

Scotland's Rural College

Factors influencing crop rotation strategies on organic farms with different time periods since conversion to organic production

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1 **Factors influencing crop rotation strategies on organic farms with different time periods**
2 **since conversion to organic production**

3 **Abstract**

4 Productive crop rotations are central to the success of organic production systems. The
5 selection and sequence of crops are determined by a combination of agronomic and economic
6 factors as well as the principles and standards of organic farming. Semi-structured interviews
7 were conducted with sixteen organic farmers in Central-east Sweden to explore the factors
8 that influence the design of crop rotations and the trade-offs between these factors, taking into
9 account the length of time since conversion to organic production.

10 We discerned three crop rotation strategies: strict, flexible and liberal, based on how crop(s)
11 are repeated over time. A major trade-off for arable farmers was between perennial leys to
12 provide nitrogen and control weeds, and the use of more inputs such as purchased nutrients
13 and mechanical weed control to allow continuous cereal production. Critical considerations
14 for livestock farmers were the length of ley for feed production and weed control, cost of re-
15 seeding leys and decisions about whether to grow crops to feed animals or cereals to sell.
16 Farmers practicing organic for a long time (more than 10 years) often had flexible rotations to
17 adapt to changing conditions, but they generally included leys and a selection of annual crops
18 in line with the principles of crop rotation and organic farming. Recently converted organic
19 farmers usually concentrated on controlling weeds and producing sufficient livestock feed by
20 following strict crop rotations. We conclude that farm type and experience strongly
21 influenced rotation strategies and that weed management and market prices were the most
22 important influences.

23 *Keywords: crop rotation strategies, decision, organic farming, semi-structured interviews,*
24 *time since conversion, trade-off*

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29 **Factors influencing crop rotation strategies on organic farms with different time periods**
30 **since conversion to organic production**

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32 **Introduction**

33 Crop rotation is the sequence of crops on the same land in sequential seasons (Bullock 1992)
34 and implies that crops generally follow a pre-determined order. Crop rotation is determined
35 by decisions made by farmers on what type of crops to grow in the current and coming
36 growing seasons. The choice of crops to include in a crop rotation can influence soil fertility
37 and nutrient cycling, risks of infestation by weeds, pests and diseases, nutrient demand, crop
38 diversity, and economic risk management (Karlen et al. 1994; Gerhardt 1997; Bertsen et al.
39 2006; Papadopoulos et al. 2006; Moncada & Sheaffer 2010). Crop rotation is of particular
40 importance in organic farming, compared to conventional farming, because of the restrictions
41 on the use of easily soluble mineral fertilisers and the prohibition of synthetic chemicals to
42 control weeds, pests and diseases. Hence, Article 5 of 834/2007 of European Union's
43 principle applicable to organic farming (EU 2007) emphasises the adoption of appropriate
44 crop rotations with diverse crops in order to maintain/improve plant and soil health, and also
45 to minimise the dependence on external inputs as far as possible. A wider description of the
46 core values and principles of organic farming was laid out by IFOAM (2005) which forms the
47 basis for the definitions.

48 In practice, the crop sequence often changes over time as an adaptation to prevailing
49 conditions, preferences and knowledge and the different trade-offs which farmers have to
50 consider when choosing crops. Dury et al. (2013) reported that the cropping plan on a farm
51 does not emerge from a single decision but from a dynamic decision-making process, which
52 among other things incorporates unanticipated situations such as lack of availability of
53 particular seeds, weather conditions and market opportunities. Since many factors influence
54 crop choice in a rotation, it is not always practical for crops to follow each other in strict,
55 repetitive cycles. This is particularly true on arable farms that depend on cash crops rather
56 than growing crops for livestock feed. Therefore, it is often more relevant in practice to
57 discuss crop sequences rather than crop rotations.

58 Castellazzi et al. (2008) identified several important factors to consider when designing well-
59 functioning crop rotations, and grouped them into four main rules. According to the first rule,
60 there should be a minimum return time period of the same crop in the rotation, or in some
61 cases, the maximum period of growing the same crop, in order to break the cycle of the build-
62 up of pests, weeds and diseases. The second rule states that crop rotations should be planned
63 to optimise the benefits from crop succession. The benefits could arise from increased
64 nitrogen supply, soil organic matter or water availability, improvements in soil structure, and
65 decrease in pests, diseases and weed competition. The third rule relates to planning the timing
66 of operations within a year to allow crops to follow each other without long gaps. The fourth
67 rule relates to diversity of crops in space and time in order to spread the risk of total crop
68 failure and economic loss, and also balance the distribution of work and the use of machinery
69 and labour.

70 Decisions of individual organic farmers on crop choice may not always address the rules of
71 crop rotations or the principles of organic agriculture, as farmers also have to consider many
72 practical aspects. Several published studies on development of crop sequence/rotation are
73 generic and based on decision support and modelling tools, e.g. Bachinger and Zander (2007),
74 Power et al. (2011). These studies use mathematical optimisation techniques to generate
75 rotations to assist in agricultural production planning. Other studies describe the different
76 phases and processes which lead/link to the decision making process (Aubry et al. 1998;
77 Öhlmer et al. 1998; Dury et al. 2013). The above tools help in designing crop rotations based
78 on generic conditions and assumptions, but they do not reflect the individual farmer's
79 experiences, motivations, arguments and uniqueness in their situations and decisions, as they
80 are based on optimisation and prediction approaches. Although, the general needs and
81 requirements of different farm types vary, individual farmers will respond to external factors,
82 in addition to the requirement of their farm types. A report from the European Commission
83 (2010) lists several factors such as climate, soil quality, water availability, local market
84 opportunities, farm resources and policies, the education level of farmers, tradition on the
85 farm or in the surrounding farming community, etc., which could influence the choice of crop
86 rotations. This report did not explore how decisions are taken by individual farmers when
87 faced with different constraints and trade-offs. The rationale behind their choices could reveal
88 the different constraints and opportunities associated with various crops and crop rotations in

89 a particular farm or farm type. To our knowledge, there are no published studies which
90 critically look into the rationale of organic farmers when determining their crop rotations.

91 We expect the longer-term organic farmers to be more knowledgeable about crop rotations
92 since they have more varied and longer experience in organic farming systems than the
93 recently converted organic farmers. This study seeks to explore crop rotations practiced by
94 farmers with varying experiences and farm types, identify the trade-offs and discuss the
95 rationales of different farmers in relation to the rules for a well-functioning crop rotation and
96 the principles of organic agriculture. We do this by analysing qualitative data from semi-
97 structured interviews with 16 organic farmers in the Uppland Province, Sweden. A qualitative
98 approach was chosen based on the premise that farmers' goals and ideologies influence their
99 decisions on crop rotations. The semi-structured interviews allowed the farmers as well as the
100 interviewers to raise doubtful issues and questions and discuss further to get more meaningful
101 answers.

102 **Materials and methods**

103 *Studied farms*

104 The study was carried out in the Province of Uppland located in Central-east Sweden.
105 Uppland has a relatively flat topography with the highest elevation point 117 m above sea
106 level. Agriculture is characterised by cereal farming on the open plains and more livestock
107 and mixed farming with a high percentage of rotational or improved grassland (grass-clover
108 ley) in the mixed and more forested areas. Rotational grass-clover leys (a mixture of clover
109 and grass species) often including red clover (*Trifolium pratense*, L.), white clover (*Trifolium*
110 *repens*, L.), timothy (*Phleum pratense*, L.) and meadow fescue (*Festuca pratensis*, L.) cover
111 about 40% of the arable land while winter wheat (*Triticum aestivum*, L.) and spring barley
112 (*Hordeum vulgare*, L.) are each grown on about 15% of the arable land (Swedish Board of
113 Agriculture 2011).

114 We conducted the study with 16 organic farm owners with diverse farm types and time
115 periods since conversion to organic farming, in order to include farmers with a variety of
116 objectives and with different levels of experience in organic farming. The farms have been
117 certified organic for between 2 and 25 years with the Swedish organic trademark, KRAV.
118 These farms were originally selected to represent organic farms with different periods since

119 conversion and have been used in several studies of biodiversity and ecosystem services
120 (Jonason et al. 2011; Jonason et al. 2012). The importance of landscape was considered in the
121 original study by selecting the farms along a gradient of landscape heterogeneity. The farms
122 have been grouped according to their main farming activity into arable, dairy, beef/sheep, pig
123 and mixed livestock farms.

124 *Interview methods and analysis*

125 We used semi-structured interviews, which are widely employed to gain a good understanding
126 of the attitudes and decisions of farmers towards different management options (Longhurst
127 2003). The interviews were carried out on the farms in spring 2011. A list of key words which
128 could describe the essential information relating to crop choice and crop rotation was prepared
129 and tested with one farmer (not within the group of farmers interviewed), and necessary
130 changes were made and then used for conducting the 16 interviews (Table 1). Using the list of
131 key words, farmers were asked open-ended questions, with probing whenever necessary to
132 obtain robust information required for the study. The interviews lasted between one and three
133 hours. Several farmers showed us around their fields and livestock units during and after the
134 interviews and these also provided opportunities to observe the management procedures and
135 also to gain additional information. All interviews were recorded and transcribed. We used
136 the software ‘Atlas.ti’ (ATLAS.ti GmbH, Germany) to help condense structure and categorise
137 the different statements of the transcribed information. This approach is recommended by
138 Kvale (1996). All the statements relating to crop rotations and their rationale were coded into
139 categories and key words.

140 [Table 1 near here]

141 **Results and discussion**

142 General farm characteristics and crop rotation strategies are summarised in Table 2. The
143 different crop rotations practiced by the farmers and their rationales are discussed within
144 different farm groups in the following sub-sections.

145 *Arable farmers*

146 The arable farmers interviewed mainly depended on cereals, mostly winter wheat, for their
147 income. Most farmers also included perennial clover and grass crops used as a green manure
148 (in the following text referred to as ‘ley’) in their crop rotations. The ley crops were under-

149 sown in annual cereal crops and remained for at least one more year during which they were
150 cut regularly to control weeds, and also in some cases to sell hay or silage to neighbouring
151 farms. In the year of ley incorporation, a short period of black fallow (repeated tillage to
152 control weeds) was often applied before sowing winter wheat benefitting from the pre-crop
153 effect of the ley. Most farmers also included a grain legume in the rotation, i.e. field beans
154 (*Vicia faba*, L.) or peas (*Pisum sativum*, L.), in pure stand or in mixtures with oats (*Avena*
155 *sativa*, L.).

156 Most of the arable farmers reported that they were growing cereals as frequently as possible
157 in the rotation and avoided the use of break crops, such as legumes. With one exception, they
158 did not follow a planned crop rotation, but adjusted their crop choice according to the
159 prevailing situation. A farmer who had managed his farm organically for more than 20 years
160 (Farmer 1) remarked:

161 *“I don’t follow a planned rotation as I might have to change crops according to market price.*
162 *I mostly grow wheat after ley. But from this year onwards; I applied Biofer (meat and bone*
163 *meal fertiliser, mainly from conventional sources) to my cereals and avoided growing ley and*
164 *legumes. I cannot have peas and beans more than every sixth year in the rotation because of*
165 *pests and diseases, and since I don’t have animals to eat them, they can easily be replaced*
166 *with cereals”.*

167 His statement indicated that he was not happy with the practice of growing leys and annual
168 legumes as he didn’t find them useful. However, frequent cultivation of cereal crops could
169 increase damage caused by pest and diseases and risk to reduce grain yields compared to more
170 diverse crop rotation. Recent research investigating effects of preceding crops using a wide
171 range of experiments from all over the world shows that wheat grown after a break crop can
172 be expected to yield between 0.5 and 1.2 t ha⁻¹ more than wheat after wheat (Angus et al.
173 2015). Management of nutrient supply was reported to be one of the greatest challenges for
174 arable (stockless) organic farmers as leys are of little economic benefit to them, and also do
175 not increase the total supply of nutrients other than nitrogen through biological nitrogen
176 fixation by legumes such as clover (Watson et al. 2002). Thus, the present farmer substituted
177 the perennial ley, which produces many system benefits, such as break crop effects on weeds,
178 pests, diseases as well as reducing external nitrogen input, with ‘Biofer’ fertiliser that provide
179 a range of nutrients but not the other benefits. Farmers appear to see a choice between

180 growing leys and annual legumes in the rotation on one hand, and applying ‘Biofer’ to have
181 more land available for cereal, on the other hand. The use of ‘Biofer’ to grow more cereal
182 crops can be seen as a shift towards a more ‘conventional’ farming approach, in terms of the
183 farmer’s reliance on off-farm nutrient inputs and more specialisation in the system. This
184 approach deviates from the rules of crop rotation as the same/similar crops are grown
185 consecutively for several years which might result in the build- up of pests, weeds and
186 diseases. In addition, the dependence on external fertiliser and less crop diversity in the farm
187 does not seem to fit with the principles of organic agriculture to utilise diversity and to use
188 legumes to provide nitrogen rather than purchasing external inputs. Replacing nitrogen fixing
189 and soil improving crops, such as grass-clover ley, with inputs from outside the system that
190 are derived from e.g. livestock raised conventionally were widely used in organic farms in
191 Denmark (Oelofse et al. 2013). Several other studies have also reported that many organic
192 farmers are moving towards ‘conventionalisation’ of their organic farms in terms of more
193 farm specialisation, larger farms and intensive use of external fertilisers and less regard for the
194 principles of organic farming (de Wit & Verhood, 2007; Darnhofer et al. 2010; Oelofse et al.
195 2011; Nowak et al. 2013). Another farmer who has been organic for the last 12 years (Farmer
196 3) already followed a more conventional approach similar to that of Farmer 1. Farmer 3 did
197 not plan his crop rotation in advance, and grew crops according to the market price. His goal
198 was intensive production reliant on purchased fertilisers. He said:

199 *“My crop sequence is almost free. I choose crops which give the most profit at the moment. So*
200 *I have a very intensive organic system. I buy organic fertilisers such as Biofer and Biovenass*
201 *(a by-product from commercial yeast production) for my crops to produce more wheat*
202 *instead of growing ley or peas.”*

203 The above quote indicates that the current market price was the most decisive factor for him
204 when choosing crops in the sequence. He was the only farmer who did not grow any ley and
205 he also reported managing the weeds successfully using modern machines and without any
206 break crops in his cereal rotation. The farmer, however, reported growing field beans in some
207 years, if the price was high enough.

208 The same farmer further commented:

209 *“I think the first farmers who started organic farming were idealists. But now it is not like*
210 *that. I think it is more that we want to have the same output as conventional farms.”*

211 His comment indicates that he thinks that there is a trend towards more market oriented
212 farming practices amongst the recent organic adopters and that he thinks it is possible to
213 achieve the same yields as in conventional agriculture. He explained that his generation of
214 organic farmers aims at increasing productivity by managing the farm intensively using
215 external fertilisers and modern machinery to control weeds. One farmer (Farmer 4) who had
216 tried to grow mostly cereals in the crop rotation describes how that led to problems with
217 weeds. Because of these problems, the farmer decided to go back to a planned crop rotation
218 with legumes and break crops in order to find solutions to the problems. He made the
219 following comment on his earlier crop rotation strategy:

220 *“Before developing this crop rotation three years ago, I had quite a free crop rotation. It was*
221 *much more depending on the market. The price of different cereals was a bit uncertain at that*
222 *time, so you never really knew what to sow. Maybe the free crop rotation caused the big*
223 *thistle problem that I have experienced. I was too eager to grow cereals, not really thinking*
224 *about the consequences.”*

225 The quote reveals how this farmer shifted his focus from a profit-oriented crop rotation to a
226 more ecological farming based on the rules and principles of crop rotations and organic
227 agriculture, because of problem with creeping thistle (*Cirsium arvense* L.). This farmer has
228 been practicing organic farming for 12 years and grew as much cereal (mainly winter wheat)
229 as possible to maximise returns until three years ago. The new rotation includes leys for one
230 or two years to control perennial weeds followed by two years of winter wheat. Thus, the
231 farmer made the choice to grow wheat with leys in the rotation to avoid weeds, rather than
232 growing more crops of wheat at low yield due to e.g. weed problems. During the interview,
233 the farmer also highlighted that his crop rotation with a ley crop in the sequence offers other
234 benefits, such as building up the nutrient stock for the winter wheat crop and improving the
235 soil structure.

236 A farmer managing his farm organically for the last 10 years (Farmer 5) did not follow a
237 planned crop rotation. He was flexible in the choice of crops species in the rotation. The
238 rationale for his decision was to be able to adapt to variable conditions such as disruptions due
239 to pests, weather, etc.

240 Crop rotation strategy of a farmer who inherited the farm from his grandfather and has been
241 managing his farm organically for 18 years (Farmer 2) was based mainly on tradition and

242 farming experience. Although the livestock component was abandoned 16 years ago in the
243 farm, he reported following the same crop rotation as in the last 70 years as he claims to have
244 good knowledge of this rotation. He remarked:

245 *“I have not changed the crop rotation that my grandfather used since the 1940s, because I*
246 *know it very well and this rotation controls the weeds. I still grow ley even though I do not*
247 *have cows now, as I trust this rotation. I can sell some of the forage to the neighbours, though*
248 *not at the same good price as the wheat.”*

249 His statement reflects the importance of experience when deciding crop choice and rotation.
250 The farmer chose to trust the well tested crop rotation which was designed with proper break
251 crops, rather than changing to a new one, which could potentially be more profitable. During
252 the interview, the farmer also mentioned that he thinks that the inclusion of ley in the rotation
253 helps to improve the soil. Rotational leys are known to increase yields of the other crops in
254 the rotation (Johnston et al. 1994; Persson et al. 2008)

255 In summary, lack of direct economic benefits of growing leys was the reason why several of
256 the arable farmers do not to grow leys and diverge away from the rules of crop rotation and
257 principles of organic agriculture. Instead, some of the farmers follow a market oriented crop
258 rotation practice focused on growing cereals with the intensive use of machines and external
259 fertilisers. The two most important trade-offs mentioned were, firstly, the use of external
260 fertilisers and intensive control of weeds to grow more cash crops, and secondly, the use of
261 legume crops and crop diversity in rotation to support soil fertility and for controlling weeds
262 and diseases. Moreover, the farmers who followed a planned crop rotation seemed to be more
263 driven by organic principles than the more commercially oriented farmers with more flexible
264 and liberal crop rotation strategies.

265 266 *Dairy farmers*

267 The typical crop rotation reported by the dairy farmers was two or three years of ley followed
268 by two years of cereals. The first year of cereal was always wheat (winter wheat preferred
269 over spring wheat), while the second year could be wheat, barley or oats, e.g.:

270 Ley 1- Ley 2-Winter wheat- Wheat/Barley/Oats-peas under sown with a clover-grass
271 mixture

272 It is evident from the general crop rotation (above), that the need for feed leads the dairy
273 farmers to incorporate more ley crops in their rotations than the arable farmers. According to
274 a farmer who had been practicing certified organic farming for 25 years (Farmer 6), he
275 followed a planned crop rotation in order to produce sufficient feed for the livestock, and also
276 some cereals for direct cash income. He included oats in the rotation even if he had more use
277 for barley and wheat as feed, because he considered oats to be more competitive towards
278 weeds, and easier to manage than higher value crops such as wheat and barley. Oats is
279 considered an important crop in areas with short growing seasons and long day-length
280 regimes and hence is well suited to the study area (Buerstmayer et al. 2007). Oats are
281 particularly suitable in organic farming where the availability of nitrogen is generally lower
282 and the need for competitive crops is larger than in conventional systems. He also wanted to
283 have great crop diversity to spread risks and because it was his experience that more crop
284 diversity leads to fewer problems with weeds, pests and diseases.

285 Furthermore, his crop rotation was aimed at managing weeds and he experimented with
286 different crop sequences to develop his farm management. He remarked the following about
287 his crop rotation for controlling the weeds:

288 *“We had problem with weeds. We have tried rotations with 3 or 4 years of ley, but then there*
289 *was the problem of the perennial weed, couch grass. The couch grass spread to the barley.*
290 *We also got less material for silage. So now, with two years of ley, there are fewer weeds and*
291 *we could get good yields. Of course it is also expensive to re-seed the ley every 2 years, but it*
292 *is better than having weeds.”*

293 His statement reflects the choice between efficient weed control and the costs of frequent re-
294 seeding of the ley crop. According to his experience, two-year leys were optimal for long
295 term yields considering the need for keeping weeds, i.e. couch grass (*Elymus repens*, L.),
296 under control in the rotation. Several other perennial weeds, particularly stationary ones such
297 as dandelion (*Taraxacum* spp.), thrive in leys, but are not very competitive in annual crops.
298 The control of couch grass depends mainly on having competitive crops and cultivating the
299 soil between crops (Håkansson 2003). This also shows that proper planning and length of
300 period of certain crops in a rotation can prevent propagation of particular problematic weed
301 species.

302 According to a farmer rearing 90 dairy cows and practicing organic farming for 13 years
303 (Farmer 7), the rationale for the crop rotation was to meet the feed requirement of the dairy
304 cows. He said the following about his crop rotation:

305 *“I follow a planned crop rotation because I am compelled to do it. I need a lot of grass-clover*
306 *ley to produce forage for the animals and then, peas and barley mixture as protein*
307 *supplement for the cows. The good thing is also that I do not need to buy fertilisers, and the*
308 *rotation is good for the soil. Thistles are controlled in this rotation if I cut the leys 3 times a*
309 *year.”*

310 The focus on producing feed for the animals is in line with Flaten et al. (2005) who reported
311 that the main cropping goal of Norwegian dairy farmers was to produce sufficient feed for the
312 livestock as organic livestock feed was reported to be expensive. Producing livestock feed on
313 farm also fits within the guidance of organic regulations for the use of locally produced feed.

314 The aim of a farmer practicing certified organic farming for 12 years (Farmer 8) was to adapt
315 his crop rotation according to the market price of cereals. He often chose to grow wheat
316 instead of protein rich crops such as peas and beans for his livestock. Thus, this farmer could
317 consider replacing feed crops with profitable cash crops and instead purchase the feed. The
318 crop rotation strategy of a recently converted organic farmer (Farmer 9) was to avoid weeds
319 and diseases in the crops. The farmer developed a crop rotation plan when he became a
320 certified organic farmer which included two years of ley followed by one year of winter wheat
321 and then a fourth year with winter wheat or *Triticale*. His strategy was to buy the protein
322 fodder from other farmers, because he considered the annual legumes difficult to grow as they
323 are susceptible to adverse weather conditions, pests and diseases.

324 To summarise, most dairy farmers followed the rules of crop rotation by having diverse crops
325 and leys to control weeds, pests and diseases. However, the strategy of a few of the farmers to
326 rely on external feed by growing more cereals is not in line with the principles of organic
327 agriculture. The most important trade-off observed amongst dairy farmers in regard to their
328 crop rotation was between growing sufficient feed for the livestock, and growing cereal crops
329 for cash. Several farmers who were flexible in their crop rotation tended to focus on cereal
330 cash crops and thus had a higher dependence on external sources for feed than other organic
331 dairy farmers interviewed. It appears that it was more important for the long term organic

332 farmers in the study to be self-sufficient in feed than it was for the recently converted farmers,
333 who were more willing to purchase feed.

334

335 *Beef and sheep farmers*

336 The crop rotation strategies of beef cattle/sheep farmers were very variable, but it was quite
337 common to have three years of ley and two years of cereals (winter wheat or spring barley).
338 Some farmers also had peas or beans after the first or second year of cereals and then added
339 another cereal crop at the end of the rotation. A typical rotation was:

340 Ley 1- Ley 2- Ley 3- Wheat /Barley- Wheat/Oat under sown with grass-clover

341 Similar to many dairy farmers, the objective of the crop rotation for Farmer 13 was to follow
342 a planned rotation in order to produce sufficient feed for the livestock as well as cereals for
343 direct cash income. Despite mentioning the problem of thistles in wheat, the farmer continues
344 growing wheat because it is profitable even if yields are quite low. Another farmer practicing
345 organic farming since 11 years (Farmer 12) claimed that the purpose of his crop rotation was
346 to solve the problem of thistle and couch grass. The farmer remarked:

347 *“Thistles are difficult to control and that is why I have three-four years of ley in the rotation.*
348 *I also avoid growing wheat after wheat or barley. The disadvantage of my rotation is that*
349 *couch grass propagates. The couch grass multiplies in the ley, especially if you have ley for*
350 *three years, but they are not as stubborn as thistle”.*

351 Similar to several arable farmers, he reported thistles to be an important factor when deciding
352 his crop rotation, which had not been mentioned by many farmers with livestock. However,
353 Farmer 12 had four years between the ley crops, which is more than any other livestock
354 farmer. According to his experience, two years of ley was not enough to control thistles. The
355 risk of having three year leys in the rotation was also highlighted by this farmer. After three
356 years of ley the problem with couch grass accelerated according to Farmer 12. This is
357 evidence of a trade-off between controlling thistle and couch grass and this farmer prioritised
358 the control of thistle, because he found couch grass easier to control by other means,
359 supposedly through tillage. It is well known that perennial weeds can easily become a major
360 problem if crop sequences are not properly planned and managed (Liebman & Dyck 1993)

361 and that the occurrence of thistle decrease with the age of the ley crops, while this is not the
362 case with couch grass (Håkansson 2003). Couch grass has a similar growth habit as the sown
363 grasses and can therefore tolerate the frequent cuttings associated with harvest well (Cussans
364 1973), while creeping thistle is sensitive to cutting (Graglia et al. 2006).

365 A long-term organic farmer who had been raising beef cattle and sheep organically for 23
366 years (Farmer 10) did not follow a crop rotation. When asked what determined his rotation,
367 the farmer replied:

368 *“I grow whatever suits me. I have a lot of ideas about different crops and rotation. But I can*
369 *never decide in advance what I am going to grow in the coming year as my chosen crops*
370 *sometimes die or fetch a lower price. As time goes on, it will tell. You have to change your*
371 *plans in order to benefit according to each particular year and I buy feed sometimes in order*
372 *to grow more cereals”.*

373 This farmer did not seem to be interested in following a planned crop rotation because of
374 several uncertainties. According to him, he could gain more by adapting to the prevailing
375 conditions and market prices than following a planned rotation and this determined his crop
376 rotation. Smit and Pilifosova (2003) reported that farmers who have experienced the effects of
377 extreme events, e.g. extreme weather, can plan better to adapt to the impacts of future extreme
378 events. Despite being a livestock farmer, his crop rotation strategy was similar to several of
379 the arable farmers.

380 A long-term organic farmer (Farmer 11) who had been raising beef cattle organically for 23
381 years mentioned that the soil type in his farm was the most important determinant for his crop
382 rotation. The farmer said:

383 *“If you run your farm organically, you should terminate the ley after a shorter length of time*
384 *to take advantage of the nitrogen. If you don't, the nitrogen just leaches. But knowing is one*
385 *thing and doing is another. The peat soils in my fields are mainly suitable for growing ley, it*
386 *is difficult to grow cereals on them, and you easily get a lot of weeds. That is why we have*
387 *mostly cereals on the mineral soils and ley on the peat soils”.*

388 He grew mainly barley on the mineral soils and ley on the peat soils (soils with a relatively
389 high percentage of organic matter). In spite of his awareness of the benefits of ley crops and
390 crop rotation, he chose to grow his leys on the peat soils, because of the difficulties of

391 producing good cereal crops without herbicides on these soils. A sheep farmer who converted
392 to organic farming four years earlier (Farmer 14) claimed to follow a planned crop rotation in
393 order to produce sufficient fodder on peat soils, with one year oats followed by three years of
394 ley in the rotation. He shared similar experience as Farmer 11 on the difficulty of growing
395 cereals on peat soils. The farmer commented:

396 *“Well, on the peat soils it is only oats, because wheat, barley and peas don’t grow well on the*
397 *peat soil and I don’t know what other crops to grow. Oats is followed by ley for some years. It*
398 *is mainly to establish a new ley crop that I have oats every fourth year and I do not need to*
399 *buy feed from neighbours.”*

400 In summary, several long-term organic farmers were aware of the ‘potential benefits’ of
401 practicing crop rotation, but they were generally quite flexible in their rotations and adapted
402 them to soil type, climate, market, and weeds. The important considerations for the farmers
403 were the number of years to keep the leys in the rotation to optimise weed control, residual
404 effect of the leys, the possibility to grow cash crops and presumably the need for feed. The
405 recently converted organic farmers seemed more eager to follow planned crop rotations and
406 the main purpose of the crop rotation planning was to control weed propagation, especially
407 thistle and couch grass. Most of the farmers in this group followed crop rotation rules quite
408 diligently.

409

410 ***Pig and mixed livestock farmers***

411 The main reason for following a planned crop rotation for a pig farmer who converted to
412 organic farming three years earlier (Farmer 16) was to achieve good break crop effects. He
413 practiced the following crop rotation:

414 Oats (under-sown with grass-clover) - Ley 1 - Ley 2 - Wheat/Barley - Oats- Pea

415 The farmer remarked on his crop rotation:

416 *“My rotation is to produce enough feed for my pigs. I avoid barley after barley in the rotation*
417 *as there could be fungi (in the crops). Maybe my application of manures worsens the fungus*
418 *situation. I am also trying to get rid of the weeds. I am a pig farmer but I grow ley to remove*
419 *the weeds. I think it has reduced the problem with fungal diseases and also fertilised the soil”.*

420 The farmer changed his earlier crop rotation because of his experience with fungal diseases
421 and weeds in the crops. He related the occurrence of fungal diseases in his crops to growing
422 barley for several consecutive years and also to the application of manures. He chose to
423 follow a proper rotation with two years of ley even though the pigs did not consume much
424 forage, as it offered other benefits such as reducing the problem of weeds and diseases and
425 also improving the soil fertility. The increase in fungal disease with animal manure that the
426 farmer report could probably be an effect of the resulting high nitrogen availability that is
427 known to increase risk of fungal diseases, but, in general, animal manure is considered to
428 promote crop health by increasing soil biological activity (van Bruggen 1995).

429 The crop rotation strategy of a farmer who had practiced organic farming for 25 years
430 (Farmer 15) was based not only on economic and agronomic reasons but also on very strong
431 ecological arguments. He practiced a highly diversified system with several farm income
432 sources: pig, beef, dairy, sheep, poultry and cereals on 170 ha farmland.

433 He claimed to follow a planned crop rotation most of the time, but sometimes interchanged
434 crops with similar properties, or changed crops as response to weather conditions. He gave the
435 following statement on his crop rotation:

436 *“The aim of my crop rotation is to produce enough to make a profit, control pests and weeds*
437 *and also enhance biodiversity. One goal is to have enough grains to sell, (which means) more*
438 *than we consume, including household consumption. We also look into the resilience of the*
439 *farm using different combination and ways of integrating crops and animals. The extension*
440 *agent advised me to invest in one species to make greater profit. But I don’t want to put all*
441 *eggs in one basket.”*

442 Although the extension agents have advised him to specialise in one type of farm enterprise in
443 order to increase profitability, the farmer had deliberately diversified the farm with several
444 crops and animal species. The farmer also mentioned that he thinks his farm will be more
445 sustainable if he has income from diversified sources. He seems to prioritise long-term farm
446 sustainability more than the short-term economic benefit. It has been shown earlier that some
447 organic farmers have a long-term concern for sustainability and these farmers are willing to
448 risk a reduced yield in the short-term for a good chance of a higher yield in the future (Mccan
449 et al. 1997). Darnhofer et al. (2005) also suggested that farmers with this focus on
450 sustainability are likely to be long-term organic farmers and that they are likely to be willing

451 to risk foregoing incomes for the cause of organic principles. The farming ideals of Farmer 15
452 seemed to be deeply rooted in the principles of organic farming and his crop rotation with
453 diverse crops and proper length of crop sequence fits well to the rules of crop rotation.

454 [Table 2 near here]

455

456 **Concluding discussion**

457 The study illustrates that farmers' past experiences with crop rotation and management
458 greatly influenced the farmers' current crop rotation strategies. The case of arable farmers
459 using 'Biofer' as a substitute for legumes is a good example where the convenience of use and
460 short-term better economic return from consecutive cereal crops makes them choose cereal
461 crops over legumes and perennial crops in the rotation. This allowed them to grow crops
462 according to market demand and price without considering the best possible use of crop
463 rotation. Although, this practice appears to be more of a conventional farming approach, it
464 seems to be getting more common among organic farmers in many parts of the world (Lockie
465 & Halpin 2005; Darnhofer et al. 2010; Oelofse et al. 2011). The intensification may also
466 increase the extent to which organic farming relies on nutrient imports from conventional
467 production as discussed by Nowak et al. (2013). The organic standards are characterised by a
468 description of what is not allowed in organic farming rather than describing the positive
469 practices. One of the difficulties of translating the principles of organic farming into practice
470 is associated with the interpretation of those principles as there is no single or exact
471 interpretation of these. Padel et al. (2009), Darnhofer et al. (2010) and Dinis et al. (2015) all
472 point out specifically that the principles of organic farming are only partly expressed in the
473 certification rules in relation to biodiversity, nutrient cycling etc. Many authors suggest that
474 this can result in a type of organic farming which is very close to conventional farming but
475 without the prohibited substances (Allen & Kovach 2000; Constance et al. 2008). The organic
476 farmers in this study who are moving away from diverse crop rotation towards the use of
477 purchased organic fertilisers and high-tech solutions of mechanical weeding could be seen as
478 falling into this category. On the contrary, there were also farmers who had experienced the
479 problem of diseases, weeds and low yield from their earlier rotation strategy that focused on
480 producing as many cash crops (cereals) as possible, and who have changed their crop rotation
481 strategies to address the problems.

482

483 The results shows that farmers decisions on their crop rotations are not necessarily based on
484 the rules of crop rotations (Castellazzi et al. 2008), and the principles of organic agriculture
485 (by IFOAM), but also by factors such as soil type, weeds, price, tradition, etc., as mentioned
486 in the European Commission (2010) report. In addition, our study has identified important
487 trade-offs which farmers have to consider when deciding their crop rotations. The case of
488 arable farmers preferring to grow more cereal crops than perennial ley or annual legumes fits
489 with the ideas of Watson et al. (2002), as these crops are of little economic benefit and also do
490 not increase the total supply of nutrients other than nitrogen. It is logical for the arable
491 farmers to focus on growing profitable cereal crops more frequently in the rotation as their
492 income comes from crops only. However, the evidence of several livestock farmers preferring
493 to grow cereal crops and purchase feed is a general cause for concern about the reliance of
494 organic farming on external (conventional) sources. Kirchmann et al. (2008) reported that
495 75% of organic mixed farms in Austria and Sweden imported fodders from external sources,
496 mainly from conventional farming. Neighbouring farmers with and without animals could
497 also collaborate in order to use resources more efficiently at a regional scale, allowing some
498 specialisation while keeping some of the advantages of the diversified systems.

499 Most of the livestock farmers in the study region, excluding the dairy farmers, have the
500 features of 'mixed farms' as their crop rotations were based on producing feed for the
501 livestock, as well as, cereals for earning direct cash income. This diversification of income
502 sources was evident amongst the long-term organic livestock farmers (more than 10 years of
503 certified organic farming) within the group. Their farming aims were to produce sufficient
504 feed as well as different cash crops. The recently converted organic livestock farmers tended
505 to be specialised and focused on producing feed for their livestock and grew few crop species.
506 Zander (2005) showed that personality of the farmer is the key driving factor for
507 diversification among organic farmers in Germany and that presence of highly qualified
508 labour on the farm was a pre-condition to successful diversification. Perhaps, the long-term
509 organic farmers in our study had gained experience and skills through many years of organic
510 farming and this might be the reason why they had more diversified systems than the recent
511 organic farmers. The case of long-term organic farmers practicing more diversified farming
512 and adhering to the principles of organic farming than the recently converted ones was also
513 reported in other parts of Europe (Best 2008, Padel 2008; Dinis et al. 2015).

514 We could distinguish three different crop rotation strategies; strict, flexible and liberal crop
515 rotation. Farmers practicing strict crop rotation strategies have a pre-planned crop sequence
516 and followed the sequence stringently through several rotations. Farmers with flexible crop
517 rotation strategies also had a pre-planned crop sequence, but the crop species in the sequence
518 sometimes varied and changed to adapt to environmental conditions and economic
519 considerations (especially cereal price). Finally, farmers practicing liberal crop rotations
520 lacked crop sequence plans and chose crops according to the market price, seed availability,
521 personal preference and weather conditions. Several recently converted organic farmers
522 practiced strict crop rotation and their strategy appeared to be mainly related to controlling
523 weeds and diseases in the cereals. Flexible and liberal crop rotation strategies were more
524 associated with long-term organic farmers and their rationale was to adapt to, or gain from the
525 changing conditions such as market and weather.

526 In conclusion, farmer's past experiences with the trade-offs between different practices
527 greatly influenced their crop rotation strategies, i.e. strict, flexible or liberal. Irrespective of
528 the farm type, the most important trade-off was to grow frequent cereal cash crops at the
529 expense of ley and legumes in the rotation leading to flexibility in their crop rotations. The
530 rotation strategies of long-term organic farmers were much influenced by organic principles
531 and they generally incorporated ley crops in their rotations. Their rationale for flexible and
532 liberal crop rotations was to be able to adapt to changing conditions. Recently converted
533 organic farmers often practiced strict rotation and followed the rules of crop rotations to
534 control weeds and diseases. Farmers who chose crops without an intended crop-rotation
535 (liberal) claimed to continuously adapt to prevailing economic and agro-environmental
536 conditions as well as their personal preferences, and their rotation strategy tend to deviate
537 from the rules of crop rotation and organic agriculture. Most livestock farmers built their crop
538 rotation around ley and forage and their overriding aim was to produce sufficient feed, but
539 some preferred to grow more cereals for sale and purchase some feed for better economic
540 return. We conclude that despite the multifunctional benefits of ley and crop rotation in
541 organic system, many farmers tend to overlook it for short term economic benefits. As a
542 result, these farmers may need to invest in technology or labour for weed control and become
543 more reliant on other external inputs.

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726 **List of Tables**

727 **Table 1.** List of keywords for the interviews.

728

729 **Table 2.** Summary of general farm characteristics and farmer's crop rotations, typical
730 sequence or crops grown, and type of rotation strategy, i.e. strict (always the same crops
731 grown in rotation if at all possible), flexible (aim for a special rotation and adjust according to
732 circumstances) and liberal (no special rotation). Ley refers to a crop mixture of red clover and
733 grasses. All crops except winter wheat and triticale are spring sown.

734

735 **Table 1.** List of keywords for the interviews

736 A .Farm Overview:

737 1. Size; Labourers; Number of crops, animals. Why?

738 2. History- ownership, farming type (crops/animals)

739 B .Farming/cropping systems:

740 1. Organic/conventional: since when, why?

741 2. Crop sequence and rotation in the farm

742 3. Purpose of the sequence/rotation

743 4. Pros and cons of the rotations , e.g. effect on soil, water, disease/weeds, yield, price

744 5. Change in crop rotations in the recent past.

745 6. Source/knowledge of crop rotation from where/whom?

746 7. Any Intercropping, how and why?

747 8. Annual crop distribution

748 9. Crops in the farm (according to area, economic expenditure and benefits),

749 10. Crops/crop rotations that are most challenging to grow, and why, how it is overcome?

750 11. Cash crops/how much for internal use? Where he sells, why? Any contract?

751 C. Decisions:

752 1. Sowing and harvesting time

753 2. When and how the decisions on crop choices are taken?

754 D. Management:

755 1. Fertiliser/manures and amount (for different crops), internal or external

756 2. Farm expenditure (ranking)

757 3. Farm challenges (rank)

758 4. Subsidies and market price on type of crop/farming

759 E. Farmers' information:

760 1. Age: Farming education; Any techniques he learnt from education or visiting farms
761 abroad

762 |

763 **Table 2.** Summary of general farm characteristics and farmer's crop rotations, typical sequence or crops grown, and type of rotation strategy, i.e.
764 strict (always the same crops grown in rotation if at all possible), flexible (aim for a special rotation and adjust according to circumstances) and
765 liberal (no special rotation). Ley refers to a crop mixture of red clover and grasses. All crops except winter wheat and triticale are spring sown.

<i>Farm no.</i>	<i>Farm type</i>	<i>Farm size (ha)</i>	<i>No. of livestock</i>	<i>Year since conversion to organic</i>	<i>Crop rotation/typical sequence</i>	<i>Rotation strategy</i>
1	Arable	70	0	20	Grow ley, winter wheat, oats, barley	Liberal
2	Arable	150	0	18	Barley (under-sown ley) - ley - ley/black fallow ¹ - winter wheat - winter wheat	Strict
3	Arable	235	0	12	Mostly winter wheat and other cereals, but occasionally also field beans	Liberal
4	Arable	163	0	12	Barley (under-sown with ley) - ley/black fallow ¹ - winter wheat - winter wheat - field beans	Strict
5	Arable	55	0	10	Oats (under-sown) - ley - wheat - oats/peas	Flexible
6	Dairy	90	50	25	Spring barley/oats (under-sown ley) -	Strict

ley - ley - winter wheat

7	Dairy	105	90	13	Barley and pea (under-sown ley) - ley - ley - ley - winter wheat	Strict
8	Dairy	310	280	12	Barley/peas/field beans (under-sown ley)-ley - ley - ley - winter cereal (Wheat/triticale)	Flexible
9	Dairy	75	21	5	Winter wheat/triticale (under sown ley)- ley - ley - winter wheat	Strict
10	Beef/sheep	85	22 beef, 33 sheep	23	Grow at least two years of ley and also other crops such as winter wheat, barley and oats	Liberal
11	Beef	34	35	23	Grow cereals, mostly barley, and ley	Liberal
12	Beef	180	150	11	Oats (under-sown ley) - ley - ley - ley - winter wheat -oats - field beans	Flexible
13	Beef	220	30	10	Mixed grains (under sown with ley) - ley - ley - winter wheat - spring wheat	Strict

14	Sheep	50	60	4	Oats (under-sown ley) - ley - ley - ley - oats/peas -	Strict
15	Mixed	179	110 pig, 20 dairy, 10 beef, 80 sheep, 350 hen	25	Barley (under sown ley) - ley- ley- winter wheat - oat- pea- winter rye	Flexible
16	Pig	145	50	3	Oats (under-sown ley) -- <u>ley</u> - ley - winter wheat/spring barley - oats - peas	Strict

766 ¹ Short period with black fallow to control perennial root weeds between incorporation of ley crop and sowing of winter wheat.

