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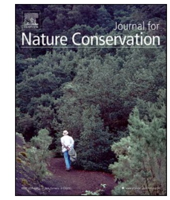

A systematic review on the effectiveness of crop architecture-related in-field measures for promoting ground-breeding farmland birds

Sina Blösch [a,b,*], Péter Batáry [c], Judith Zellweger-Fischer [d], Eva Knop [b,e,*]

[a] School of Agricultural, Forest and Food Sciences HAFL, Bern University of Applied Sciences, Länggasse 85, 3052 Zollikofen, Switzerland
[b] Agroscope, Reckenholzstrasse 191, 8904 Zürich, Switzerland
[c] 'Lendület' Landscape and Conservation Ecology, Institute of Ecology and Botany, HUN-REN Centre for Ecological Research, Alkotmány u. 2-4, 2163 Vácrátót, Hungary
[d] Swiss Ornithological Institute, Seerose 1, 6204 Sempach, Switzerland
[e] Department of Evolutionary Biology and Environmental Studies, University of Zurich, Winterthurerstrasse 190, 8057 Zürich, Switzerland

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ABSTRACT

Ground-breeding farmland birds are disproportionately negatively affected by the impact of agricultural intensification and mostly still dramatically declining in Europe. One main reason for this decline is the lack of suitable nesting sites. While some off-field measures showed positive effects on bird productivity, we are currently not achieving sufficient conservation with these, so that supplementing them with in-field measures seems inevitable. Over the past years, several in-field measures have been developed aiming at providing suitable nesting sites in crop fields by manipulating the crop architecture, i.e., the density and/or height of the crops. However, we currently lack an overview on what has been tested and resulted in stabilizing population of ground-breeding farmland birds. In this systematic review, we provide a qualitative assessment of current knowledge and knowledge gaps on such in-field measures and their effects on European crop-breeding farmland birds. In doing so, we accounted for specific birds' requirements on their breeding habitat. We found only very few studies on the effectiveness of crop architecture-related in-field measures on ground-breeding farmland birds. Knowledge gaps exist for effects on individual species in general, their reproduction (rather than population density), the influence of landscape and local contexts on the effectiveness, and the optimal spatial arrangement of measures to maximize their efficiency. This shows an urgent need for more research on a holistic scale. However, the few existing studies suggest, that there is a high potential for crop architecture-related in-field measures to promote ground-breeding farmland birds, and thus bring them back as 'agricultural by-products'.

1. Introduction

Halting the decline of biodiversity is among the most important challenges of the twenty-first century (Leclère et al., 2020). A second silent spring has already been proclaimed, and the decline of birds partly reflect the declines of the invertebrates and plants upon which they depend (Krebs et al., 1999). In this context, the decline of birds in agriculture has been greater than in any other habitat (Gregory et al., 2005; Tscharntke and Batáry, 2023), so that in the meantime no other habitat supports as many bird species of European conservation concern (Tucker and Evans, 1997; Inger et al., 2015), with ground-breeders showing overproportionately negative population trends (McMahon et al., 2020; Reif et al., 2023). Agricultural intensification has been identified as the (multivariate) main cause of those declines, with underlying changes mainly affecting the amount of habitat and food available (Newton, 2004; Butler et al., 2010; Lopez-Antia et al., 2016), driven by e.g., the simplification and homogenization of structures (Wilson et al., 2005). A resulting key factor for the decline of ground-breeding farmland birds is the lack of suitable nesting sites, which do not allow sufficient breeding productivity to stabilize populations (Newton, 2004; Wilson et al., 2005). Given that the most effective conservation measures in intensively farmed agricultural landscapes are those minimizing negative effects of intensification on the species' reproductive performance (Benton et al., 2003; Casas and Viñuela,

* Corresponding authors at: School of Agricultural, Forest and Food Sciences HAFL, Bern University of Applied Sciences, Länggasse 85, 3052 Zollikofen, Switzerland. Agroscope, Reckenholzstrasse 191, 8904 Zürich, Switzerland; Agroscope, Reckenholzstrasse 191, 8904 Zürich, Switzerland.

E-mail addresses: sina.bloesch@bfh.ch (S. Blösch), batary.peter@ecolres.hu (P. Batáry), judith.zellweger@vogelwarte.ch (J. Zellweger-Fischer), eva.knop@ieu.uzh.ch (E. Knop).

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2010; Morris et al., 2005; Guerrero et al., 2012), delivering appropriate and sufficient nesting sites is key for halting the declines of ground-breeding farmland birds.

Measures to promote ground-breeding farmland birds can be implemented on or off land that is being used for farming. So far, many efforts have focused on measures outside of production areas, the so called off-field (synonym 'off-production') measures, such as set-asides or wildflower strips (Van Buskirk and Willi, 2004; Tarjuelo et al., 2020; Schmidt et al., 2022). Such measures often show positive effects on ground-breeding farmland birds (Tarjuelo et al., 2020; Schmidt et al., 2022), as they provide resources to the birds that are currently missing (e.g., suitable nesting sites, food supply) (Newton, 2004). However, their acceptance and, accordingly, their adoption by the agricultural sector is relatively low, mainly because its implementation is at the expense of productive land (Bailey et al., 2015; Kleijn et al., 2019). In addition, arable crop specialists that rely on crop swards for breeding remain disregarded within these measures (Green et al., 2005; Setchfield and Peach, 2016). Consequently, at present, off-field measures are not a solitary viable solution to reverse the decline of crop-breeding farmland birds, and it seems indispensable to complement existing off-field measures with farmer-friendly in-field measures (synonym 'in-production', or 'in-crop' when applied to crop fields) (Wilson et al., 2005; Sharps et al., 2022).

To date, however, in-field measures are often less effective in promoting biodiversity as compared to off-field measures (Batáry et al., 2015). The reason for this might be, that they usually support general environmentally sensitive approaches to manage production areas, e.g., the reduction of agro-chemicals or conservation tillage, with organic farming being the most widespread in-crop measure (Kleijn et al., 2009; Batáry et al., 2015). While mitigating many negative environmental impacts (Gomiero et al., 2011), however, such a general approach may prove weak in promoting specific biodiversity subjects (Batáry et al., 2015). For example, ground-breeding farmland birds that suffer from missing suitable nesting habitats might not benefit from restricted pesticide applications. Apart from this, the existing in-crop measures are often accompanied by yield losses and thus more land is required for the same production volume, which in turn can have negative consequences for biodiversity, e.g., on the preservation of intact natural habitats (Green et al., 2005; Tscharntke et al., 2021; Batáry and Tscharntke, 2022). Thus, we currently largely lack suitable in-crop measures that effectively promote ground-breeding farmland birds and at the same time do not lead to a yield reduction (Kleijn et al., 2009; Batáry et al., 2015).

A promising approach for such tailored in-field measures for crop-breeding farmland birds that can avoid yield losses might be the manipulation of crop architecture, i.e., the alteration of the density and/or height (of parts of) crop fields (Wilson et al., 2005; Blösch et al., 2023). Crop architecture determines field habitat conditions in terms of accessibility, microclimatic conditions, food availability, and cover and is thus key for the survival and reproduction of farmland birds. For example, with respect to (nest) predation risks, ground-breeding birds are in a constant trade-off between concealment and view of the surrounding, further exacerbated by accessibility and exposure to weather extremes (regarding nest-site selection) and accessibility and efficiency (regarding foraging) (Götmark et al., 1995; Wilson et al., 2005). Accordingly, different species have developed different strategies to face these pressures, resulting on the one hand in specialists for sparse and low vegetation, e.g., species with well-developed perceptual abilities and anti-predator behavior, and perch-and-wait foraging techniques (Tobias et al., 2022). On the other hand, there are specialists for dense and tall vegetation, e.g., species which rely on hiding their nests in the vegetation and developed hovering and aerial chasing techniques for foraging (Tobias et al., 2022). The crop architecture, in turn, can be specifically designed to meet different requirements, for example by being made more dense (e.g., double-drilled rows (Setchfield and Peach, 2016)) or more sparse (e.g., unsown patches (Morris et al., 2004) or unsown strips (Schmidt et al., 2017a)). Thus, the manipulation of crop architecture is an encouraging measure, which can easily account for the different needs of the birds. However, such in-field measures specifically manipulating vegetation parameters are only now getting more attention, and there is no consensus yet on how the measures perform in promoting farmland birds and are thus suitable as conservation measures. More specifically, we currently lack an overview of which of the different approaches of manipulating crop architecture indeed promotes (which) ground-nesting farmland birds.

Thus, the objective of this study is to summarize the effects of such crop architecture-related in-field measures on ground-breeding farmland birds based on available published peer-reviewed studies, thereby providing the first qualitative assessment of current knowledge, identifying knowledge gaps, and drawing conclusions for future studies. We do so by conducting a systematic review that focuses on in-field measures that specifically target the crop vegetation structure, i.e., crop architecture, and by accounting for specific birds' requirements. We focused on crop-breeding farmland birds included in the Common European Farmland Bird Indicator (introduced by Gregory et al., 2005; European Bird Census Council, 2021). More specifically, we asked, (i) whether crop architecture-manipulating measures can generally promote crop-breeding farmland birds and (ii) which measure is effective for bird species requiring sparse and low or dense and tall vegetation for breeding. In this context, we also examined the representation of different species, measures, landscape and local contexts (i.e., landscape composition, parcel sizes, agricultural intensity), and geographical areas in the available studies to detect potential biases.

2. Materials and methods

We studied the effects of in-crop measures creating suitable nesting sites on European crop-breeding farmland birds within a systematic review to generate higher-order conclusions. For this purpose, we grouped measures and bird species according to whether they targeted or required a sparse and low or dense and tall vegetation.

2.1. Literature search and study selection

The systematic literature survey was conducted using Scopus and ISI Web of Science Core Collection databases for studies published until 01st June 2023. Search terms were built following the PICO (Population, Intervention, Comparator, Outcome) approach (Higgins and Green, 2008), although we only used **Population AND Intervention,** in order not to miss any studies due to too restricted search terms, and because we were interested in various outcomes. Population was defined from the Common European Farmland Bird Indicator (European Bird Census Council, 2021) and refined by including only species that (i) breed on the ground and (ii) in crops. Interventions comprised crop architecture-related in-field measures. The search string is shown in the supplementary information ('Search string' section and Table S1) and was applied to title, abstract and keywords with no limitation regarding document types or year of publication. This resulted in a total of 1,702 potential articles.

Only studies published in peer-reviewed journals were included, relying on the peer-reviewed process as quality control. After duplicate filtering for hits located by both databases with Mendeley reference manager software (Mendeley, 2015), we performed filtering through the title and abstract of each article, then through the full text of each potentially relevant article to decide whether the article matched our selection criteria (for the detailed selection process, see the PRISMA flow diagram in Fig. S1). Inclusion of a study in our systematic review was based on the following criteria: (i) relevant bird species, (ii) in-crop measures to provide suitable nesting sites, (iii) appropriate comparator. Relevant bird species comprised all crop-breeding species from the Common European Farmland Bird Indicator (Fig. S2). In-crop measures to provide suitable nesting sites had to be located exclusively on production land (Batáry et al., 2015). Methodologically, we selected for studies that compared fields with measures (intervention) to fields without measures (comparator) to identify effects on bird species. We did not exclude any studies based on language criteria, but all potentially relevant studies not written in English were reviewed by native speakers.

Of the 1,702 studies reviewed, ten fitted the criteria (Table S2), comprising 18 observations (Table S3). A list of the articles excluded from the full-text search, along with the reasons for exclusion, is shown in Table S4. Given this limited number of studies, a formal *meta*-analysis was currently not possible, therefore, here we qualitatively summarized our findings and highlighted knowledge gaps.

2.2. Grouping of species and measures

The common European crop-breeding farmland birds were grouped regarding their habitat requirements for breeding from a separate literature search and expert knowledge (Table S5). Categories comprised generalists able to breed in sparse or dense, short or tall vegetation, specialists requiring sparse and short vegetation, and specialists requiring dense and tall vegetation (Fig. S2).

Accordingly, the measures were categorized based on whether they were intended to create a sparse and short or dense and tall crop architecture (relative to what is typical for the crops in the spring in Europe); further differentiated by scale and design. Thus, the following categories were established: wide-spaced rows (row space $\geq$ 20 and $<$ 30 cm; slight modification); unsown strips (at least 30 cm wide; comprised all forms of unsown strips (sometimes also called 'additional tramlines'), e.g., also beetle banks; considerable modification); unsown patches (at least 7 m^2; considerable modification); double-drilled rows (row space $<$ 12.5 cm; slight modification) (Fig. 1).

2.3. Calculating results

Some articles included multiple species and/or multiple measures, so we distinguished between number of observations and number of case studies (see Fig. S1 and Table S3), where a study only provided multiple observations when multiple separate analyses were conducted on different measures and/or different species. Observations from each article were disentangled in terms of their study parameters to represent whether their outcome pertained to life history parameters (i.e., breeding parameters such as nest density, breeding success, or nestling body condition) or population density parameters (e.g., territory density) (Table S3). We rated results of observations on improvement of the habitat for crop-breeding farmland birds by categorizing them as 'positive' or 'neutral' (Table S3). No observation showed negative effects. Effects could affect both population density and life history parameters. In addition, the studies were reviewed in terms of geographic origin and inclusion of landscape and local contexts, i.e., whether landscape composition, parcel sizes and agricultural intensity in the study area were described or analyzed, respectively (Table S3).

3. Results

3.1. Study situation: Geographical origin and landscape and local contexts

Out of the 1,702 studies, we found ten studies on the effects of crop architecture manipulation on common European crop-breeding farmland birds, published between 1997 and 2017. The studies were not evenly distributed across European countries and thus not across the respective different agricultural conditions (e.g., intensity, parcel sizes) (Fig. S3), leading to a geographical bias and a knowledge gap regarding the effectiveness of measures under different agricultural conditions. In addition, one out of ten studies described parcellation and landscape composition and three out of ten studies described agricultural intensity in their study area, but none of them included these landscape and local parameters in their analyses (Table S3).

3.2. Study situation: Representation of species and examination parameters

Sixty-two percent (five out of 13) of the common European crop-breeding farmland bird species were not the subject of any study on the effects of altered crop architecture, resulting in a complete knowledge gap for the Common Stonechat, Calandra Lark, Crested Lark, Eurasian Stone-curlew, Greater Short-toed Lark, Little Bustard, Thekla Lark and Red-legged Partridge, all of which have negative population trends and could benefit from such measures (Fig. 2). Three of the five species studied belonged to the group of species requiring sparse and short vegetation for breeding, making this the best studied species group with 15 observations. Half of the observations found examined population density parameters (such as presence-absence data or territories per ha) of the target species and half of the observations both, population density and life history parameters (such as nest density, breeding success, or nestling body condition). Accordingly, there were twice as many observations of effects of crop manipulating measures at the population level than at the life history level (Fig. 2, detailed outcome

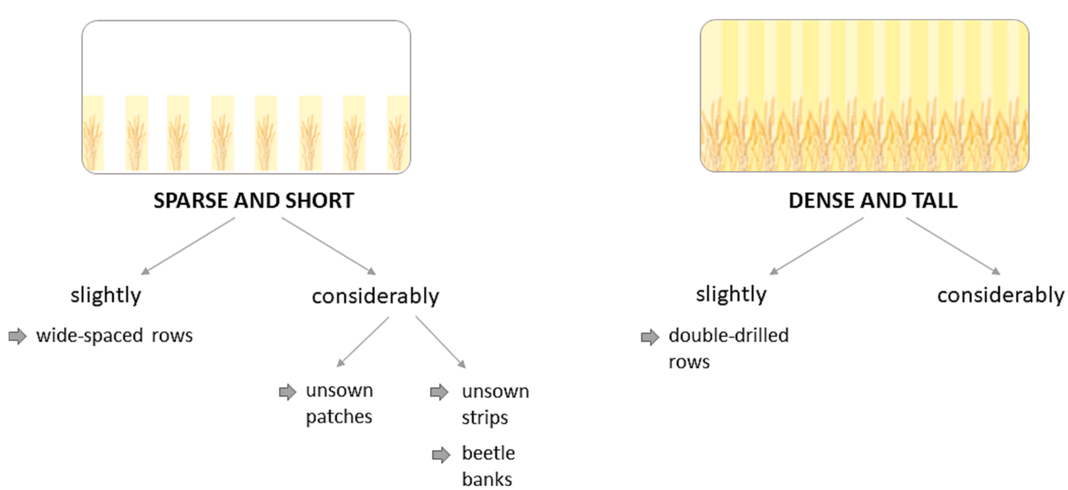

Fig. 1. Classification of measures according to whether and to what extent they aim to make vegetation sparser and shorter or denser and tall. Measures intended to create either a sparse and short or dense and tall crop architecture are listed under each category. The extent is differentiated into slight and considerable (for 'dense and tall', no measure with considerable modification is known).

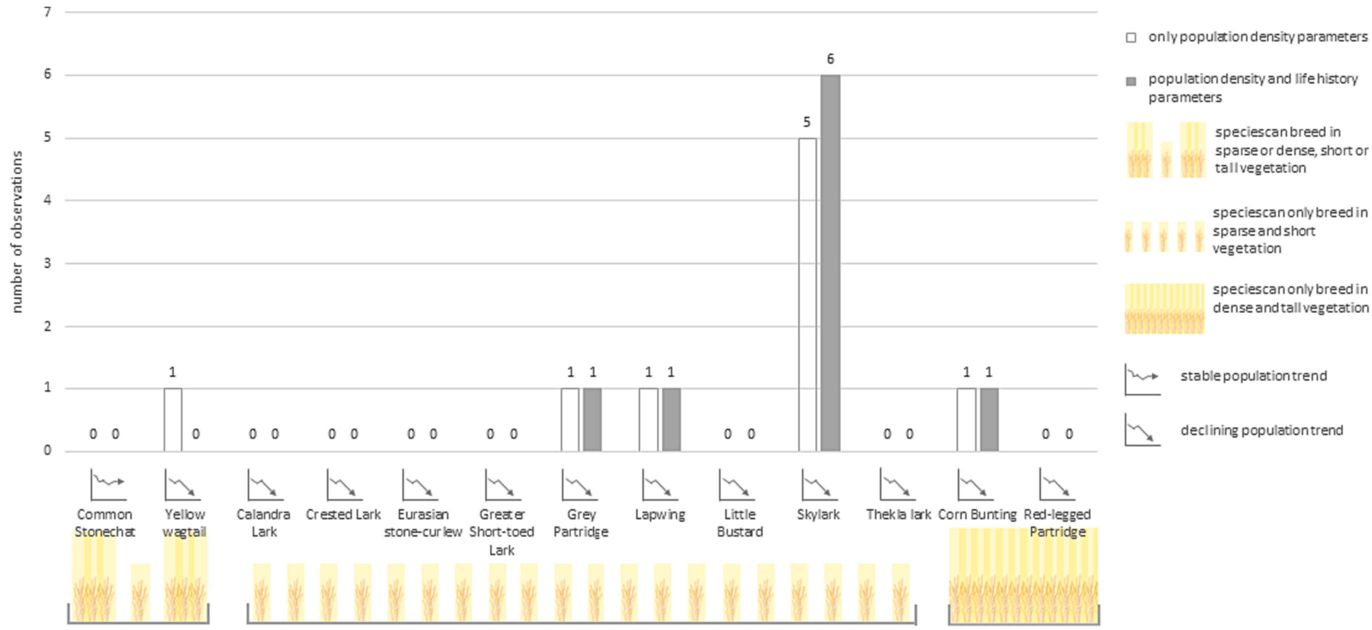

Fig. 2. Number and type of observations on effects of crop architecture-related in-field measures per common European crop-breeding farmland bird species. Observations were separated by outcome (population density, life history). Species were grouped in terms of their requirements on the crop architecture. Population trend for each species is shown (European Bird Census Council, 2021).

per case study and observation in Table S3). Best studied was the Skylark with five observations on population and six on both, population and life history parameters. Taking different measures and outcomes into account, also this best studied species is not examined sufficiently, e.g., for a *meta*-analysis.

3.3. *Effects of crop architecture-related in-field measures on European crop-breeding farmland birds*

All measures (double-drilled rows, unsown patches, unsown strips, and wide-spaced rows) showed predominantly positive effects on examined bird species (Fig. 3). For example, seasonal decreases were mitigated for Skylark territories in unsown strips (Fischer et al., 2009; Schmidt et al., 2017a) and for nesting Skylarks in unsown patches (Morris et al., 2004). Lapwings showed higher hatching success in unsown plots (Schmidt et al., 2017b) and nest densities of Corn Buntings were higher in double-drilled rows (Setchfield and Peach, 2016). Only once did unsown patches or wide-spaced rows not have positive effects on the target species. Detailed effects from each observation can be found in Table S3. The group of measures aiming at considerably

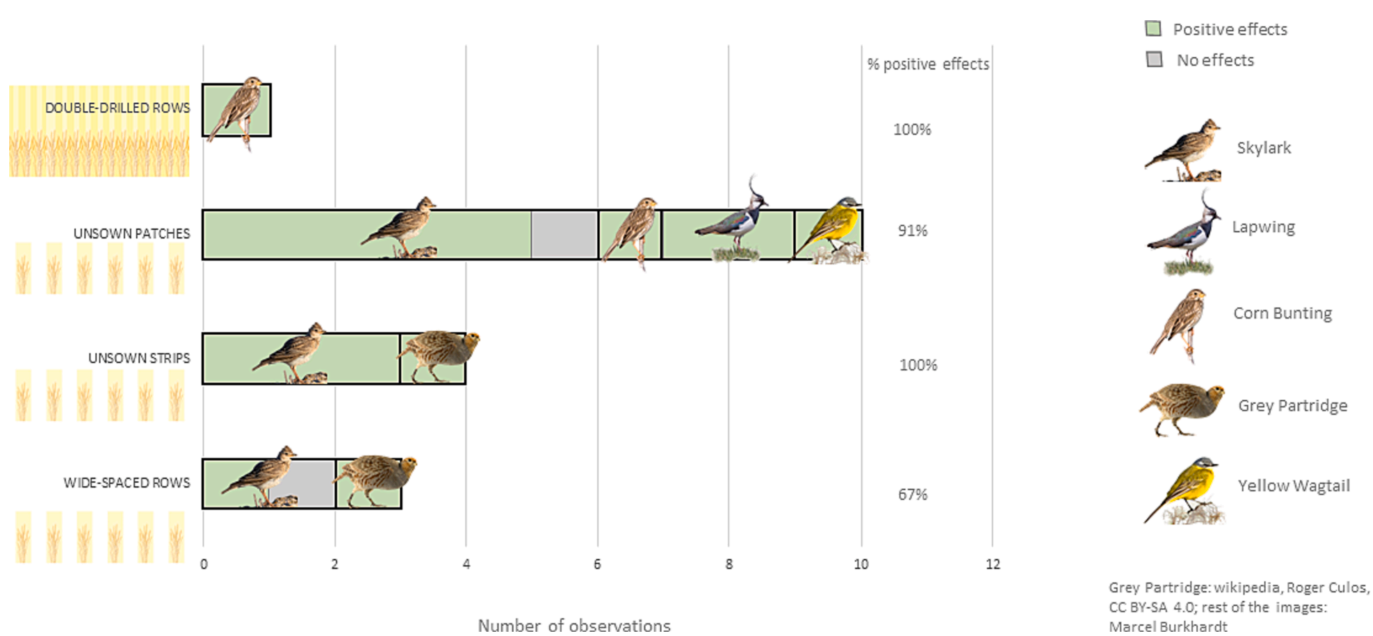

Fig. 3. Effects of crop architecture-related in-field measures on common European crop-breeding farmland bird species. Number of observations with positive or neutral effects per species, separated for each group of measures. Measures were categorized based on whether they were intended to create a sparse and short or dense and tall crop architecture; further differentiated by scale and design with the following categories: double-drilled rows (row space < 12.5 cm; slight modification); unsown patches (at least 7 m^2, considerable modification); unsown strips (at least 30 cm wide; unsown strips (sometimes also called 'additional tramlines') and beetle banks; considerable modification); wide-spaced rows (row space ≥ 20 and < 30 cm; slight modification).

sparsen and shorten the crop architecture was the best studied group of measures with unsown patches (ten observations) being studied more than twice as often as unsown strips (four observations). Skylark was the most frequently studied of these. Wide-spaced rows, which only slightly sparsen and shorten the crop architecture were examined three times and double-drilled rows, which slightly increase the density of the crop architecture was examined once. In summary, different measures and species have been studied to varying degrees with knowledge gaps for all measures and species.

4. Discussion

Most studies reported positive effects of measures that manipulated the crop architecture, i.e., the density and/or height of the vegetation in crop fields, on the examined common European ground-breeding farmland birds. Observed effects included a wide range of benefits, from increased territory density to increased breeding success via reduced nest predation losses, increased hatching success, and increased foraging efficiency. This suggests that manipulating the crop architecture is a promising measure to create conditions that allow ground-breeding farmland birds to better survive and reproduce in otherwise intensively managed cropland – a hint that crop architecture-related in-field measures are generally suited to promote ground-breeding farmland birds. Such measures would promote ground-breeding birds as a kind of 'agricultural by-product' and would therefore likely be better accepted by the agricultural sector than (less popular) off-field measures (Bailey et al., 2015, Kleijn et al., 2019), so that they could (more) easily be applied widely. Moreover, crop architecture-manipulating measures are usually associated with little additional workload or disruptions to farming operations and often do not result in yield losses (see supplementary information 'Agronomic perspective on crop-architecture-manipulating measures'). However, our review clearly shows that there is a serious lack of studies focusing on the effectiveness of in-crop measures for increasing ground-breeding bird abundance (or diversity) other than in-crop measures that simply reduce the amount of agrochemicals. All crop architecture-related in-field measures as well as all potentially benefitting bird species have not been sufficiently studied to evaluate, e.g., which measure is most effective for which bird species or group of species in which life-concerns. Even for the best studied species, the Skylark, there is still too little data to conduct a *meta*-analysis. This highlights the gaps in knowledge for the less studied species and/or groups.

Although not yet sufficiently evidenced, measures that resulted in a considerably sparser and shorter crop architecture (unsown patches or strips; > 7 m^2 or > 30 cm) showed tendencies for higher probabilities of success than those that resulted in only a slight modification (wide-spaced rows; ≥ 20 and < 30 cm). The latter run the risk of nevertheless leading to canopy closure early in the season and thus inaccessibility to several species (Morris et al., 2004), which may explain lower successes. In the group of measures aiming at considerably sparsen and shorten the crop architecture, unsown patches were studied more than twice as often as unsown strips. Thus, unsown patches have received more attention so far, even though it is unclear whether they are the more promising approach and both measures have similar prerequisites in terms of agronomic and vegetation-structural aspects (see supplementary information 'Agronomic perspective on crop-architecture-manipulating measures' and 'Vegetation-structural aspects of crop-architecture-manipulating measures'). Given that the two measures may have different effects on attractiveness, reproductive performance, and energy balance (e.g., via chilling effects (Dawson et al., 1992) and foraging efficiency (Vickery and Arlettaz, 2012)) of bird species, we emphasize the importance of determining the most beneficial spatial arrangement of sparse and short vegetation in crop fields to maximize the efficiency of in-crop measures.

The latter also requires resolving how the surrounding landscape and local context can influence the success of measures. Although the heterogeneity of the landscape in terms of its impact on biodiversity is often emphasized (Tews et al., 2004; Fahrig et al., 2011), no study in this systematic review did incorporate the composition and configuration of the surrounding landscape in the effects of crop architecture-manipulating measures on farmland birds. Besides, e.g., the influence of the existing species pool in the landscape (Tscharntke et al., 2012), the success of crop architecture-related in-field measures could be particularly determined by the attractiveness of the measures to birds (Koleček et al., 2015). For example, a winter wheat field with unsown patches might be more attractive and thus better accepted by birds in simplified large-parcel monocultures than in small-parcel heterogeneous landscapes where other nesting sites/crops are available (whether or not they are ultimately suitable or rather ecological traps, e.g., frequently mown meadows). Considering the landscape and local context becomes even more important when the geographical bias of the study pool is included within the context of different socio-economic histories of European countries and the resulting characteristics of agricultural systems, such as parcel sizes, crop diversity, or intensity (Gayer et al., 2019). Future studies are thus called to include the landscape and local context to disentangle the potential influence of the surrounding landscape and agricultural production factors on the effectiveness of crop architecture-manipulating measures and to be able to reliably extrapolate identified effects of measures to other regions.

Given that the most effective conservation measures in intensively farmed agricultural landscapes are those minimizing the impact of intensification on the species' reproductive performance (Benton et al., 2003; Casas and Viñuela, 2010; Morris et al., 2005; Guerrero et al., 2012), it is alarming that half of the studies have considered only population density levels, such as territory density, and no life-history traits, such as survival and reproduction. The study of breeding parameters for in-crop measures targeting suitable nesting sites gains even more urgency since conservation measures generally run the risk of becoming ecological traps. This is when man-made areas appear suitable as nesting sites based on physical and/or vegetative characteristics, but become population sinks rather than population sources for the species that settle there due to confounding factors (e.g., predation) (Best, 1986). For example, it has already been shown that isolated patches of dense vegetation can act as ecological traps by attracting nesting birds but also their predators (Jimenez and Conover, 2001). This leads to other knowledge gaps regarding the most successful spatial arrangement of sparse and short vegetation: for example, do unsown strips or patches vary in their ability to attract breeding birds but not predators? Or what is the effect of different numbers of unsown strips or patches per ha?

In addition to providing suitable nesting sites, measures manipulating the crop architecture could increase the reproductive output of target species by increasing the availability of (nestling) food. In general, sparser and shorter vegetation improves foraging efficiency of species feeding on ground- or sward-dwelling invertebrates due to enhanced ground locomotion and increased probability of detecting prey items (Odderskær et al., 1997; Vickery and Arlettaz, 2012). Whether food abundance is increased *per se* in fields with measures that sparsen and shorten the crop architecture has not yet been conclusively resolved. While there is no evidence that unsown patches or wide-spaced rows promote invertebrates (Morris et al., 2004; Smith et al., 2009; MacDonald et al., 2012), higher activity density, species richness and/or larger individuals of different functional groups of ground beetles have been found in areas of unsown strips compared to areas in conventionally sown winter wheat (Blösch et al., 2023). To the best of our knowledge, there is no information yet on the food supply in fields with double-drilled rows (which represents the only measure aiming at a dense and tall crop architecture). Thus, findings to date do not yet provide a fully comprehensive representation of food abundance in fields with manipulated crop architectures.

In sum, we suggest that crop architecture-related in-field measures have the potential to make a major contribution to the conservation of ground-breeding farmland bird species by providing suitable nesting sites. However, to successfully realize this, more studies that prove the effectiveness of in-crop measures are urgently needed. Further, whether the benefits from currently existing crop architecture-related in-field measures also include a sufficient food supply for feeding nestlings has not yet been clarified. Albeit, to effectively promote farmland birds, all life-cycle requirements must be fulfilled. These include, for example, seed- and insect-rich foraging habitats (Wilson et al., 2009; Sharps et al., 2023), which have been shown to be provided by, for example, off-field biodiversity focus areas (Moreby and Aebischer, 1992; Poulsen et al., 1998; Vickery et al., 2002; Volpato et al., 2021).

Whether in-crop measures are generally equivalent to off-field measures with respect to promoting farmland birds remains to be tested. Also, in addition to the open questions related to in-field measures manipulating the crop architecture discussed above, there is a general need for research on various types and aspects of in-crop measures. For example, along with the manipulation of sward structures, the management intensity is a critical factor: current findings from yet unpublished or grey literature indicate that in-crop measures are more effective for various taxa when cropping intensity is reduced (Illner et al., 2004; Oppermann et al., 2022). We therefore recommend analyzing different input levels and weighing potential effectiveness gains against potential yield losses (while also considering the need for potentially increased production areas when production volumes per unit area decrease (Batáry and Tscharntke, 2022)). Thus, along with ecological data, agronomically relevant parameters are an important metric for in-crop studies as well. Besides yield assessments, information on practicability can be valuable in developing the most promising measures, though it generally seems that in-crop measures are easier to implement and more feasible on a larger scale as compared to off-field measures (Sharps et al., 2023). As we are now also facing severe declines in the former stronghold of farmland birds in Eastern Europe (Reif and Vermouzek, 2019) rapid and holistic action is urgently needed.

5. Conclusions

Evidence is accumulating that the manipulation of crop architecture comprises promising (in-crop) options for incorporating suitable habitats for crop-breeding farmland birds into production areas at low costs. This could allow these species to return to our fields on a large scale as 'agricultural by-products'. However, further studies are needed to adequately evaluate and develop the best options, e.g., in terms of spatial arrangement of measures within the crop fields for different species (groups) and thus maximize their efficiency. In particular, we call for studies examining the influence of different landscape and local contexts on the effectiveness of various crop architecture-related in-field measures with focus on breeding parameters of target bird species.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data used for the rersearch described is provided in the supplementary information.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jnc.2023.126515.

References

Bailey, A. (2015) *Report on farmer' s attitude towards on-site ecosystem services*. Liberation Project, Deliverable, 5.

Batáry, P., Dicks, L. V., Kleijn, D., & Sutherland, W. J. (2015). The role of agri-environment schemes in conservation and environmental management. *Conservation Biology, 29*(4), 1006–1016.

Batáry, P., & Tscharntke, T. (2022). Scale-dependent effectiveness of on-field vs. off-field agri-environmental measures for wild bees. *Basic and Applied Ecology, 62*, 55–60.

Benton, T. G., Vickery, J. A., & Wilson, J. D. (2003). Farmland biodiversity: Is habitat heterogeneity the key? *Trends in Ecology & Evolution, 18*(4), 182–188.

Best, L. B. (1986). Conservation tillage: ecological traps for nesting birds? *Wildlife Society Bulletin (1973-2006), 14*(3), 308–317.

Blösch, S., Albrecht, M., Jenny, M., Streit, B., & Knop, E. (2023). Rows make the field: Winter wheat fields with manipulated crop architecture show potential for ecological intensification based on higher natural pest and weed seed control. *Agriculture, Ecosystems & Environment, 348*, Article 108404.

Butler, S. J., Boccaccio, L., Gregory, R., Vorisek, P., & Norris, K. (2010). Quantifying the impact of land-use change to European farmland bird populations. *Agriculture, Ecosystems & Environment, 137*(3–4), 348–357.

Casas, F., & Viñuela, J. (2010). Agricultural practices or game management: Which is the key to improve red-legged partridge nesting success in agricultural landscapes? *Environmental Conservation, 37*(2), 177–186.

Dawson, W. R., Carey, C., & Van't Hof, T. J. (1992). Metabolic aspects of shivering thermogenesis in passerines during winter. *Ornis Scandinavica*, 381–387.

European Bird Census Council (2021) Common Farmland Birds Indicator, Europe. European Indicators | PECBMS - PECBMS, accessed June 2023.

Fahrig, L., Baudry, J., Brotons, L., Burel, F. G., Crist, T. O., Fuller, R. J., … Martin, J. L. (2011). Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. *Ecology Letters, 14*(2), 101–112.

Fischer, J., Jenny, M., & Jenni, L. (2009). Suitability of patches and in-field strips for Sky Larks Alauda arvensis in a small-parcelled mixed farming area. *Bird Study, 56*(1), 34–42.

Gayer, C., Kurucz, K., Fischer, C., Tscharntke, T., & Batáry, P. (2019). Agricultural intensification at local and landscape scales impairs farmland birds, but not skylarks (Alauda arvensis). *Agriculture, Ecosystems & Environment, 277*, 21–24.

Gomiero, T., Pimentel, D., & Paoletti, M. G. (2011). Environmental impact of different agricultural management practices: Conventional vs. organic agriculture. *Critical Reviews in Plant Sciences, 30*(1–2), 95–124.

Götmark, F., Blomqvist, D., Johansson, O. C., & Bergkvist, J. (1995). Nest site selection: A trade-off between concealment and view of the surroundings? *Journal of Avian Biology, 26*(4), 305–312.

Green, R. E., Cornell, S. J., Scharlemann, J. P., & Balmford, A. (2005). Farming and the fate of wild nature. *Science, 307*(5709), 550–555.

Gregory, R. D., Van Strien, A., Vorisek, P., Gmelig Meyling, A. W., Noble, D. G., Foppen, R. P., & Gibbons, D. W. (2005). Developing indicators for European birds. *Philosophical Transactions of the Royal Society B: Biological Sciences, 360*(1454), 269–288.

Guerrero, I., Morales, M. B., Oñate, J. J., Geiger, F., Berendse, F., de Snoo, G., … Clement, L. W. (2012). Response of ground-nesting farmland birds to agricultural intensification across Europe: Landscape and field level management factors. *Biological Conservation, 152*, 74–80.

Higgins, J., & Green, S. (2008). *Cochrane handbook for systematic reviews of interventions* (1st ed., p. 649). Chichester, UK: Wiley.

Illner, H., Salm, P., Braband, D. (2004) Modellvorhaben "Extensivierte Ackerstreifen im Kreis Soest". Ein Projekt zum Erhalt und zur Förderung typischer Lebensgemeinschaften der intensiv ackerbaulich genutzten Landschaften. In: LÖBF-Mitteilungen 2/04, S. 33–39.

Inger, R., Gregory, R., Duffy, J. P., Stott, I., Voříšek, P., & Gaston, K. J. (2015). Common European birds are declining rapidly while less abundant species' numbers are rising. *Ecology Letters, 18*(1), 28–36.

Jimenez, J. E., & Conover, M. R. (2001). Ecological approaches to reduce predation on ground-nesting gamebirds and their nests. *Wildlife Society Bulletin, 29*(1), 62–69.

Kleijn, D., Bommarco, R., Fijen, T. P., Garibaldi, L. A., Potts, S. G., & Van Der Putten, W. H. (2019). Ecological intensification: Bridging the gap between science and practice. *Trends in Ecology & Evolution, 34*(2), 154–166.

Koleček, J., Reif, J., & Weidinger, K. (2015). The abundance of a farmland specialist bird, the skylark, in three European regions with contrasting agricultural management. *Agriculture, Ecosystems & Environment, 212*, 30–37.

Krebs, J. R., Wilson, J. D., Bradbury, R. B., & Siriwardena, G. M. (1999). The second silent spring? *Nature, 400*(6745), 611–612.

Leclère, D., Obersteiner, M., Barrett, M., Butchart, S. H., Chaudhary, A., De Palma, A., … Dürauer, M. (2020). Bending the curve of terrestrial biodiversity needs an integrated strategy. *Nature, 585*(7826), 551–556.

Lopez-Antia, A., Feliu, J., Camarero, P. R., Ortiz-Santaliestra, M. E., & Mateo, R. (2016). Risk assessment of pesticide seed treatment for farmland birds using refined field data. *Journal of Applied Ecology, 53*(5), 1373–1381.

MacDonald, M. A., Maniakowski, M., Cobbold, G., Grice, P. V., & Anderson, G. Q. A. (2012). Effects of agri-environment management for stone curlews on other biodiversity. *Biological Conservation, 148*(1), 134–145.

McMahon, B. J., Doyle, S., Gray, A., Kelly, S. B., & Redpath, S. M. (2020). European bird declines: Do we need to rethink approaches to the management of abundant generalist predators? *Journal of Applied Ecology, 57*(10), 1885–1890.

Mendeley (2015). Mendeley reference manager. Version 1.15.2. London, UK: Mendeley Ltd. Retrieved from http://www.mendeley.com.

Moreby, S., & Aebischer, N. (1992). Invertebrate abundance on cereal fields and set-aside land: Implications for wild gamebird chicks. *Monographs-British Crop Protection Council*, 181.

Morris, A. J., Holland, J. M., Smith, B., & Jones, N. E. (2004). Sustainable Arable Farming For an Improved Environment (SAFFIE): Managing winter wheat sward structure for Skylarks Alauda arvensis. *Ibis, 146*, 155–162.

Morris, A. J., Wilson, J. D., Whittingham, M. J., & Bradbury, R. B. (2005). Indirect effects of pesticides on breeding yellowhammer (Emberiza citrinella). *Agriculture, Ecosystems & Environment, 106*(1), 1–16.

Newton, I. (2004). The recent declines of farmland bird populations in Britain: An appraisal of causal factors and conservation actions. *Ibis, 146*(4), 579–600.

Odderskær, P., Prang, A., Poulsen, J. G., Andersen, P. N., & Elmegaard, N. (1997). Skylark (Alauda arvensis) utilisation of micro-habitats in spring barley fields. *Agriculture Ecosystems & Environment, 62*(1), 21–29.

Oppermann, R., Chalwatzis, D., Wangert, S., Pfister, S.; Klöble, U., Bukhovets, O., (2022) *Weite-Reihe-Getreide mit blühender Untersaat. Zwischenergebnisse 2022.* Institut für Agrarökologie und Biodiversität (IFAB); Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL). Mannheim, Darmstadt.

Poulsen, J. G., Sotherton, N. W., & Aebischer, N. J. (1998). Comparative nesting and feeding ecology of skylarks Alauda arvensis on arable farmland in southern England with special reference to set-aside. *Journal of Applied Ecology, 35*(1), 131–147.

Reif, J., Koleček, J., Morelli, F., & Benedetti, Y. (2023). Population trends of ground-nesting birds indicate increasing environmental impacts from Eastern to Western Europe: Different patterns for open-habitat and woodland species. *Frontiers in Environmental Science, 11*, 543.

Reif, J., & Vermouzek, Z. (2019). Collapse of farmland bird populations in an Eastern European country following its EU accession. *Conservation Letters, 12*(1), e12585.

Schmidt, J.-U., Eilers, A., Schimkat, M., Krause-Heiber, J., Timm, A., Nachtigall, W., & Kleber, A. (2017a). Effect of Sky Lark plots and additional tramlines on territory densities of the Sky Lark Alauda arvensis in an intensively managed agricultural landscape. *Bird Study, 64*(1), 1–11.

Schmidt, J.-U., Eilers, A., Schimkat, M., Krause-Heiber, J., Timm, A., Siegel, S., … Kleber, A. (2017b). Factors influencing the success of within-field AES fallow plots as key sites for the Northern Lapwing Vanellus vanellus in an industrialised agricultural landscape of Central Europe. *Journal for Nature Conservation, 35*, 66–76.

Schmidt, A., Fartmann, T., Kiehl, K., Kirmer, A., & Tischew, S. (2022). Effects of perennial wildflower strips and landscape structure on birds in intensively farmed agricultural landscapes. *Basic and Applied Ecology, 58*, 15–25.

Setchfield, R. P., & Peach, W. J. (2016). The influence of crop tiller density on the breeding performance of a cereal-nesting specialist. *Journal of Applied Ecology, 53*(5), 1430–1439.

Sharps, E., Hawkes, R. W., Bladon, A. J., Buckingham, D. L., Border, J., Morris, A. J., … Peach, W. J. (2023). Reversing declines in farmland birds: How much agri-environment provision is needed at farm and landscape scales? *Journal of Applied Ecology, 60*(4), 568–580.

Smith, B., Holland, J., Jones, N., Moreby, S., Morris, A. J., & Southway, S. (2009). Enhancing invertebrate food resources for skylarks in cereal ecosystems: How useful are in-crop agri-environment scheme management options? *Journal of Applied Ecology, 46*(3), 692–702.

Tarjuelo, R., Margalida, A., & Mougeot, F. (2020). Changing the fallow paradigm: A win–win strategy for the post-2020 Common Agricultural Policy to halt farmland bird declines. *Journal of Applied Ecology, 57*(3), 642–649.

Tews, J., Brose, U., Grimm, V., Tielbörger, K., Wichmann, M. C., Schwager, M., & Jeltsch, F. (2004). Animal species diversity driven by habitat heterogeneity/diversity: The importance of keystone structures. *Journal of Biogeography, 31*(1), 79–92.

Tobias, J. A., Sheard, C., Pigot, A. L., Devenish, A. J., Yang, J., Sayol, F., … Barber, R. A. (2022). AVONET: Morphological, ecological and geographical data for all birds. *Ecology Letters, 25*(3), 581–597.

Tscharntke, T., & Batáry, P. (2023). Agriculture, urbanization, climate, and forest change drive bird declines. *Proceedings of the National Academy of Sciences, 120*(22), Article e2305216120.

Tscharntke, T., Grass, I., Wanger, T. C., Westphal, C., & Batáry, P. (2021). Beyond organic farming–harnessing biodiversity-friendly landscapes. *Trends in Ecology & Evolution, 36*(10), 919–930.

Tscharntke, T., Tylianakis, J. M., Rand, T. A., Didham, R. K., Fahrig, L., Batáry, P., … Dormann, C. F. (2012). Landscape moderation of biodiversity patterns and processes-eight hypotheses. *Biological reviews, 87*(3), 661–685.

Tucker, G. M., & Evans, M. I. (1997). *Habitats for birds in Europe: a conservation strategy for the wider environment* (Vol 6). BirdLife International.

Van Buskirk, J., & Willi, Y. (2004). Enhancement of farmland biodiversity within set-aside land. *Conservation Biology, 18*(4), 987–994.

Vickery, J., Carter, N., & Fuller, R. J. (2002). The potential value of managed cereal field margins as foraging habitats for farmland birds in the UK. *Agriculture, Ecosystems & Environment, 89*(1–2), 41–52.

Vickery, J., & Arlettaz, R. (2012). The importance of habitat heterogeneity at multiple scales for birds in European agricultural landscapes. In R. J. Fuller (Ed.), *Birds and habitat: relationships in changing landscapes* (pp. 177–204). New York: Cambridge University Press.

Volpato, A., & Moran, J. (2021). Ecological value of different vegetated strip types in providing valuable insect-rich habitats for grey partridge chicks. *Irish Journal of Agricultural and Food Research, 60*(1), 180–190.

Wilson, J. D., Evans, A. D., & Grice, P. V. (2009). *Bird conservation and agriculture*. Cambridge: Cambridge University Press.

Wilson, J. D., Whittingham, M. J., & Bradbury, R. B. (2005). The management of crop structure: A general approach to reversing the impacts of agricultural intensification on birds? *Ibis, 147*(3), 453–463.