units (cow-calf only), DM: dry matter

183 For the environmental and agronomic indicators, we developed a multicriteria method to
 184 assess the role of grasslands in these two domains. Grasslands were classified into types based
 185 on the length of time since their establishment, their botanical composition (grass or grass-
 186 legume mixture), and the crop rotations in which they were included. Based on the literature
 187 (Peeters, 2009; Thiebaud *et al.*, 2001), each grassland type was scored according to the
 188 environmental benefits (carbon storage, related biodiversity, nitrogen emissions, soil
 189 protection) or agronomic benefits (species diversity, residual fertilising effect, biomass
 190 production, nitrogen fertilisation autonomy) associated with it. Both environmental scores
 191 (Table 4) and agronomic scores (Table 5) were qualitatively ranked in 5 classes based on
 192 available knowledge, including local references.

193 The environmental and agronomic scores were therefore calculated by summing the products
 194 of the percentage of UAA in rotations that include grasslands and the aggregated score of the

195 associated grassland type. To compare the agronomic and environmental roles of grasslands
 196 on the farms, the sums obtained were normalised (Benini, 2012) according to the theoretical
 197 maximum that could be obtained.

198 **Table 4. Variables used to assess environmental benefits of grasslands**

Type	Grassland duration	Following crop	C storage ¹	N emission ²	Soil protection ³	Associated biodiversity ³	Aggregated score	% of UAA in rotations including grasslands
Rotation	1-2 years	Cereals 1-2 years	1	3	1	1	6	<i>u</i>
	3-5 years	Cereals 2-3 years	2	1	2	2	7	<i>v</i>
	> 5 years	Cereals 2-3 years	3	2	3	3	11	<i>w</i>
	> 5 years	TG > 5 years	4	3	4	3	14	<i>x</i>
	> 10 years	Cereals 3-4 years	4	4	4	4	16	<i>y</i>
No rotation	Permanent Grassland	/	5	5	5	5	20	<i>z</i>
Sum of % of UAA in rotations that include grasslands × overall weight								$Sum\ I = 6u + 7v + 11w + 14x + 16y + 20z$
Sum divided by the theoretical maximum of the sample (i.e. 100% of UAA in rotations that include grasslands with the maximum overall weight)								$= Sum\ I / (100 \times 20)$

199 ¹ from Dollé and Klumpp (2015), and 4p1000 INRA study 2018 (in press) - 1: C loss, 2: C stable, 3: low C storage, 4: moderate C storage, 5: high C storage

200 ² from Peeters (2009); Vertès et al.,(2007) - 1: high N emission risk to 5: low N emission risk

201 ³ from Peeters (2009); Garrigues et al., (2012) - 1: frequent bare soil to 4: no bare soil and 1: low to 5: high fauna and soil biodiversity

202 UAA: utilised agricultural area, TG: temporary grassland

203 **Table 5. Variables used to assess agronomic benefits of grasslands.**

Type	Grassland duration	Following crop	Residual fertilising effect ^{1,3}	Biomass production ^{2,3}	Species diversity ^{2,3}	Legume bonus	Aggregated score	% of UAA in rotations including grasslands
Rotation	1-2 years	Cereals 1-2 years	1	3	1	bonus +1 when legumes in grassland, 0 elsewhere	5 (+1)	<i>u</i>
	3-5 years	Cereals 2-3 years	2	5	2		9 (+1)	<i>v</i>
	> 5 years	Cereals 2-3 years	5	4	3		12 (+1)	<i>w</i>
	> 5 years	TG > 5 years	3	4	4		11 (+1)	<i>x</i>
	> 10 years	Cereals 3-4 years	4	2	4		10 (+1)	<i>y</i>
No rotation	Permanent Grassland	/	/	1	5	6 (+1)	<i>z</i>	
Sum of % of UAA in rotations that include grasslands × overall weight								$\begin{aligned} & Sum\ 2 = 5(+1)u \\ & + 9(+1)v + 12 \\ & (+1)w + 11 \\ & (+1)x + 10 \\ & (+1)y + 6(+1)z \end{aligned}$
Sum divided by the theoretical maximum of the sample (i.e. 100% of UAA in rotations that include grasslands with the maximum overall weight)								$= Sum\ 2 / (100\ x\ (12+1))$

204 ¹ from Peeters (2009); Vertès et al., (2007)

205 ² from Peeters (2009); Thiebaud et al., (2001)

206 ³ other source: Huyghe et al. 2014

207 UAA: utilised agricultural area, TG: temporary grassland

208

209 **2.4.2. Establishment of grassland practices pathways**

210 The grassland practices pathway (GPP) accounts for changes in the role of grasslands within
 211 the production system. The method to create them was divided into two steps. We first
 212 performed multivariate analysis to classify StabPs based on grassland practices. The statistical
 213 individual is the StabP independent of the farm. Time is not used as a covariate when
 214 analysing StabPs. Next, by chronologically associating the StabPs classified for a given farm,
 215 the GPP of each farm was determined.

216 The method developed in ecology by Doledec and Chessel (1987) for the analysis of temporal
 217 phenomena across multiple sites was adapted to develop a typology of StabPs. Each StabP is
 218 described by a set of qualitative and quantitative variables. Initially, we performed factor
 219 analysis of mixed data (FAMD; Pages, 2004) across all the StabPs identified. FAMD is
 220 appropriate for multivariate descriptive analysis of matrices of individuals described by

221 quantitative and qualitative data to identify the main differences between individuals. It
222 allowed us to summarise, for each StabP, all the information resulting from the variables used
223 for a statistical individual described by its factorial coordinates. All statistical analyses were
224 performed with R software, version 3.2.3 (R Core Team, 2007) using the *FactoMineR*
225 package (Lê *et al.*, 2008). To construct clusters of similar StabPs, Hierarchical Ascendant
226 Classification (HAC) was performed according to the Ward method (1963) on the factorial
227 coordinates of each individual from the FAMD. HAC was performed with the *cluster* package
228 (Maechler *et al.*, 2016) and consolidated according to the k-means method. Each cluster of
229 StabPs was then compared to the others using quantitative variables via pairwise comparison
230 of means. Differences were considered significant at a $p < 0.05$ threshold. The relation
231 between the class of qualitative variables and a cluster was characterised by the frequency of
232 this class among individuals in the cluster compared to that in other clusters. It was tested via
233 a Chi-Square test with a $p < 0.05$ threshold value. Clusters were sorted based on the place of
234 grasslands in the system (from the lowest to the highest).

235 To construct GPP, we grouped StabPs of each farm chronologically, which illustrates changes
236 in grassland use over time. Finally we grouped GPP with the same shape (direction of
237 changes in the pathways) and discussed the changes that occurred in the farming systems.

238 **2.5. Identification of farmers' perceptions of grasslands**

239 A second interview aimed to characterise the way dairy farmers think about fodder
240 management, including grassland uses, use of maize and concentrates, production strategies,
241 and roles of animals in the system (Appendix 3). These interviews were recorded and
242 transcribed in their entirety. Farmers' perceptions about grasslands and fodder management
243 were identified by analysing their statements. Various items were processed and categorised:
244 their attitude toward fodder, maize, concentrates, grassland management, use of grasslands,
245 grazing management, and grassland-animal relations for production and health. The meaning

246 of their words was analysed through their relation within the sentence in which they were
247 used (Benveniste, 1980; Darré, 2006). It was thus the association between the words used to
248 talk about their practices that revealed the farmer's opinion. Based on these items, 6 key
249 aspects of information in farmers' statements were extracted: (i) the aim of grassland use; (ii)
250 grassland management methods; (iii) the use of maize; (iv) the role of animals and their place
251 in the system; (v) the economic strategy; and (vi) the labour. The analysis allowed us to
252 identify similarities and differences among the farmers. For each item, different classes
253 characterising the farmers' perceptions about grasslands were identified. Based on these
254 classes, a typology based on different sociological representations of grasslands was
255 established, drawing on the concept of the ideal-type, a sociological construct in which the
256 main aspects of a sociological phenomenon are stated (Weber, 1992).

257 **3. Results**

258 **3.1. Construction of grassland practices pathways**

259 **3.1.1. Characterisation of StabP in relation to the grassland practices pathway**

260 The FAMD, followed by the HAC on the factorial coordinates of StabPs, identified 7 clusters
261 relating to the GPP. These 7 clusters correspond to configurations of production systems that
262 are stable during a given StabP (Table 6):

- 263 • **G--** (n=10): StabPs during which production systems rarely include a large percentage of
264 grasslands (35% of the UAA and 56% of the FA) and use them relatively little. The
265 stocking rate is high (2.83 LU/ha of grassland). All TG are grass-legume mixtures. Less
266 than half of the rotations include grasslands, for durations of less than 5 years (47% of
267 rotations, 33% of the UAA in question). The fodder system is based on maize silage.
268 Grasslands are almost exclusively grazed for a short period during the spring, with less
269 than 30 grazeable ares/DC. They do not permit the accumulation of large stores of grass

270 (10% of fodder stores), which are also restricted to a few forms. Their agronomic and
271 environmental roles are moderate. This use of grasslands limits carbon storage and soil
272 protection without providing a marked residual fertilising effect.

273 • **G-** (n=3): StabPs during which production systems include grasslands as 48% of the UAA
274 and 67% of the FA. The stocking rate is 2.0 LU/ha of grassland. TG are mainly pure grass
275 (86%). They are included for 1-2 years in 50% of crop rotations (45% of the UAA
276 concerned). The production system is based on a mixed maize-grassland system.
277 Grasslands are grazed with a management method requiring few interventions, with less
278 than 30 grazeable ares/DC. They provide 29% of fodder stores in a limited number of
279 forms. Grasslands provide few agronomic and environmental benefits: carbon storage, soil
280 protection, and the residual fertilising effect remain limited, which is partially
281 compensated by the large percentage of UAA in rotations that include these types of
282 grasslands.

283 • **G-dehy** (n=4): StabPs during which production systems include grasslands as 42% of the
284 UAA and 60% of the FA. The stocking rate is 2.0 LU/ha of grassland. They have at least 3
285 types of TG, which are mainly grass-legume mixtures (92% of the grasslands). They are
286 included for 3-5 years in 41% of crop rotations (37% of the UAA concerned). Maize
287 silage is the primary fodder resource; consequently, little attention is paid to grazing
288 management, although 30-60 grazeable ares/DC are available. Grasslands account for
289 19% of fodder stores in a wide diversity of forms. In particular, their dehydrated form has
290 an important role (11% of fodder stores). Grasslands have interesting agronomic and
291 environmental roles that are nonetheless relatively small at the scale of the UAA.

292 • **G=** (n=14): StabPs during which production systems include grasslands as 43% of the
293 UAA and 67% of the FA. The stocking rate is 1.9 LU/ha of grassland. They have 1-3
294 types of TG, which are mainly grass-legume mixtures (93%). They are included for 3-5

295 years in 55% of the crop rotations (52% of the UAA concerned). These systems are based
296 on maize silage but aim for optimal use of grasslands through grazing management,
297 stocking rate, and forms of stores. Grazing is performed in strips with less than 30
298 grazeable ares/DC. Grasslands provide 31% of fodder stores in 3-4 forms. They have
299 beneficial agronomic and environmental roles which are nonetheless relatively small at
300 the scale of the UAA.

301 • **G+** (n=4): StabPs during which production systems include grasslands as 57% of the
302 UAA and 69% of the FA. The stocking rate is 2.18 LU/ha of grassland. TG, which are
303 exclusively grass-legume mixtures, have little diversity. They are integrated for durations
304 that may exceed 5 years in all crop rotations (79% of the UAA in question). These
305 systems are based on maize silage, despite the high percentage of grasslands in the FA.
306 Close attention is paid to grazing, with more than 60 grazeable ares/DC. Grasslands
307 provide 26% of fodder stores in 1-4 forms, and moderate attention is paid to fodder
308 quality. They have marked agronomic and environmental roles, contributing to carbon
309 storage and soil protection, all the while combining biomass production and the residual
310 fertilising effect.

311 • **G++** (n=8): StabPs during which production systems include grasslands as 58% of the
312 UAA and 71% of the FA. The stocking rate is 1.96 LU/ha of grassland. TG, which are
313 exclusively grasses/legume mixtures, have little diversity. They are integrated for
314 durations that may exceed 5 years in 68% of crop rotations (61% of the UAA in question).
315 These systems are based on maize silage, despite the high percentage of grass in the FA.
316 Attention is paid to grazing, for which 30 to more than 60 grazeable ares/DC are available.
317 Grasslands provide 35% of stores in limited forms (one single form), and close attention is
318 paid to quality. They have moderate agronomic and environmental roles, contributing to

319 carbon storage and the production of soils, while combining the production of biomass
320 and the residual fertilising effect.

321 • **G+++** (n=14): StabPs during which production systems include grasslands as 81% of the
322 UAA and 93% of the FA. The stocking rate is 1.4 LU/ha of grassland. TG, which are
323 exclusively grass-legume mixtures, are diversified (> 2 types). They are integrated for
324 durations that often exceed 5 years in 95% of crop rotations (93% of the UAA concerned).
325 These systems are based on grasslands. Maize silage is a source of security in certain
326 systems. The attention paid to grazing management varies, despite grazing areas greater
327 than 60 ares/DC. Grasslands provide 83% of fodder stores based on a wide diversity of
328 forms (> 4). The agronomic and environmental roles are large because of the diversity and
329 place of grasslands in the UAA.

330 **Table 6. Characteristics of 7 clusters of stability periods (StabP) (***: p < 0.001; a, b, c, d: significantly different**
331 **(least-square means test) at p < 0.05; * for qualitative variables: class significantly representative of the cluster)**

Criterion	1	2	3	4	6	5	7	mean	SD	p-value
	G--	G-	G-dehy	G=	G+	G++	G+++			
	10	3	4	14	4	8	14			
Percentage of grassland in UAA	35 ^a	48 ^{ab}	42 ^{ab}	43 ^{ac}	57 ^{bc}	58 ^b	81 ^d	54	19	***
Percentage of grassland in FA	56 ^a	67 ^{ab}	60 ^{ab}	67 ^b	69 ^b	71 ^b	93 ^c	72	14	***
Stocking rate on grasslands	2.83 ^b	1.92 ^{ab}	2.00 ^{ab}	1.93 ^a	2.18 ^{ab}	1.96 ^a	1.40 ^a	1.9	0.9	***
Percentage of grassland in fodder store	10 ^a	29 ^{ab}	19 ^{ab}	31 ^b	26 ^{ab}	35 ^b	83 ^c	39	28	***
Nitrogen fertilisation autonomy	90 ^b	14 ^a	92 ^b	93 ^b	100 ^b	100 ^b	100 ^b	91	23	***
Rotations that include grasslands	47 ^a	50 ^a	41 ^a	55 ^a	100 ^b	68 ^a	95 ^b	67	24	***
Place of grasslands in rotations	33 ^a	45 ^{ab}	37 ^{ab}	52 ^b	79 ^{cd}	61 ^{bc}	93 ^d	61	25	***
Percentage of dehydrated legumes produced in stores	1.7 ^a	0 ^a	11.2 ^b	2.9 ^a	0 ^a	0 ^a	0.3 ^a	1.9	4.6	***
Agronomic indicator	0.28 ^a	0.36 ^{ac}	0.34 ^{ab}	0.41 ^{bc}	0.63 ^{de}	0.52 ^{cd}	0.76 ^e	0.40	0.19	***
Environmental indicator	0.24 ^a	0.37 ^{ab}	0.32 ^{ab}	0.31 ^a	0.49 ^{bc}	0.47 ^{bc}	0.57 ^c	0.50	0.16	***
Diversity of botanical composition of grasslands	1-2	1	3*	2*	1	1*	2*			***
Diversity of grassland uses (other than grazing)	1*	1	1-2-3	2*	1-2	1*	3*			***
Use of permanent grassland	1-2	2*	2*	1*	3*	1-2	1-2			***
Grazing management	1-2-3	1*	2	2-3	3	2-3-4*	2-3-4			***
Quality of fodder	1*	1*	2*	3*	2*	3*	3*			***
Area available per dairy cow	1*	1-2	2*	1*	3*	2-3	3*			***

332 SD: standard deviation, UAA: utilised agricultural area, FA: fodder area

333 3.1.2. Characterisation of the grassland practices pathways of farms

334 The GPP were grouped into 6 types based on the form of the pathway and the cluster to which
335 the final StabP of the GPP belonged (Table 7).

336 **Table 7: 6 groups of grassland practices pathways of farms**

Criterion	1	2	3	4	6	5	7	
	G--	G-	G-dehy	G=	G+	G++	G+++	
	10	3	4	14	4	8	14	
farm2 (3 StabP) farm8 (3 StabP)							StabG--	
farm10 (3 StabP) farm6 (4 StabP)							↗G-dehy	
farm3 (3 StabP) farm4 (3 StabP) farm7 (6 StabP)							StabG=	
farm12 (4 StabP)							↘G=	
farm5 (3 StabP) farm9 (4 StabP)							StabG+/++	
farm11 (3 StabP) farm14 (3 StabP) farm15 (6 StabP) farm13 (4 StabP) farm1 (5 StabP)							↗G+++	

337 ↗: increase in uses and roles of grasslands, ↘: decrease in uses and roles of grasslands; G--/G-/G=/G+/G++/G+++ : level of final point of the
338 pathway.

- 339
- 340 • **StabG-- (n=2)**: farms whose pathway is stable, with a low percentage of grasslands in
341 the feeding strategy (35% of UAA for 10% of fodder stores). Transformations are rare.
 - 342 • **↗G-dehy (n=2)**: farms whose pathway shows an increase in the percentage of
343 grasslands in the UAA and the FA, as well as an increase in established types and
344 forms of use, in particular dehydrated. Among the 15 farms, the final pathway state
345 has a below-average percentage of grasslands (42% of the UAA for 19% of fodder
346 stores).
 - 347 • **StabG= (n=3)**: farms whose final pathway state has an average percentage of
348 grasslands among the 15 farms (43% of the UAA for 31% of fodder stores). For this
349 pathway, transformations are rare and do not lead to modification of the production
350 system.
 - 351 • **↘G= (n=1)**: a pathway of slight reduction in the percentage of grasslands in the UAA
352 and the FA (43% of the UAA for 26% of fodder stores), as well as a simplification of
the botanical composition diversity and the use of grasslands.

- 353 • **StabG+/++ (n=2)**: farms whose final pathways are stable and have an above-average
354 percentage of grasslands among the 15 farms (57-58% of the UAA for 26-31% of
355 fodder stores).
- 356 • **7G+++ (n=5)**: farms whose final pathway state place grasslands at the heart of the
357 fodder system (81% of the UAA for 83% of fodder stores). The percentage of
358 grasslands in the UAA and FA increases, and practices are transformed (stores become
359 dominated by grass, low stocking rate and large area per DC with high levels of
360 grazing, multi-species grasslands in all crop rotations).

361 **3.2.Farmers' perceptions of grasslands and fodder management**

362 The analysis of farmers' statements highlighted common rules in their perceptions of
363 grasslands and the factors that distinguish them. Common rules concerned (i) the location of
364 grasslands, which must lie near animal housing; (ii) use of grasslands primarily through
365 grazing instead of storage; and (iii) the use of TG with perennial ryegrass-white clover for DC
366 and permanent grasslands for dry cows and heifers. Based on the factors highlighted for the 6
367 key aspects of information identified, 5 perceptions of fodder management and grassland use
368 were identified (Figure 2):

- 369 • **Traditional (n=2)**: farmers for whom grasslands belong to an inherited fodder system
370 without a long-term strategy. They consider grasslands to be to be one part of fodder
371 systems but not to be more important than other systems. They also believe that a
372 dairy farm has to produce maize, grasslands, and cereals because that is how their
373 parents did it in the past. These farmers are less engaged in professional groups and
374 seek less advice.
- 375 • **Production security (n=3)**: farmers who consider maize the only crop capable of
376 ensuring high levels of milk production. These farmers are looking for a farming
377 system that is easy to manage and has a high level of production. They aim to increase

378 production without reducing gross margins. Fodders are considered according to how
379 much milk they can produce. Grasslands are considered an economic booster crop
380 used during a short period of the year (spring) only through grazing. These farmers
381 belong to the predominant professional groups (CETA, GEDA) or seek individual
382 advice.

383 • Sustainable (n=4): farmers who consider that grasslands increase the sustainability of
384 fodder systems which rely heavily on maize. Farmers are aware of the general
385 economic context and the fact that they will be able to increase their income, not by
386 increasing the amount produced, but rather by decreasing expenses. The fodder system
387 is varied and includes grasslands, which are considered a mechanism for flexibility.
388 These farmers adapt techniques that they have observed on other farms (Grazing and
389 Careful grazing). Grasslands are managed for high productivity and are maintained
390 over a longer period (5 years) to decrease expenses. These farmers belong to the
391 predominant professional groups (e.g. CETA - Centre d'études techniques agricoles,
392 GEDA - Groupes d'Etude et de Développement Agricole), but challenge some of the
393 advice provided, and discuss their farming practices with neighbours who belong to
394 alternative groups.

395 • Careful grazing (n=2): farmers who consider grasslands important but nonetheless
396 require maize silage to ensure milk production. These farmers combine dairy
397 production with on-farm product processing (e.g. cheese, bread). Thus, farming means
398 more than simply producing; the value and the sale of products are also a part of the
399 job. In this perception, grasslands have to be productive, with a large amount of
400 biomass per hectare. These farmers also belong to professional groups that promote
401 farm fodder autonomy based on grassland use (e.g. CIVAM, AgroBio).

402 • Grazing (n=4): farmers who want to adapt dairy production to the natural potential of
 403 their farm. They consider grasslands central to the fodder system, which excludes
 404 maize due to its negative social image and the scheduling conflict between maize and
 405 grassland fodder production. For these farmers, grassland management is technical
 406 and is considered a fundamental dimension of the job. They claim to have specific
 407 knowledge that sets them apart from the other farmers, and they belong to professional
 408 groups which promote farm fodder autonomy based on grassland use (e.g. CIVAM -
 409 Centres d'Initiatives pour Valoriser l'Agriculture et le Milieu rural, AgroBio).

	Traditional (n=2)	Production security (n=3)	Sustainable (n=4)	Careful grazing (n=2)	Grazing (n=4)
Aim of grassland use	Grasslands have always been there; no reason to change	Grassland, an economical forage, but with quality variations	Grassland, one forage among others	Grassland allows the expression of the natural animal behaviour	
Grassland management methods	Selected species in grassland for high forage production			Grassland must have stable production; if not, maize will be used	Grassland naturally adapts to the environment
Use of maize	Moderate use of maize. Good forage but cannot be the only one	Maize is the best forage for high milk yields	Complement to productive grassland		Maize is incompatible with ideology or work
Animals' role and place in the system	Animals are tools that transform plants into milk. High efficiency and milk production are goals limited by health status and genetic potential			Animals must allow flexible management of feeding strategy	Farming system is adapted to animal requirements
Economic strategy	Maintain the farming system without changing anything	Simply produce milk	Produce, but not at any cost	On-farm processing of milk	Agri-ecological production
Labour	Farming is time consuming and overwhelming	Farming requires full-time engagement	Keeping time for the family and hobbies is important	Dairy farming and processing is a way of life but time consuming	Farm is a place of work and personal fulfilment. Getting off the farm is important

410
 411 **Figure 2. Construction of the five types of perceptions of fodder management of the 15 farmers according to 6 key**
 412 **aspects**

413 **3.3. Combined analysis of grassland practices pathways and farmers'** 414 **perceptions of grasslands**

415 Combined analysis of GPP and farmers' perceptions of grasslands shows consistency between
 416 the way grassland uses have evolved in the farming systems and farmers' perceptions.
 417 Pathways characterised by a significant increase in grassland use or by stability at a high level
 418 ($\nearrow G+++$ and $StabG+/++$) are related to Grazing and Careful grazing perceptions. Grasslands
 419 are a pillar of the fodder system and are associated mainly with an agro-ecological approach

420 to production. These perceptions seem to favour in-depth changes in fodder systems, as
421 demonstrated by pathways transitioning from low levels of grassland use to high levels.

422 Sustainable and Traditional perceptions of grasslands are related to moderate grassland use
423 that is stable or increasing over time (StabG= and ↗G-dehy). These perceptions highlight that
424 farmers look to reach a sustainable fodder system not only via grassland but also via maize
425 silage. The pathways associated with these perceptions illustrate incremental change in
426 grassland use. Traditional farmers use a mixed fodder system based on both types of fodder
427 (↘G+ and StabG=) with few changes in perceptions of fodder.

428 Finally, the Production security perception can be characterised by a decrease in grassland use
429 or by stability at a low level of grassland use in the fodder system (↘G+ and StabG--).

430 Grasslands are not integrated into either the fodder system or the farmer's perception.

431 **Discussion**

432 **A new method to outline grassland use pathways over the long term at the farm scale**

433 From a methodological point of view, our analysis of the maintenance of grasslands through
434 the modelling of pathways based on empirical data highlights different changes in the ways of
435 using grasslands and their maintenance over time. This approach is original in that it (i)
436 objectifies as much as possible the multifunctionality of a complex agricultural object and (ii)
437 monitors this multifunctionality over a long period in relation to the historical context of the
438 farm on which it is set.

439 Assessment of the role of grasslands on farms over time is based on multiple criteria
440 (quantitatively speaking, their place in crop rotations and animals' rations; qualitatively
441 speaking, their agronomic and an environmental benefits). To our knowledge, few attempts
442 have been made to objectify this role using survey data collected for this purpose. As with

443 research that studies multi-performance situations (e.g. sustainability, milk quality, animal
444 welfare), multicriteria analysis seems to be well suited to this type of issue because it is
445 designed to reflect a complex reality. Multicriteria characterisation of the place and role of
446 grasslands in the long term therefore appears original, because it combines quantitative data,
447 weighted indicators (agri-ecological roles) and qualitative characteristics of fodder from
448 grasslands. This type of method helps reconnect characterisation of the fodder system to
449 environmental and agronomic elements. It thus sheds light on the contribution of grasslands to
450 sustainable development, not only at a given time, but also in the long term. As other authors
451 have pointed out, this type of approach can be called into question because it requires
452 weighting on the basis of sometimes scant knowledge that may be monocriterion or stem from
453 different sources (e.g. researchers, farmers, advisers) (Fraser *et al.*, 2006; Reed *et al.*, 2006). It
454 nevertheless has the merit of offering an objective method to simultaneously analyse different
455 functions of grasslands within a StabP and to compare different StabPs. In our study, the
456 method is based on researchers' expertise and combined analysis of literature, especially in
457 the perceptions of agronomic and environmental roles. In this sense, it is partially a top-down
458 multicriteria analysis approach (Roy and Chan, 2012) at the farm scale (Binder and Feola,
459 2013). To include viewpoints on agronomic and environmental roles besides scientific ones,
460 several authors (Fraser *et al.*, 2006; Reed *et al.*, 2006) propose involving local actors to assess
461 the performance of grasslands in the region under study.

462 In addition, by categorising StabPs according to the roles of grasslands and by then combining
463 them according to a farm's pathway, our method enables objective study of the evolution of
464 these roles in the long term, at the scale of a production system.

465 The relevance of this method for studying transformations in farms over the long term is
466 confirmed, as Ryschawy *et al.* (2013), Rueff and Gibon (2010), and Mottet *et al.* (2006) have
467 shown. Our approach nevertheless differs from theirs. By basing the study of pathways on

468 transformations in farms over the course of a farmer's career, we closely retrace the states of
469 the production system during different periods at the farm scale. As we confined our study to
470 the period of the past during which farmers were actors in the changes on farms, we decreased
471 the risk of inaccuracies and of incorrectly reconstructing the past that Cialdella *et al.* (2009)
472 pointed out regarding research on pathways spanning almost 50 years. Because the data
473 collected are based on memory, they lose quality as the time between the actual events and the
474 discourse increases. The intrinsic risk of this type of memory bias is the incorrect
475 reconstruction of the past (Lamine and Bellon, 2009). One way of limiting this risk is to base
476 data collection on farm archives, and then, during interviews, to validate information by
477 cross-comparisons in order to reveal contradictions. We did this, for example, to ensure
478 appropriate changes in grasslands, stocking rates, and feeding practices (areas fit for grazing
479 and grass-based fodder stocks). Moreover, given this risk, to analyse evolution of the
480 maintenance of grasslands over time, at the farm scale (quantitative place and use), and with
481 the aim of then comparing it to actors' perceptions, it seems important to base the analysis on
482 the actors' experience.

483 The method we developed was designed to capture changes occurring on farms. Rueff (2010)
484 and Ryschawy (2011) researched fixed intervals of time (5 and 10 years, respectively),
485 regardless of the exact periods of internal changes in the system. Methodologically, we chose,
486 as Moulin (2008) did, to break down pathways into StabPs specific to each farm in order to
487 best describe the singular processes of system transformation in the most objective way
488 possible. It appears to be a relevant tool for monographic studies of farm pathways and can
489 easily be discussed along with social science approaches that endeavour to trace social
490 pathways of individuals and relations between farmers' practices and their perceptions
491 (Compagnone *et al.*, 2015; Mathieu *et al.*, 2006).

492 Nevertheless, the method's results may depend heavily on the sample of farms used to
493 construct pathways. We selected surveyed farms which had representative structural
494 characteristics. The pathways identified confirm, at individual farm scale, changes in farming
495 systems shown at regional scale from 1960-2010 by Petit *et al.* (2017). The heterogeneity of
496 farms at the final point of their pathway echoes the wide diversity of dairy farming systems:
497 mixed crop-livestock systems, recent dairy specialisation of the animal sub-system, and agri-
498 ecological changes in grassland use by some of the farms. However, as we aimed to
499 characterise farmers' perceptions of grasslands and their implicit sociological characteristics
500 independent of their farms, we chose not to use sociological characteristics when constructing
501 the sample. In addition, several sociological characteristics were not easily available for
502 constructing our farm sample. Consequently, our results show that sociological characteristics
503 such as career history, age and membership in professional or non-agricultural networks are
504 involved in farmers' perceptions of grasslands and can influence changes in the GPP.

505 This method does more than simply reconstruct the individual pathway of a farm, as in this
506 study, for it allows one to construct patterns of similar pathways, which shed light on the
507 forms of changes in the use of grasslands shared by multiple farms at a larger scale (e.g. small
508 agricultural area, catchment). The method is therefore an original tool for studying stages of
509 the transformation of farms with a view to better integrating grasslands locally. It allows the
510 main variables indicating grassland maintenance to be identified at the farm scale. Using these
511 indicators in a survey of a larger sample could help outline farm pathways at a regional scale.
512 By allowing the results to be discussed among local actors, this method can also help define
513 ways in which grasslands could be extended locally, without interfering with the individual
514 pathways of farms.

515 **New types of grasslands for broader roles at the farm scale**

516 Besides the change in surface area, the types of grasslands used on farms have evolved over
517 time. Thus, grass-legume mixtures, initially developed in France by alternative farming
518 systems (Deléage and Sabin, 2012; Pochon, 1993), have been widely adopted by dairy
519 farmers. As discussed by Duru (2008), the same phenomenon seems to be occurring today
520 with the multi-species grassland used to diversify and optimise fodder production. Moreover,
521 initially sown for less than 5 years, these grasslands are today maintained for more than 5
522 years. In farmers' perceptions, the distinction between TG and permanent grasslands seems to
523 be becoming less rigid.

524 In recent years, nitrogen-fixing cover crops, such as Italian ryegrass and red clover, seem to
525 have become relevant for fodder production. Although these crops are not considered
526 grassland according to French agricultural terminology (because they are sown for less than
527 one year), their role in farming systems raises questions about the definition of a grassland. As
528 for permanent grasslands, whose definition varies among agricultural actors (Plantureux *et al.*,
529 2012), the inclusion of nitrogen-fixing cover crops in the analysis of the fodder system should
530 be discussed among animal scientists, agronomists, and ecologists.

531 **Efficiency-Substitution-Redesign processes explain the maintenance of grasslands**

532 These dynamics of grassland uses can be interpreted according to the Efficiency-Substitution-
533 Redesign framework of Hill and MacRae (1995), which in this case is used to describe the
534 level of inclusion of grasslands on farms. We use this analysis framework to describe the agri-
535 ecological transformations that occur on farms due to profound disruptions in pathways or
536 through more progressive changes (Hill, 1998).

537 In the analysis, the farms that appear to have helped maintain grasslands the most are those
538 that have profoundly changed management of their fodder system (Redesign pathway).
539 Despite the uniqueness of individual pathways, they have one common denominator: at the

540 end of the pathway, grasslands constitute the pillar of the fodder system. They are
541 increasingly used for fodder production and agronomic functions, as well as for the
542 organisation of work and health benefits for animals. To implement this change, the
543 significant transformations – often ruptures – that occurred on the farms concerned de-
544 intensification of milk production per animal and per hectare based on low stocking rates,
545 rustic breeds or cross-breeding, production supported by fodder and supplements produced on
546 the farm, and types of grasslands and crop rotations that favour grassland sustainability. These
547 pathways, which are novel within a region of intensive dairy production (Devienne, 2013), are
548 nonetheless not unknown elsewhere. Alard *et al.* (2002) presented them as early as the mid-
549 1990s as an alternative to the intensive pathways found in Brittany.

550 In contrast with these pathways marked by significant changes, other farms helped maintain
551 grasslands by optimising existing areas (Efficiency and/or Substitution pathway). Grasslands
552 were used mainly for zootechnical purposes, which were differentiated on a quantitative scale
553 of place (\nearrow G-dehy, StabG=, \searrow G+, StabG++). On these farms, grassland areas tended to
554 change little, but the practices associated with them did change, thus improving the services
555 provided, as seen above (new types of grasslands for broader roles).

556 On the fringes of pathways evolving towards positive reconsideration of grasslands, certain
557 farms are distinguished by stability of grassland inclusion at similar levels (G=dehy, G=),
558 reflecting small changes in the way grasslands are used in the system. Finally, certain farms
559 follow a pathway indicating a weakening role of grasslands (G+ to G=dehy) or one that is
560 stable at a low level (G--). In these systems, grasslands are considered a marginal resource
561 that is rarely used in the fodder system. These dairy or mixed-livestock farms intensify
562 production per animal and/or per hectare. They confirm a potential form of change in the
563 intensive dairy production systems mentioned by Lelyon *et al.* (2008), in which nutrition is
564 based on maize silage, and grasslands are excluded from feeding strategies.

565 **Farmers' perceptions of fodder systems, a key driver of grassland maintenance at the farm scale**

566 The different perceptions and approaches for maintaining grasslands show a wide diversity of
567 reference models and professional perceptions in the evolution of grassland management.
568 They are consistent with the findings of Couzy and Dockes (2006). They revolve around the
569 relations among living systems, technical expertise, and the economic management of the
570 farm, showing that grasslands can be integrated either as a central element of the fodder
571 system or as merely one component among others.

572 However, as our sample seems to be younger than the rest of the farmer population in the
573 region (60% are younger than 50 years old vs. the regional average of 47% (Agreste, 2010),
574 we can hypothesise that the younger farmers are, the more likely they are to adopt innovations
575 early in their careers (Diederer et al., 2003). This effect could explain part of the GPP,
576 grassland perceptions, and ability to change practices observed in our study. Nevertheless, as
577 all farmers in the sample are young, even Traditional and Production security farmers (G--
578 pathways), we can assume that age is not the only factor explaining grassland maintenance in
579 the region.

580 The systems that show distinct disruptions in pathways are the Grazing and Careful grazing
581 types. The reasons for these disruptions, their timing, and the time intervals between them
582 raise questions about the history of the farmers themselves, the initial state of the pathway
583 (Lamine, 2011), and the resources that livestock farmers invest in technical transformations.
584 In this sense, our findings corroborate those of Coquil *et al.* (2014b), which demonstrate that
585 transitions towards more independent production systems are supported by the rediscovery
586 and use of internal resources that are given preference over external inputs. They also pertain
587 to the search for new meaning in farmers' work. Thus, maintaining grasslands on farms that
588 are evolving in that direction will require reinventing the profession of the livestock farmer by
589 adopting different practices and changing production strategies.

590 The most original aspect of our work lies in the identification of farmers who have adopted
591 ‘Sustainable’ perceptions in relation to pathways that seek to increase grassland efficiency
592 (\nearrow G-dehy, StabG=, \searrow G+ pathways). These practices permit high levels of dairy production
593 per hectare while controlling costs (Delaby and Peyraud, 2009; Dillon *et al.*, 2005; Shalloo,
594 2009). This fodder logic and these pathways seem to indicate that maize and grassland use lie
595 on a gradient, which reflects a blurring of the well-documented opposition between them
596 (Coquil, 2014; Frappat *et al.*, 2012, 2014) Instead, use of both types of fodder appears to be
597 complementary, to achieve intensive and sustainable milk production. The sharing of farmers’
598 experiences in local professional groups, not only with ‘Grazing’ and ‘Careful grazing’
599 farmers (\nearrow G+++ and StabG+ / ++ pathways, CIVAM and Agrobio professional groups), but
600 also with ‘Production security’ farmers (\searrow G+ and StabG- pathways, CETA and GEDA
601 professional groups), echoes the process of hybridisation of intensive production systems
602 integrating low-input production practices that were initially developed on farms following an
603 agri-ecological approach (Ansaloni and Fouilleux, 2006). Perceptions of fodder production
604 that previously influenced professional differentiation, as shown by Deléage (2011), are
605 fading, and the demarcation between farmers is becoming more permeable. This illustrates
606 that production models are being combined or used concurrently (Deléage and Sabin, 2012),
607 and that hybridisation of practices is underway (Ansaloni and Fouilleux, 2006). This process
608 can easily be compared to transformations occurring locally, through both supply-chain
609 dynamics and local dynamics (Petit *et al.*, 2017). This result agrees with Devienne (2013): the
610 transformations occurring in the production environment, whether due to regulations or
611 scientific or technological advances, are factors of change in production systems. At the
612 regional scale, although urbanisation of the peri-urban area and pedoclimatic conditions may
613 have impeded grassland maintenance at the farm scale (Petit *et al.*, 2017), farmers never cited
614 these factors as obstacles to grassland use, despite having fragmented fields.

615 More broadly speaking, development of agri-ecological systems must be analysed in relation
616 to farmers' pathways, and the redesign must extend further than the technical system alone, to
617 also include interactions with agri-food systems (Lamine, 2011). As farms are not isolated
618 systems, they co-evolve with their environment. In this respect, development of agro-
619 ecological projects at the regional scale is expected to help transform farms in this direction.
620 The local production context (Petit *et al.*, 2017) seems to correspond to this type of favourable
621 environment for the farms studied.

622 **4. Conclusion**

623 Long-term maintenance of grasslands on farms is a phenomenon that can take several forms,
624 in terms of both GPP and of the underlying approach to fodder. Therefore, grasslands can be
625 maintained on production systems besides those based primarily on grass and that depart from
626 the dominant model. Changes can be made step by step. These changes are built on an
627 essential, noteworthy element: farmers' ability to no longer view maize and grasslands as
628 mutually exclusive when constructing fodder systems. These changes are facilitated by local
629 factors of the production environment that are conducive to agriculture or that initiate
630 transformations in how agriculture is perceived, particularly due to combining practices.

631

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- 846

847 **Appendices**

848 Appendix 1. Survey performed to characterise the production pathway (past and present) and identify
849 stability periods

850 The aim of this step was to fill out a farm-evolution form (Figure 3). After providing an introduction that
851 explained the goal of the survey, we asked to the farmer to explain how his or her farm had evolved from
852 its establishment to the present day. To ensure that we collected information for each line of the form, we
853 used reminders to prompt the farmer about each subject.

854 Using the fully completed form, we analysed changes that had occurred in farm production due to changes
855 in the workforce, animal intensification, and the intensive use of the utilised agricultural area (UAA). This
856 analysis made it possible to identify stability periods (StabPs) of each farm.

857 Questions:

858 *The aim of this survey is to understand what changes have occurred on your farm from when you*
859 *established it to today. Would you explain how your farm has evolved in terms of structure, system and sub-*
860 *systems, production target, and crop rotations? For each change, please provide the date that it occurred.*
861 *If you prefer to provide periods during which these elements did not change, please provide temporal*
862 *boundaries.*

863

Dates				
Structural changes	Utilised Agricultural Area (UAA) (ha)			
	Workforce			
	Food chain / Quality label			
	Production target			
Crops (ha)	Cereals			
	Maize			
	Others			
Grasslands (ha)	Temporary			
	Permanent			
Animal sub-systems	Dairy cows (numbers, milk quota, breeds, feeding strategy, housing)			
	Suckler cows			
	Others bovines			
	Granivores			
Professional groups				
		↓	↓	↓
		StabP 1	StabP 2	StabP 3

864

865 **Figure 3. Form to collect data about farm evolution**

866

867 Appendix 2. Survey performed to characterise the grassland practices pathway

868 For each StabP previously identified, the survey aimed to fill out a data collection form (Table 8) with
 869 information about the place and roles of grasslands. These variables were described with raw data, but
 870 other variables were calculated from these data to build a quantitative and qualitative database of StabP
 871 (see section 2.4).

872 **Table 8. Survey about the place and roles of grasslands at the farm scale**

Dates		d1	d2	d3	d4
StabPs		StabP 1	StabP 2	StabP 3	
Animal (management of groups of animals)	dairy cows				
	heifers				
	dry cows				
	bull calves				
Stores (different fodder stores produced: quantity, from which grassland)	Hay				
	Haylage				
	Grass silage				
	Maize silage				
	Dehydrated				
Grazing (which group of animal grazes which grassland)					
Crop rotation (duration, species in the rotation)	Rotation 1				
	Rotation 2				
	Rotation 3				
	rules for location of rotations				

873

874 Appendix 3. Survey to characterise farmers' perception of fodder and identify sociological determinants

875 The aim of this step was to understand who the farmers were, what they thought about farming, and what
 876 they thought about grassland in the farming system. The survey was divided among main questions (Table
 877 8, 1st column), and reminders were given if the farmer did not address a given subject (2nd column). We
 878 collected farmers' statements, which contained justifications and rationales about their former and present
 879 practices.

880 **Table 9. Survey about farmers' perceptions**

Main questions	Reminders
<ul style="list-style-type: none"> • Would you tell me how you became farmer? 	<ul style="list-style-type: none"> • Did you work with your parents? • Did you work elsewhere before starting your farm? • What were your motivations? • What difficulties did you encounter?
<ul style="list-style-type: none"> • Would you explain what grassland means to you? 	<ul style="list-style-type: none"> • In relation to animals? • In relation to crop rotations? • As a fodder? • In relation to other fodders? • In relation to the economic efficiency of your farm? • In relation to society? • In relation to food products? • In relation to the workload on the farm?
<ul style="list-style-type: none"> • How were you or are you engaged in professional groups? 	<ul style="list-style-type: none"> • Why did you/do you engage in professional groups? • What were/are the subjects of your meetings? • How did you/do you address grasslands in your

	<i>groups?</i>
<ul style="list-style-type: none"> • <i>How did you or do you interact with people other than farmers?</i> 	<ul style="list-style-type: none"> • <i>Are you engaged in an association?</i> • <i>Are you engaged in local political groups?</i> • <i>Are you engaged in a sports club?</i>
<ul style="list-style-type: none"> • <i>How do you imagine the future?</i> 	<ul style="list-style-type: none"> • <i>For your profession?</i> • <i>For your farm?</i> • <i>For agriculture?</i>

881