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Weed control method drives conservation tillage efficiency on farmland breeding birds

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Abstract

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

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

1. Introduction

Historically, agricultural areas, and more specifically arable lands, represent an important proportion of Europe (respectively 35.6 and 21.1%; Eurostat, 2016a). Changes in farmland, such as intensification processes including increased use of fertilizers, pesticides, and homogenization of the farming landscape in space and time, are the main causes of decline in the diversity and abundance of wildlife (Bengtsson et al., 2005; Benton et al., 2003). These effects have been observed on many taxa in Europe (e.g. plants and invertebrates: Wilson et al., 1999; birds: Donald et al., 2001; bats: Wickramasinghe et al., 2003; moths: Fox, 2013). The Common Agricultural Policy (CAP) has been, and still is, a major driving force behind land use intensification through the stimulation and modernization of agricultural production (Van Zanten et al., 2014). Since 2013, the CAP includes new greening requirements (e.g. reduction of grassland fertilization, grass strips, mowing deferment, flowery fallows) such as ecological focused areas (EFA, direct payments in the first pillar) and changes in agri-environmental schemes (AES) including agri-environmental managements (AEM, payments on a voluntary basis in the second pillar). Within the European policy, greening measures are increasingly claimed to be important tools for the maintenance and restoration of farmland biodiversity in Europe. While AES do not result in a decrease of crop yields (Pywell et al., 2015), so far they have only had marginal to moderate positive effects on biodiversity, especially because they do not differentiate common and endangered species and are applied on too small and/or wild areas (Kleijn et al., 2006). The CAP also encourages farmland to be managed as EFA in order to maintain biodiversity. These EFA, covering 3-7% of European farms, can contribute to increase richness of species, but differences between the 3 and 7% limits were considerable for butterflies, birds and hoverflies (Cormont et al., 2016). In addition, a meta-analysis conducted by Batary *et al.* (Batary et al., 2011) showed that AEM were not a very efficient way of spending the limited funds available for biodiversity conservation on farmland. While AEM and EFA can concern a few Used Agricultural Area in Europe (Eurostat, 2009), extensification of cropping practices could positively affect farmland biodiversity on larger surfaces (Fuller et al., 2005). Some of these cropping practices, such as lengthening and diversification of crop rotation (Josefsson et al., 2016; Miguet et al., 2013) and the reduction of soil tillage (Holland, 2004), have been identified as providing more favourable conditions for biodiversity in farmland. Such alternative practices are not included in AES/AEM and EFA policies.

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

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

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

Hence, there is a need to assess the conservation tillage impact on biodiversity compared to conventional tillage according to the weed control method to untangle ambiguous results from previous studies. To take into account underlying weed control method of conservation tillage types, which in turn could affect the response of farmland birds, this study is placed at the conservation tillage system level. Thus, we compare the abundance of breeding farmland bird species of two conservation tillage systems with conventional tillage in wheat and oilseed rape crops: (1) conservation tillage using a cover crop *vs*. conventional tillage, and (2) conservation tillage using only herbicide *vs*. conventional tillage. There is no soil-inversion and no superficial tillage in both conservation tillage systems.

2. Materials and methods

2.1. Study area and sampling design

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

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

2.2. Features of studied farming practices

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

Studied CT fields were characterized by non-inversion of soil for several years, and no superficial tillage with direct seeding under stubble of the previous crop. We studied two types of CT which differed in weed control methods. The first type of CT (site A) used a cover crop (CTcc) of oilseed rape suckers (after an oilseed rape crop) and/or leguminous crops (as a complement of rape suckers or alone after a wheat crop) between the harvest of the previous crop and seeding of the new one (Figure 2). The cover crop was seeded while harvesting, and destroyed when seeding using a steamroller and one selective herbicide, thus allowing the newly seeded crop to grow and take over. The second type of CT (site B) used a non-selective herbicide (glyphosate) to control weeds (CTh), without cover crop, with 1-2 treatment events between harvest and seeding, and one selective herbicide following seeding. Thus, in all 3 systems one selective herbicide is used when seeding the next crop (in CTcc it is the same as to destroy the cover crop), then 1 or 2 until spring. Thus, CTh uses more numerous herbicide treatments than T and CTcc (Figure 2). In all 3 systems, wheat and oilseed rape were harvested in late July to early August, and the seeding was performed in

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

2.3. Bird census

We sampled bird abundance using the “point” counts method for CTcc and CTh, and their respective controls (i.e. T in site A and B) in wheat and oilseed rape crops (Table 1). All counts were performed by the same observer (Kévin Barré). Bird counts were carried out in spring 2015 at 163 points across 10 mornings between June 5th and June 15th, following the recommendations of the French Breeding Bird Survey (Jiguet et al., 2012; STOC-EPS, 2013). For each sampling date we performed a number of CT and T point counts by balancing as far as possible (Appendix B, table B3). For a given field, points were separated by at least 200 m to ensure their independence. For the most of CTcc and CTh fields due to their scarcity, we performed a maximum of independent point counts per field. It was the same way for some T fields, and few point counts in all other fields when minimization of differences in landscape between CTcc and T as well as CTh and T was needed. Thus, the maximum number of point counts per field depended on field size (range: 1-8 point counts/field). The duration of count per point was 5 minutes between 6:00 am to 10:00 am when species are known to be most active (Ralph et al., 1995). The detectability of birds is influenced by weather and time-of-day parameters (Bas et al., 2008). Thus, the exact time of count was recorded, as well as the date, wind speed, temperature and cloud coverage. Note that bird counts were only carried out when weather conditions were favourable (i.e. no rain, low wind speed of < 4 m/s, temperature > 12 °C). For each point count, all detected individuals in a radius of 100 m, identified from their call or song, or using binoculars, were recorded. The observer placed himself on the side of selected fields, at least 100 m away from a field corner, in order that the selected field covers at least 50% of the area within 100 m radius. No difference in wheat or oilseed rape structure (density, height) were detected across systems (CTcc, CTh, T). Thus, we hypothesized that the mean detectability of a given species, for a given crop type, was the same across systems and did not require accounting for detectability by setting up a replicated design.

2.4. Environmental covariates

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

2.5. Statistical analyses

We performed generalized linear mixed models (GLMM, R package *glmmADMB*) with the aim to test potential difference of species abundances among farming systems. Our response variable was thus bird count at the point count and model included as fixed effect targeted variables (farming systems: CTcc, CTh and T; crop type: oilseed rape and wheat), environmental covariates (local and landscape characteristics) and site effect (A and B). Site effect was included to take into account potential abundance differences of species in T modality between both sites in order to allow accurate CTcc/T (site A) and CTh/T (site B) comparisons. Date of session, here a categorical variable, was included as random effect to account for weather conditions of sampling points performed in the same day and for take into account the hierarchical structure of the sampling (i.e. different farming systems sampled the same day).

Analyses (CTcc/T and CTh/T comparisons) were performed on species with sufficient occurrences (species presence in more than 10% of point counts) using data from sites A and B. For some species (*Linnaria cannabina*, *Sylvia communis* and *Turdus merula*), the few occurrences found in site B did not allowed analyses. Consequently for these species, analyses were only performed for site A (CTcc/T comparison). For *L. cannabina* crop type was not included because there was no count event in wheat. Full models were constructed checking correlations between covariates and targeted variables (Kruskal Wallis tests, appendix B, tables B5 & B6), and between covariates ($r > 0.7$, appendix B, tables B7 & B8). Few correlations were detected and only between some covariates and targeted variables. However, this slight correlation did not involve multicollinearity problems in full models. We performed a variance-inflation factors (R package *VIF*) on each full model (Fox and Monette, 1992). All variables showed a VIF value <2, meaning there was no striking evidence of multicollinearity (Chatterjee and Hadi, 2006). According to the characteristics of each species dataset (species in site A and B: n=163 point counts; species only in site A: n=100 point counts) we took into account respectively 8 and 6 variables in full models to avoid an over parametrization. For each species, we used a hierarchical partitioning (R package *hier.part*) to identify covariates (distances to wetland, to forest, to urban area, proportion of arable land within 200 m radius, crop number, proportion of rare crops, herbaceous boundaries length, minute after sunrise and field area) having the best conjoint contributions in order to implement them with targeted variables and site effect in full models (the 5 best predictive variables for models with both sites A and B and the 4 best predictive variables for models with only the site A). These steps allowed the construction of full models (Appendix C, table C9), in which we performed an interaction between tillage type and crop type:

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

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

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

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

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

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

3. Results

3.1. Sampled species

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

3.2. Selected candidate models

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

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

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

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

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

4. Discussion

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

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

4.1. Limitations and mechanism hypotheses

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

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

Concerning seeds (ii), global quantity and availability on the ground surface is higher in CT than T, and also when a cover crop is used rather than only more herbicides to control weeds in CT (Baldassarre et al., 1983; Hoffman et al., 1998; Nichols et al., 2015). As herbicides target weeds, differences in seed quantities could concern mainly seeds from weeds (for all studied systems) and cover crop (for CTcc). This could cause a lower quantity of seeds in CTh compared to CTcc and T, despite the ploughing as CTh receive more herbicide and no cover crop. Thus, omnivorous bird species more dependent on seeds in their diet (i.e. 60% for *A. arvensis* and 85% for *E. calandra*; Holland et al., 2006) could be negatively affected in systems with greater herbicide use and less cover crop. This result was found for species which were less abundant in CTh *vs.* T (i.e. *A. arvensis*), and also less abundant in T *vs.* CTcc (i.e. *A. arvensis*, *E. calandra* and *T. merula*).

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

4.2. Conservation management perspectives

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

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

Authors’ Contributions

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

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Competing interests

The collaboration with Agrosolutions, which is the agri-environmental expert consulting subsidiary of the InVivo agricultural cooperative group, did not influence the sampling design, analyses and conclusions. We have no competing interests.

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Supplementary material

Appendix A. Study area and agricultural context.

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

Appendix C. Additional results about bird census and statistical analyses

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

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

Table 2. Model results for the two conservation tillage types (CTcc: cover crop; CTh: herbicide) compared to conventional tillage (T), crop type (OR: oilseed rape) and their interaction using a multi-model inference averaging on a delta AICc<2. For each species we show estimates (β), standard errors (SE) and p-values. Because *Linaria cannabina* was not found in wheat crop, results for crop type and interactions are missing. In some cases, interaction results are not presented because they were not selected (*n.s.*) in the multi-model inference or suffering from a data deficiency (*d.d*) with aberrant estimates. Results for other covariates, predicted and observed abundances can be found in table C13 & C17 (Appendix 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)
Alauda arvensis						
β (SE)	**1.49 (0.31)**	**-0.70 (0.25)**	**0.61 (0.18)**	0.65 (0.42)	**-1.11 (0.50)**	**-0.93 (0.39)**
p-value	**< 0.001**	**0.005**	**0.026**	0.125	**0.027**	**0.018**
Emberiza calandra						
β (SE)	**1.41 (0.65)**	-0.31 (0.35)	0.18 (0.31)	2.11 (1.11)	**-1.66 (0.74)**	**-1.48 (0.62)**
p-value	**0.031**	0.380	0.560	0.060	**0.026**	**0.018**
Linaria cannabina						
β (SE)	0.44 (0.70)	/	/	/	/	/
p-value	0.534	/	/	/	/	/
Motacilla flava						
β (SE)	**0.78 (0.39)**	**-0.72 (0.29)**	**-0.58 (0.21)**	*n.s.*	*n.s.*	*n.s.*
p-value	**0.046**	**0.013**	**0.006**	-	-	-
Sylvia communis						
β (SE)	**1.54 (0.36)**	/	**-2.24 (0.49)**	*n.s.*	/	*n.s.*
p-value	**< 0.001**	/	**< 0.001**	-	/	-
Turdus merula						
β (SE)	**1.70 (0.57)**	/	**-2.47 (0.76)**	*d.d.*	/	**-1.77 (0.69)**
p-value	**0.003**	/	**0.001**	-	/	**0.011**

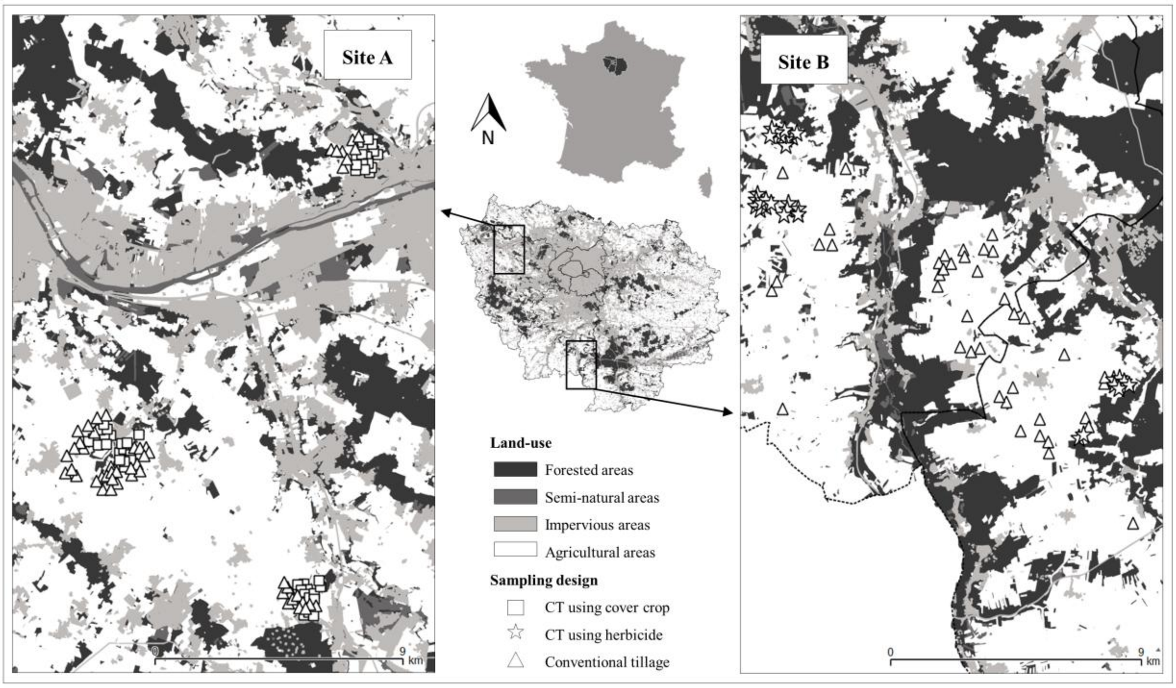

Figure 1. Land-use map of the two study areas in Île-de-France region showing sampling points of conservation tillage (CTcc, CTh) and conventional tillage (T).

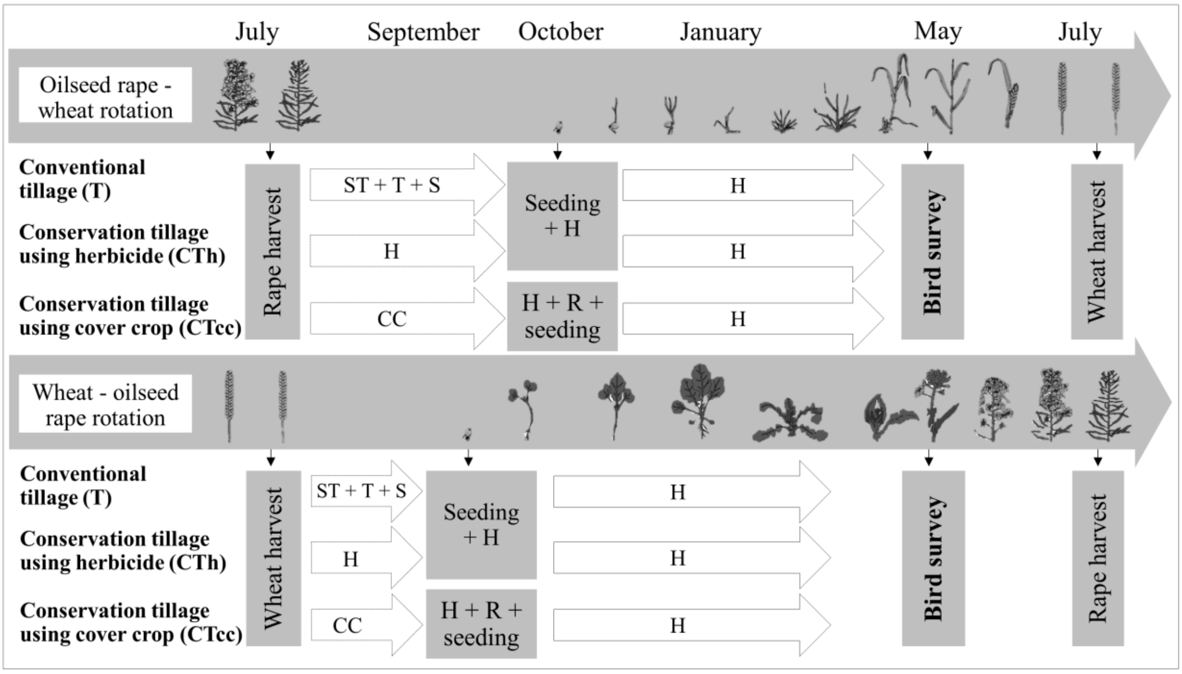

Figure 2. Chronology of interventions for an entire year in wheat and oilseed rape fields in the 3 studied systems (ST: superficial tillage; T: tillage, S: soil surface smoothing; H: herbicide; CC: cover crop; R: steamroller).

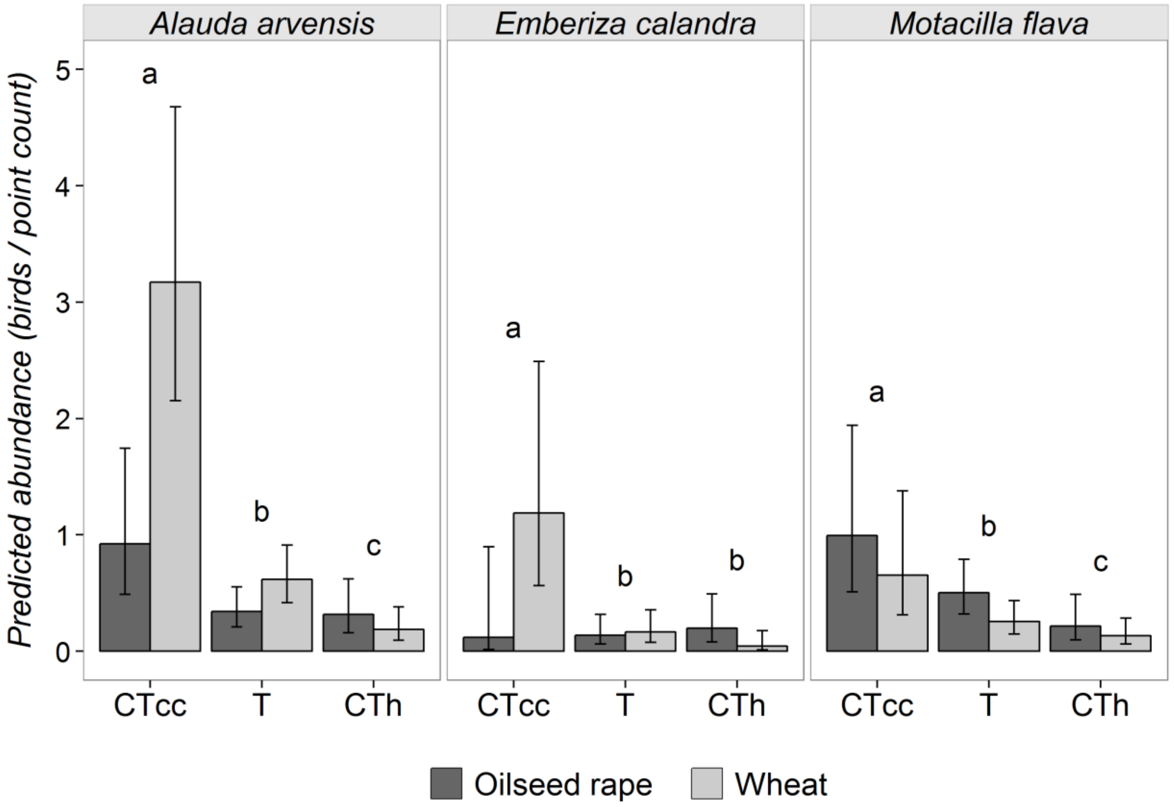

Figure 3. Predicted abundance per point count for *Alauda arvensis*, *Emberiza calandra* and *Motacilla flava* according to the 3 farming systems studied (CTcc: conservation tillage using cover crop; T: conventional tillage; CTh: conservation tillage using herbicide) and the crop type. Global significant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