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1 **Weed control method drives conservation tillage efficiency on**  
2 **farmland breeding birds**

3

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23 **Abstract**

24

25 Crops management is known to influence biodiversity, especially conservation tillage (CT,  
26 no-till) often found as a positive method compared to conventional tillage (T, inversion of  
27 soil) but without controlling for underlying farming practices. There are many ways to  
28 perform CT, in particular concerning the control of weeds, but few studies have taken into  
29 account these methods, which could explain the lack of consensus about the effect of CT  
30 compared to T. We tested differences in breeding birds abundance between CT and T while  
31 accounting for weed control methods in oilseed rape and wheat CT fields. During the  
32 intercrop period, one CT system used a cover crop to control weeds (CTcc), the other used  
33 herbicides (CTh) and the control (T) system only used a tillage. We made CTcc/T and CTh/T  
34 comparisons by sampling bird abundance (respectively 49 CTcc/51 T and 30 CTh/33 T point  
35 counts). We show substantial differences between CTcc/T and CTh/T comparisons as we  
36 detected greater bird abundances in CTcc than T for 5 species (2.3- 4.1 times more  
37 individuals) and a lower abundance in CTh than T for 2 species (2.1- 2.2 times less  
38 individuals). Our results demonstrate the importance to account for system features to ensure  
39 the CT efficiency for farmland birds, declining strongly in Europe since 1980 (-55 to -67%).  
40 Results also highlight an even more negative impact of herbicides than tillage, showing that  
41 stopping tillage to intensify herbicide use is not a promising way.

42

43 Key words: direct seeding, farmland biodiversity, farming practices, herbicide, no-till,  
44 ploughing.

45

## 46 **1. Introduction**

47

48 Historically, agricultural areas, and more specifically arable lands, represent an important  
49 proportion of Europe (respectively 35.6 and 21.1%; Eurostat, 2016a). Changes in farmland,  
50 such as intensification processes including increased use of fertilizers, pesticides, and  
51 homogenization of the farming landscape in space and time, are the main causes of decline in  
52 the diversity and abundance of wildlife (Bengtsson et al., 2005; Benton et al., 2003). These  
53 effects have been observed on many taxa in Europe (e.g. plants and invertebrates: Wilson et  
54 al., 1999; birds: Donald et al., 2001; bats: Wickramasinghe et al., 2003; moths: Fox, 2013).  
55 The Common Agricultural Policy (CAP) has been, and still is, a major driving force behind  
56 land use intensification through the stimulation and modernization of agricultural production  
57 (Van Zanten et al., 2014). Since 2013, the CAP includes new greening requirements (e.g.  
58 reduction of grassland fertilization, grass strips, mowing deferment, flowery fallows) such as  
59 ecological focused areas (EFA, direct payments in the first pillar) and changes in agri-  
60 environmental schemes (AES) including agri-environmental managements (AEM, payments  
61 on a voluntary basis in the second pillar). Within the European policy, greening measures are  
62 increasingly claimed to be important tools for the maintenance and restoration of farmland  
63 biodiversity in Europe. While AES do not result in a decrease of crop yields (Pywell et al.,  
64 2015), so far they have only had marginal to moderate positive effects on biodiversity,  
65 especially because they do not differentiate common and endangered species and are applied  
66 on too small and/or wild areas (Kleijn et al., 2006). The CAP also encourages farmland to be  
67 managed as EFA in order to maintain biodiversity. These EFA, covering 3-7% of European  
68 farms, can contribute to increase richness of species, but differences between the 3 and 7%  
69 limits were considerable for butterflies, birds and hoverflies (Cormont et al., 2016). In  
70 addition, a meta-analysis conducted by Batary *et al.* (Batary et al., 2011) showed that AEM

71 were not a very efficient way of spending the limited funds available for biodiversity  
72 conservation on farmland. While AEM and EFA can concern a few Used Agricultural Area in  
73 Europe (Eurostat, 2009), extensification of cropping practices could positively affect farmland  
74 biodiversity on larger surfaces (Fuller et al., 2005). Some of these cropping practices, such as  
75 lengthening and diversification of crop rotation (Josefsson et al., 2016; Miguet et al., 2013)  
76 and the reduction of soil tillage (Holland, 2004), have been identified as providing more  
77 favourable conditions for biodiversity in farmland. Such alternative practices are not included  
78 in AES/AEM and EFA policies.

79 Compared to conventional tillage (inversion of soil with a minimum of 30 cm depth),  
80 conservation tillage (i.e. non-inversion of soil) can have beneficial consequences on soil  
81 structure and fertility, soil organic carbon sequestration, crop diseases and pests, hydrology  
82 and water quality regulation, weed control (Holland, 2004; Kuhn et al., 2016; Power, 2010;  
83 Soane et al., 2012; Tamburini et al., 2016b), and biodiversity (Boscutti et al., 2014; Holland,  
84 2004; Kladivko, 2001). Therefore, it is expected to have positive effects for many taxa such as  
85 flora, soil fauna and birds (Holland, 2004). However, this effect is strongly modified  
86 regionally nearly for all taxa (Tryjanowski et al., 2011; Sutcliffe et al., 2015). It was also  
87 found to improve aphid predation, and to mitigate the negative effects of landscape  
88 simplification on biological control (Tamburini et al., 2016a). Several studies have shown that  
89 the abundance and diversity of bird species during the breeding period was higher in  
90 conservation tillage fields (Flickinger and Pendleton, 1994; Lokemoen and Beiser, 1997;  
91 Shutler et al., 2000). Positive effects of conservation tillage have also been identified in the  
92 wintering period, with a higher abundance of seed-eating birds on arable fields compared to  
93 conventional tillage (Field et al., 2007). However, at the community level, Filippi-Codaccioni  
94 et al. (2009) did not detect any differences in habitat specialist species abundance between  
95 conservation and conventional tillage. Moreover, they found that farmland specialist bird

96 species have lower abundance in conservation tillage compared to conventional tillage  
97 (Filippi-Codaccioni et al., 2009), including some farmland flagship species such as the  
98 Eurasian skylark (*Alauda arvensis*).

99 Thus, according to published studies, there is no consensus on the net effect of conservation  
100 tillage. Possibly, this lack of consistent effects of conservation tillage could be linked to  
101 variations in other farming practices associated to conservation tillage and especially the  
102 method used to control weeds (combining cover crop or superficial tillage with herbicide, or  
103 using herbicides only). However, few of the published studies accurately specified the method  
104 of weed control occurring between harvest of the previous crop and seeding of the new one,  
105 and in the case of cover crop, how this cover is destroyed before seeding the next crop (Field  
106 et al., 2007; Filippi-Codaccioni et al., 2009; Flickinger and Pendleton, 1994; Lokemoen and  
107 Beiser, 1997; Shutler et al., 2000). In addition, the study that best describes practices during  
108 the intercrop (Field et al., 2007) did not conduct bird counts during the breeding period of  
109 birds.

110 To our knowledge, only one study (VanBeek et al., 2014) compared two systems of weed  
111 control in conservation tillage in soybean crops: (i) a superficial tillage (8-10 cm depth), using  
112 a cultipacker to smooth the soil surface and (ii) a no-till with direct seeding into the soil  
113 surface between rows of standing corn stubble (previous crop). In both systems, weeds were  
114 further controlled with a non-selective herbicide after seeding. The study found the highest  
115 bird nesting density in the no-till system (VanBeek et al., 2014). However, the study did not  
116 compare these systems with conventional tillage.

117 Hence, there is a need to assess the conservation tillage impact on biodiversity compared to  
118 conventional tillage according to the weed control method to untangle ambiguous results from  
119 previous studies. To take into account underlying weed control method of conservation tillage  
120 types, which in turn could affect the response of farmland birds, this study is placed at the

121 conservation tillage system level. Thus, we compare the abundance of breeding farmland bird  
122 species of two conservation tillage systems with conventional tillage in wheat and oilseed  
123 rape crops: (1) conservation tillage using a cover crop vs. conventional tillage, and (2)  
124 conservation tillage using only herbicide vs. conventional tillage. There is no soil-inversion  
125 and no superficial tillage in both conservation tillage systems.  
126

127 **2. Materials and methods**

128

129 *2.1. Study area and sampling design*

130 The study was conducted in France, in the Île-de-France region (Essonne, Seine-et-Marne and  
131 Yvelines departments), in an intensive agricultural landscape with a higher yield production  
132 than the national average except for sugar beet (Appendix A, table A1). This region is covered  
133 by 59% agricultural areas, 22% forest and semi natural areas, 18% artificial surfaces and 1%  
134 wetlands and water bodies, calculated from Corine Land Cover data. The agricultural areas  
135 are dominated by arable land (90%) for intensive cropping of cereals (62 %, wheat, and  
136 barley), rape (14%), corn (14%), sugar beet (6%) and peas (4%; Agreste, 2010). Due to the  
137 scarcity of conservation tillage (CT) systems, two study sites 58 km apart were selected, one  
138 for the conservation tillage using a cover crop (CTcc) vs. conventional tillage (T) comparison  
139 (site A) and one for the conservation tillage using herbicides (CTh) vs. conventional tillage  
140 (T) comparison (site B; Figure 1). Land use around the two study sites, calculated from  
141 convex polygon of sampled points, was representative to the typical land use in Île-de-France  
142 (Appendix A, table A2).

143 We selected all known CTcc and CTh fields in the study area. Our conventional tillage fields  
144 (T) were chosen with the aim to minimize differences in landscape composition with CT  
145 fields (CTcc and CTh), in the same farming landscapes and relatively close to CT fields  
146 (range: 0.2-14 km, mean= 3.7 km, SD=4.7 km), to minimize as possible the landscape context  
147 effect (Figure 1; Appendix B, figure B1). However, we accounted for this environmental  
148 context in modelling procedure (see statistical analyses). The number and the mean area of  
149 fields for both systems in the two sites (i.e. CTcc/T in site A and CTh/T in site B) were  
150 heterogeneous (Table 1) and were thus taken into account in statistical analyses.

151



152 *2.2. Features of studied farming practices*

153 Firstly, the tillage type and underlying practices were confounded and depended on each  
154 other. The aim of the study being to take into account the different ways to perform  
155 conservation tillage, expected to be the source of ambiguous previous results in literature,  
156 farming practices were studied at the system level (see statistical analyses section). For all  
157 fields in both study sites, we characterised farming practices and particularly weed control  
158 methods. The weed control in T fields (site A and B) between the harvest of the previous crop  
159 in late summer and the seeding of the new one in autumn, included one or two events of  
160 superficial tillage of the upper soil layer (8-10 cm depth). Then, a tillage (ploughing, soil  
161 inversion to a minimum of 30 cm depth) was performed followed by a smoothing of soil  
162 surface, and finally seeding of the next crop followed by one herbicide (Figure 2).

163 Studied CT fields were characterized by non-inversion of soil for several years, and no  
164 superficial tillage with direct seeding under stubble of the previous crop. We studied two  
165 types of CT which differed in weed control methods. The first type of CT (site A) used a  
166 cover crop (CTcc) of oilseed rape suckers (after an oilseed rape crop) and/or leguminous  
167 crops (as a complement of rape suckers or alone after a wheat crop) between the harvest of the  
168 previous crop and seeding of the new one (Figure 2). The cover crop was seeded while  
169 harvesting, and destroyed when seeding using a steamroller and one selective herbicide, thus  
170 allowing the newly seeded crop to grow and take over. The second type of CT (site B) used a  
171 non-selective herbicide (glyphosate) to control weeds (CTh), without cover crop, with 1-2  
172 treatment events between harvest and seeding, and one selective herbicide following seeding.

173 Thus, in all 3 systems one selective herbicide is used when seeding the next crop (in CTcc it is  
174 the same as to destroy the cover crop), then 1 or 2 until spring. Thus, CTh uses more  
175 numerous herbicide treatments than T and CTcc (Figure 2). In all 3 systems, wheat and  
176 oilseed rape were harvested in late July to early August, and the seeding was performed in

177 October for wheat and in late August to early September for oilseed rape (Figure 2). In both  
178 study sites, for CT fields, the crop rotation is 2 years with wheat followed by oilseed rape, and  
179 for T fields the rotation is 3 years, with wheat every 2 years followed by either oilseed rape,  
180 spring barley, sugar beet, corn, field bean, potato, or pea.

181

### 182 *2.3. Bird census*

183 We sampled bird abundance using the “point” counts method for CTcc and CTh, and their  
184 respective controls (i.e. T in site A and B) in wheat and oilseed rape crops (Table 1). All  
185 counts were performed by the same observer (Kévin Barré). Bird counts were carried out in  
186 spring 2015 at 163 points across 10 mornings between June 5th and June 15th, following the  
187 recommendations of the French Breeding Bird Survey (Jiguet et al., 2012; STOC-EPS, 2013).  
188 For each sampling date we performed a number of CT and T point counts by balancing as far  
189 as possible (Appendix B, table B3). For a given field, points were separated by at least 200 m  
190 to ensure their independence. For the most of CTcc and CTh fields due to their scarcity, we  
191 performed a maximum of independent point counts per field. It was the same way for some T  
192 fields, and few point counts in all other fields when minimization of differences in landscape  
193 between CTcc and T as well as CTh and T was needed. Thus, the maximum number of point  
194 counts per field depended on field size (range: 1-8 point counts/field). The duration of count  
195 per point was 5 minutes between 6:00 am to 10:00 am when species are known to be most  
196 active (Ralph et al., 1995). The detectability of birds is influenced by weather and time-of-day  
197 parameters (Bas et al., 2008). Thus, the exact time of count was recorded, as well as the date,  
198 wind speed, temperature and cloud coverage. Note that bird counts were only carried out  
199 when weather conditions were favourable (i.e. no rain, low wind speed of  $< 4$  m/s,  
200 temperature  $> 12$  °C). For each point count, all detected individuals in a radius of 100 m,  
201 identified from their call or song, or using binoculars, were recorded. The observer placed

202 himself on the side of selected fields, at least 100 m away from a field corner, in order that the  
203 selected field covers at least 50% of the area within 100 m radius. No difference in wheat or  
204 oilseed rape structure (density, height) were detected across systems (CTcc, CTh, T). Thus,  
205 we hypothesized that the mean detectability of a given species, for a given crop type, was the  
206 same across systems and did not require accounting for detectability by setting up a replicated  
207 design.

208

#### 209 *2.4. Environmental covariates*

210 Assuming that local farmland bird abundance depends on local land-use and landscape  
211 characteristics (Berg et al., 2015), in order to be consistent with the counting radius, we  
212 measured within a 100 m radius around point counts: the length of herbaceous boundaries, the  
213 number of crops, the field area and the proportion of the land-use covered by rare crops who  
214 are in less than 5% of point counts (Site A: corn, field bean, potato and pea; Site B: corn and  
215 pea; Appendix B, table B4). In addition, we took into account descriptors of landscape  
216 composition: the distance to the nearest forest, wetland and urban area, and the proportion of  
217 arable land within 200 m radius (Appendix B, §B1). Landscape data was provided by the  
218 National Institute of Geography, from BD Topo for data on forest and urban areas and from  
219 BD Carthage for wetland data. Distances and areas were calculated using QGIS 2.6.

220

#### 221 *2.5. Statistical analyses*

222 We performed generalized linear mixed models (GLMM, R package *glmmADMB*) with the  
223 aim to test potential difference of species abundances among farming systems. Our response  
224 variable was thus bird count at the point count and model included as fixed effect targeted  
225 variables (farming systems: CTcc, CTh and T; crop type: oilseed rape and wheat),  
226 environmental covariates (local and landscape characteristics) and site effect (A and B). Site

227 effect was included to take into account potential abundance differences of species in T  
228 modality between both sites in order to allow accurate CTcc/T (site A) and CTh/T (site B)  
229 comparisons. Date of session, here a categorical variable, was included as random effect to  
230 account for weather conditions of sampling points performed in the same day and for take into  
231 account the hierarchical structure of the sampling (i.e. different farming systems sampled the  
232 same day).

233 Analyses (CTcc/T and CTh/T comparisons) were performed on species with sufficient  
234 occurrences (species presence in more than 10% of point counts) using data from sites A and  
235 B. For some species (*Linnaria cannabina*, *Sylvia communis* and *Turdus merula*), the few  
236 occurrences found in site B did not allowed analyses. Consequently for these species, analyses  
237 were only performed for site A (CTcc/T comparison). For *L. cannabina* crop type was not  
238 included because there was no count event in wheat. Full models were constructed checking  
239 correlations between covariates and targeted variables (Kruskal Wallis tests, appendix B,  
240 tables B5 & B6), and between covariates ( $r > 0.7$ , appendix B, tables B7 & B8). Few  
241 correlations were detected and only between some covariates and targeted variables.

242 However, this slight correlation did not involve multicollinearity problems in full models. We  
243 performed a variance-inflation factors (R package *VIF*) on each full model (Fox and Monette,  
244 1992). All variables showed a VIF value  $< 2$ , meaning there was no striking evidence of  
245 multicollinearity (Chatterjee and Hadi, 2006). According to the characteristics of each species  
246 dataset (species in site A and B:  $n=163$  point counts; species only in site A:  $n=100$  point  
247 counts) we took into account respectively 8 and 6 variables in full models to avoid an over  
248 parametrization. For each species, we used a hierarchical partitioning (R package *hier.part*) to  
249 identify covariates (distances to wetland, to forest, to urban area, proportion of arable land  
250 within 200 m radius, crop number, proportion of rare crops, herbaceous boundaries length,  
251 minute after sunrise and field area) having the best conjoint contributions in order to

252 implement them with targeted variables and site effect in full models (the 5 best predictive  
253 variables for models with both sites A and B and the 4 best predictive variables for models  
254 with only the site A). These steps allowed the construction of full models (Appendix C, table  
255 C9), in which we performed an interaction between tillage type and crop type:

256

257 Species abundance ~ tillage type\* + crop type + tillage type : crop type + site + the 5 best  
258 predictive covariates + (1|Date)

259 \* For *L. cannabina*, *S. communis* and *T. merula* the CTh/T comparison was removed due to  
260 low occurrences of these species in site B.

261

262 In addition to this model simultaneously including CTcc/T (site A) and CTh/T (site B)  
263 comparisons using the site covariate, we performed separated models for each site (i.e.  
264 without site covariate) to check the consistency of the results.

265 According to the nature of the response variables (bird counts) we used a Poisson error  
266 distribution (O'Hara and Kotze, 2010; Zuur et al., 2009). We checked the potential no-linear  
267 relation of minute after sunrise variable for each species using an additive generalized mixed  
268 model (GAMM, R package *mgcv*) in order to evaluate the potential interest of including  
269 additional effects such as quadratic effects.

270 We generated from all full species models a set of candidate models containing all possible  
271 variable combinations ranked by corrected Akaike Information Criterion (AICc) using the  
272 *dredge* function. As the site effect for site A and B models was essential, we always kept it for  
273 all candidate models. For each set of candidate models, we did multi-model inference  
274 averaging on a delta AICc < 2 using the *model.avg* function to obtain an averaged regression  
275 coefficient for each fixed effect (R package *MuMIn*, Barton, 2015; Appendix C, table C10).

276 We used the *allEffects* function (R package *effects*) to get a predicted abundance of bird  
277 species from the best models in Figure 3. We checked the non-spatial autocorrelation on  
278 residuals of the full and best models for each species using *dnearneigh* and *sp.correlogram*  
279 functions associated to the Moran's I method (R package *spatial*, (Moran, 1950); Appendix C,  
280 Figures C2 and C3). Even if we did not detected a spatial autocorrelation in models, we  
281 checked the consistency of the results when accounting for the field effect as random term.  
282 We then assessed goodness-of-fit of GLMMs using the *r.squaredGLMM* function (R package  
283 *MuMIn*, Nakagawa and Schielzeth, 2013) to calculate the explained variance ( $R^2$ ; Appendix  
284 C, table C11). We did not detect any problem in overdispersion ratios with values below 1.5  
285 (0.77 to 1.39) on full and best models following Zuur et al. (2009) recommendations. Note  
286 that for *T. merula*, we used a negative binomial distribution rather than a Poisson distribution  
287 in order to improve the overdispersion ratio which should ideally tend towards 1 (Zuur et al.,  
288 2009; Appendix C, table C9). Finally, we compared estimated parameters and errors from the  
289 models averaged containing environmental covariates, and from the models only containing  
290 targeted variables, in order to check no-problems of confounding effects with environmental  
291 covariates. All significant tests were performed using a threshold of 5% in R statistical  
292 software v.3.3.1 (The R foundation for Statistical Computing 2016).  
293

294 **3. Results**

295

296 *3.1. Sampled species*

297 Among the 13 and 16 bird species detected in A and B sites respectively, 3 species (*A.*  
298 *arvensis*, *Motacilla flava* and *Emberiza calandra*) were sufficiently frequent to perform  
299 analyses using data from sites A and B (i.e. CTcc/T and /CTh/T comparisons), and 3 species  
300 (*L. cannabina*, *S. communis* and *T. merula*) at the site A (i.e. CTcc/T comparison; Appendix  
301 C, table C12).

302

303 *3.2. Selected candidate models*

304 All candidate models with a delta AICc < 2 contained targeted variables (tillage and crop  
305 types), except for *L. cannabina* for which only 4 among 8 candidate models contained them.  
306 The tillage/crop type interaction was selected in all candidate models of *A. arvensis* and *E.*  
307 *calandra*, as well as one candidate model for *T. merula* (Appendix C, table C10).

308

309 *3.3. Effect of conservation tillage according to the method of weed control*

310 Contrasting effects of conservation tillage vs. conventional tillage were observed for both  
311 methods of weed control. In comparison to T, CTcc had a positive effect on the abundance of  
312 each species, with a significant effect for *A. arvensis*, *E. calandra*, *M. flava*, *S. communis* and  
313 *T. merula*, and no significant effect for *L. cannabina* (Table 2; Figure 3). It was the opposite  
314 for CTh which had a negative effect compared to T for all species, with a significant effect for  
315 *A. arvensis* and *M. flava*, and no significant effect for *E. calandra* (Table 2; Figure 3).  
316 *A. arvensis* was significantly more abundant in wheat than in oilseed rape, while *M. flava*, *S.*  
317 *communis* and *T. merula* were significantly less abundant in wheat (Table 3).

318 The positive effect of CTcc was never preferentially linked to a given crop type. Similarly, the  
319 negative effects of CTh and T were always significantly linked to oilseed rape rather than  
320 wheat (Table 3).

321 Estimated parameters and their associated errors from models containing targeted variables  
322 alone did not differ to models adjusted by environmental covariates (Appendix C, table C13  
323 & C14). We also checked the consistency of the results by performing separated models for  
324 each site (i.e. model 1 for site A: CTcc vs. T; model 2 for site B: CTh vs. T; Appendix C, table  
325 C15). Accounting for the field effect in addition to the date as random term did not change the  
326 results except a gain of statistical significance in CTh/T comparison for *E. calandra* and a loss  
327 of statistical significance in CTh/T comparison for *M. flava* (Appendix C, table C16).”

328



329 **4. Discussion**

330

331 There are many ways to perform conservation tillage (CT), but few studies accurately  
332 describe the farming system in which CT is carried out. Here, we have analysed the effects of  
333 two opposed farming systems associated to CT: conservation tillage using a cover crop  
334 (CTcc) and conservation tillage using herbicide (CTh) on common farmland bird abundance,  
335 with conventional tillage (T) as a control. The parameters which differed between systems  
336 were tillage type, herbicide quantities and cover crop implementation.

337 We detected greater farmland bird abundance in CTcc than in T and in T than in CTh. This  
338 could explain opposite results in literature where Filippi-Codaccioni et al. (2009) found less  
339 farmland birds in CT than T, unlike other studies (Field et al., 2007; Flickinger and Pendleton,  
340 1994; Lokemoen and Beiser, 1997; Shutler et al., 2000). Differences found between CTcc/T  
341 and CTh/T comparisons are substantial because CTcc is significantly better than T (except for  
342 *L. cannabina* with no differences) and CTh is significantly less favourable than T (except for  
343 *E. Calandra* with no differences). Thus, positive and negative effect of CTcc and CTh vs. T  
344 affect both insectivorous (*M. flava* and *S. communis*) and omnivorous species (*A. arvensis*, *E.*  
345 *calandra* and *T. merula*). Our results suggest that the less the cover crop is disturbed, such as  
346 shown by VanBeek, Brawn & Ward (2014), and the smaller the amount of herbicides are  
347 applied, the higher the abundance of farmland birds. All models have VIFs<2 which suggests  
348 no obvious problems of multicollinearity. Even if VIFs of 2 may cause non-significant  
349 parameter estimates when ecological signals are weak (Zuur et al., 2010), estimated  
350 parameters and errors for targeted variables do not change when covariates are removed. The  
351 slight correlations between some targeted variables and environmental covariates do not result  
352 in confounding effects for the interpretation.

353

354 4.1. Limitations and mechanism hypotheses

355 Conservation tillage is a potential key to improve biodiversity management in front of the  
356 failure of EU agricultural reforms (Pe'er et al., 2014). Yet, our results suggest that  
357 biodiversity gain depends on the associated farming system. There is a need to extend such  
358 analyses in other farming contexts and for other farmland bird communities for a  
359 generalisation. However, the species studied here are the most common and representative  
360 species of European farmland landscapes, according to the European Bird Census Council  
361 (EBCC) and the studied crops (wheat and oilseed rape) are among the most widespread in  
362 Europe (Eurostat, 2016b). We also need to understand the underlying mechanisms of such  
363 ecological gains. But it remains difficult to isolate the relative influence of each parameter of  
364 these systems leading to such causalities between soil management regime and bird  
365 abundance. We hypothesise that the weed control method associated to CT is the driver of  
366 feeding resource availability for birds, affecting both (i) arthropods and (ii) seeds  
367 compartments of the species diet.

368 Arthropods (i) are systematically more abundant in CT than in T (Holland and Reynolds,  
369 2003; Rodríguez et al., 2006), however increasing herbicide quantity in a given CT system  
370 negatively affects arthropods (Pereira et al., 2007). Thus, strict insectivorous bird species (i.e.  
371 *M. flava* and *S. communis*; Holland et al., 2006) are expected to be more abundant in CTcc  
372 than CTh and T, and more abundant in CTh than T. This result was found for *M. flava* and *S.*  
373 *communis* which were more abundant in CTcc than T, but not for CTh/T comparison for  
374 which *M. flava* was less abundant in CTh than T. Thus, it seems that herbicide quantity may  
375 make CT lower than T for insectivorous species, likely affecting host plants needed to the  
376 development of prey.

377 Concerning seeds (ii), global quantity and availability on the ground surface is higher in CT  
378 than T, and also when a cover crop is used rather than only more herbicides to control weeds

379 in CT (Baldassarre et al., 1983; Hoffman et al., 1998; Nichols et al., 2015). As herbicides  
380 target weeds, differences in seed quantities could concern mainly seeds from weeds (for all  
381 studied systems) and cover crop (for CTcc). This could cause a lower quantity of seeds in  
382 CTh compared to CTcc and T, despite the ploughing as CTh receive more herbicide and no  
383 cover crop. Thus, omnivorous bird species more dependent on seeds in their diet (i.e. 60% for  
384 *A. arvensis* and 85% for *E. calandra*; Holland et al., 2006) could be negatively affected in  
385 systems with greater herbicide use and less cover crop. This result was found for species  
386 which were less abundant in CTh vs. T (i.e. *A. arvensis*), and also less abundant in T vs. CTcc  
387 (i.e. *A. arvensis*, *E. calandra* and *T. merula*).

388 Consequently, with the aim to produce accurate recommendations to improve biodiversity in  
389 farmland, future studies should accurately describe the type of conservation tillage. Indeed,  
390 the nomenclature “conservation tillage” brings together very different practices with  
391 contrasting impacts on biodiversity. In addition, in order to test the assumption we made  
392 about the bird abundance gain in relation to resources and diet type, future studies should  
393 attempt to measure arthropod and seed availability for birds while investigating the impact of  
394 different farming practises. We detected robust relationships, however such study should be  
395 reproduced in other landscapes/countries in order to assess the genericity of our results. In  
396 addition to this in natura study, it would be interesting to conceive experimental studies not  
397 placed at the system level in order to identify the mechanisms involved allowing to separate  
398 the effect of the tillage and the herbicides Finally, we tested separately CTcc and CTh vs. T  
399 effects in two different sites, although close to each other and in similar farming landscapes,  
400 due to the scarcity of the conservation tillage studied (1.4% of the utilized agricultural land in  
401 France; Agreste 2011). In a context where more and more farmers are investigating the effect  
402 and feasibility of alternative practices to deep ploughing, the development of these situations

403 can be expected to make it easier to compare relative effects of CTcc and CTh systems in  
404 natura. Experiments on this type of mixed system in the same site could then be developed.

405

#### 406 4.2. Conservation management perspectives

407 Ecological gains provided by CTcc compared to T seem to be high (with mean factors of 3.9  
408 (2.3 to 5.1) for *A. arvensis*, 2.3 (1.6 to 3.2) for *M. flava*, 3.7 (0 to 7.1) for *E. calandra*, 4.1 (1.3  
409 to 5.8) for *S. communis* and 5.7 (3.4 to 8.5) for *T. merula* (Appendix C, table C17). They  
410 could be at least as beneficial as gains from other farming practices, such as organic systems  
411 (factors 1.5 to 1.7 for *A. arvensis* in favour of organic systems compared to conventional  
412 systems, and not significant for *S. communis*; Chamberlain et al., 1999). Note that the studied  
413 CT are likely the two extremes of the CT gradient (no-till using few herbicides with cover  
414 crop vs. no-till using more herbicides without cover crop), which can explain these high  
415 differences. Such ecological gains could be an efficient method to counteract biodiversity  
416 losses due to human activities and land settlement. Farmland specialist birds sensitive to CT  
417 in our study have strongly decreased over the period 1980-2014 in Europe (*i.e.* -55% for *A.*  
418 *arvensis* and *M. flava*, -67% for *E. calandra*; EBCC, 2016). This kind of change in practice  
419 (such as CTcc system) that provides an ecological gain could therefore play an important role  
420 on a large scale in Europe for the conservation of these farmland species. The ecological gain  
421 associated with such practices may be considered in agri-environment schemes (AES) but  
422 also possibly in the process of offset measures implementation on arable land. These potential  
423 changes of farming practices could indeed be implemented on larger surfaces than usual offset  
424 measures (e.g. hedgerows grass/flower strips or fallows) and could better correspond to the  
425 constraints and expectations of farmers, with whom management agreements must be  
426 concluded. Changing T to CT in a broad sense, in the case of wheat, would only pose a small  
427 economic risk, because the negative impact of this change on yields on a large scale is about

428 2.6% (Pittelkow et al., 2015). This causes a lower yield in the first 1–2 years following  
429 implementation, but equals after 3-10 years. Thus, conservation tillage using a cover crop to  
430 control weeds during intercropping appears a promising approach which may add to crop  
431 diversification. However, these changes of practice should be accompanied by additional  
432 measures: they only will be adopted if the key actors involved see the advantages. Policy  
433 makers concerned with biodiversity friendly measures must consider the needs of farmers  
434 affected by these changes (e.g. training on weed management in the absence of tillage,  
435 funding possibilities to compensate potential economics losses in the first years following  
436 implementation).

437

438 **Authors' Contributions**

439 KB conceived the ideas, designed methodology and collected the data; KB and CK analysed  
440 the data; all authors led the writing of the manuscript. All authors contributed critically to the  
441 drafts and gave final approval for publication.

442

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448

449 **Competing interests**

450 The collaboration with Agrosolutions, which is the agri-environmental expert consulting  
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453

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458

459 **Supplementary material**

460 Appendix A. Study area and agricultural context.

461 Appendix B. Sampling design dates, land-use characteristics and landscape composition  
462 around bird point counts

463 Appendix C. Additional results about bird census and statistical analyses

464

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654 *Biology and Health*. <http://dx.doi.org/10.1007/978-0-387-87458-6>.

655

656 Table 1. Number of independent count points sampled, number and mean area of fields ( $\pm$   
 657 standard deviation) under conservation tillage (CT) and conventional tillage (T) systems  
 658 according to the weed control method (cc: cover crop; h: herbicides) and crops.

659

	Site A		Site B	
	CTcc	T	CTh	T
<i>Count points</i>				
Wheat	25	25	19	18
Oilseed rape	24	26	11	15
<i>Number of fields</i>				
Wheat	9	14	4	13
Oilseed rape	9	11	3	10
<i>Mean area of fields (ha)</i>				
Wheat	14.0 ( $\pm$ 13.2)	14.5 ( $\pm$ 8.0)	25.4 ( $\pm$ 6.9)	18.6 ( $\pm$ 8.1)
Oilseed rape	8.6 ( $\pm$ 3.7)	14.3 ( $\pm$ 7.3)	14.3 ( $\pm$ 5.6)	7.9 ( $\pm$ 3.4)

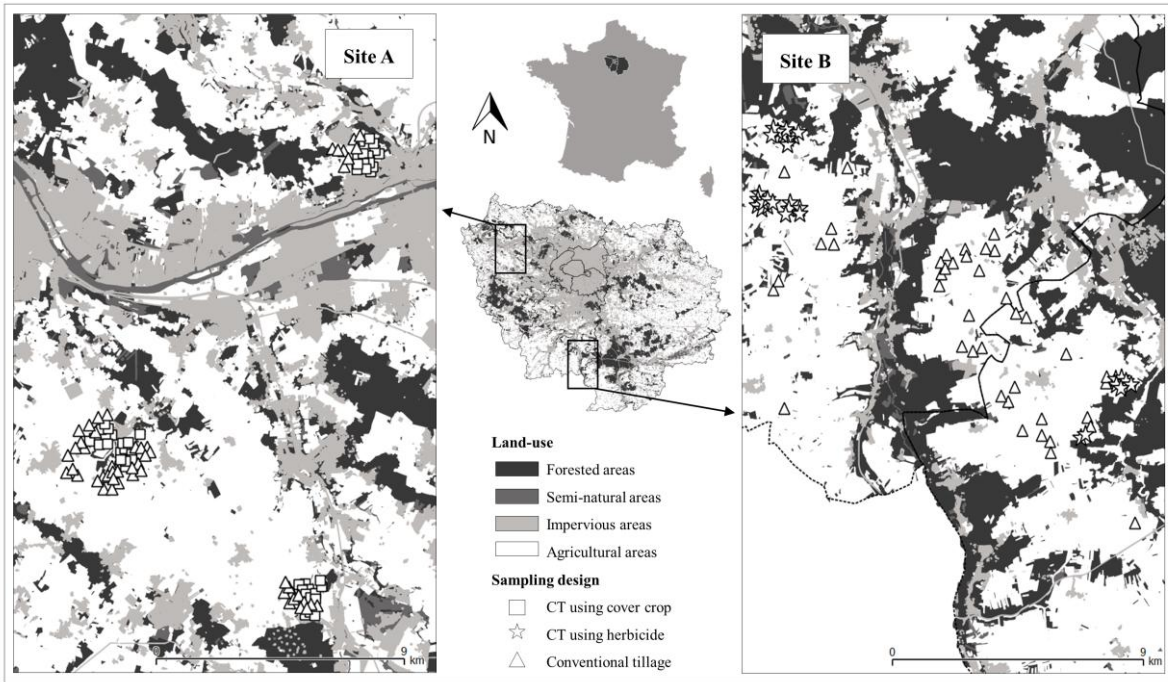
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661

662 Table 2. Model results for the two conservation tillage types (CTcc: cover crop; CTh:  
663 herbicide) compared to conventional tillage (T), crop type (OR: oilseed rape) and their  
664 interaction using a multi-model inference averaging on a delta AICc<2. For each species we  
665 show estimates ( $\beta$ ), standard errors (SE) and p-values. Because *Linaria cannabina* was not  
666 found in wheat crop, results for crop type and interactions are missing. In some cases,  
667 interaction results are not presented because they were not selected (*n.s.*) in the multi-model  
668 inference or suffering from a data deficiency (*d.d.*) with aberrant estimates. Results for other  
669 covariates, predicted and observed abundances can be found in table C13 & C17 (Appendix  
670 C).

Species	Conservation tillage type		Crop type	Tillage type : crop type		
	CTcc (vs. T)	CTh (vs. T)	Wheat (vs. OR)	CTcc : wheat (vs. OR)	CTh : wheat (vs. OR)	T : wheat (vs. OR)
<i>Alauda arvensis</i>						
$\beta$ (SE)	<b>1.49 (0.31)</b>	<b>-0.70 (0.25)</b>	<b>0.61 (0.18)</b>	0.65 (0.42)	<b>-1.11 (0.50)</b>	<b>-0.93 (0.39)</b>
p-value	<b>&lt; 0.001</b>	<b>0.005</b>	<b>0.026</b>	0.125	<b>0.027</b>	<b>0.018</b>
<i>Emberiza calandra</i>						
$\beta$ (SE)	<b>1.41 (0.65)</b>	-0.31 (0.35)	0.18 (0.31)	2.11 (1.11)	<b>-1.66 (0.74)</b>	<b>-1.48 (0.62)</b>
p-value	<b>0.031</b>	0.380	0.560	0.060	<b>0.026</b>	<b>0.018</b>
<i>Linaria cannabina</i>						
$\beta$ (SE)	0.44 (0.70)	/	/	/	/	/
p-value	0.534	/	/	/	/	/
<i>Motacilla flava</i>						
$\beta$ (SE)	<b>0.78 (0.39)</b>	<b>-0.72 (0.29)</b>	<b>-0.58 (0.21)</b>	<i>n.s.</i>	<i>n.s.</i>	<i>n.s.</i>
p-value	<b>0.046</b>	<b>0.013</b>	<b>0.006</b>	-	-	-
<i>Sylvia communis</i>						
$\beta$ (SE)	<b>1.54 (0.36)</b>	/	<b>-2.24 (0.49)</b>	<i>n.s.</i>	/	<i>n.s.</i>
p-value	<b>&lt; 0.001</b>	/	<b>&lt; 0.001</b>	-	/	-
<i>Turdus merula</i>						
$\beta$ (SE)	<b>1.70 (0.57)</b>	/	<b>-2.47 (0.76)</b>	<i>d.d.</i>	/	<b>-1.77 (0.69)</b>
p-value	<b>0.003</b>	/	<b>0.001</b>	-	/	<b>0.011</b>

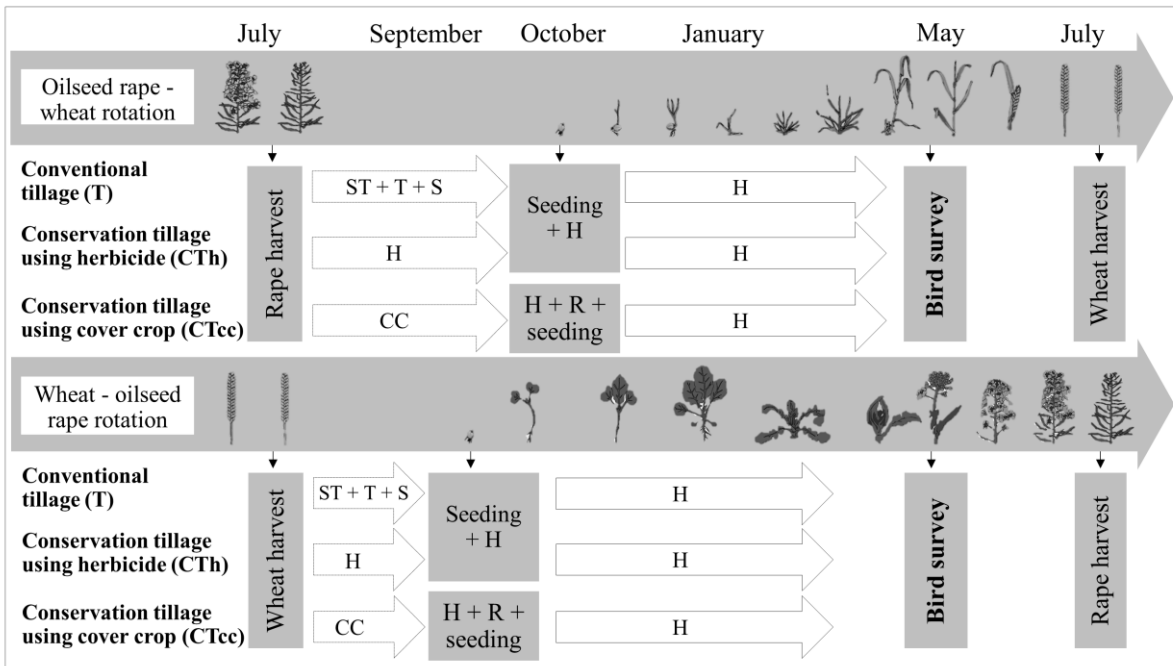
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672

673 Figure 1. Land-use map of the two study areas in Île-de-France region showing sampling

674 points of conservation tillage (CTcc, CTh) and conventional tillage (T).



675

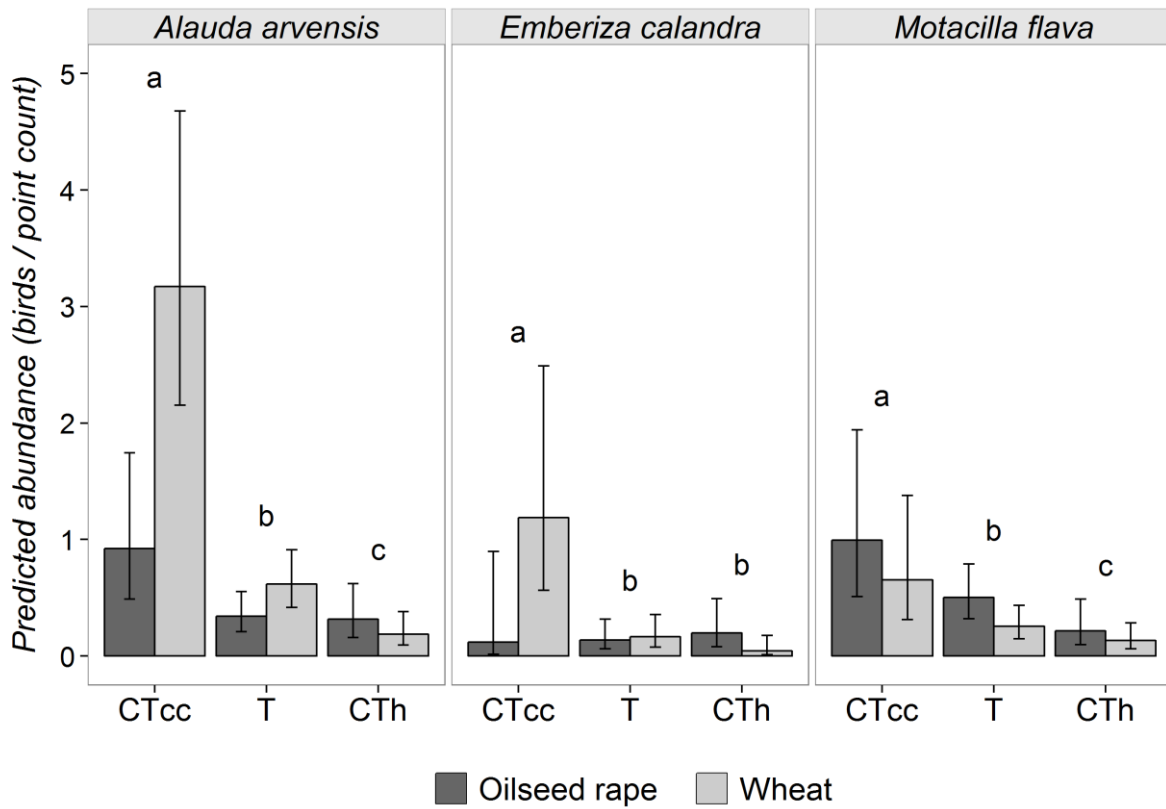
676 Figure 2. Chronology of interventions for an entire year in wheat and oilseed rape fields in the

677 3 studied systems (ST: superficial tillage; T: tillage, S: soil surface smoothing; H: herbicide;

678 CC: cover crop; R: steamroller).

679





680

681 Figure 3. Predicted abundance per point count for *Alauda arvensis*, *Emberiza calandra* and  
 682 *Motacilla flava* according to the 3 farming systems studied (CTcc: conservation tillage using  
 683 cover crop; T: conventional tillage; CTh: conservation tillage using herbicide) and the crop  
 684 type. Global significant differences between systems are shown in letter differences (a, b and  
 685 c).