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Reviewing the evidence base for synergies and trade-offs between agriculture and biodiversity along a land-use intensity gradient

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SHOWCASE

SHOWCASing synergies between agriculture, biodiversity and Ecosystem services to help farmers capitalising on native biodiversity

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1 Summary

As farmland biodiversity declines worldwide with an accelerated speed in the last decades, several agri-environment schemes (AES) have been developed to combat this challenge. Common AES in Europe to support arthropods are organic farming, sown flower strips/areas, grassy field margins, or hedgerows. AES is implemented in the agricultural landscape to increase biodiversity and maintain ecosystem services, such as pollination or pest control. However, the effectiveness of AES in increasing biodiversity and agricultural yield, especially their trade-offs, is still poorly understood. In this task (3.1), we performed a systematic review to investigate synergies and trade-offs between the effectiveness of AES for arthropods and agricultural yield on cropland. We tested the recent hypothesis by Seppelt et al. (2020), that yield in AES fields is often (but not always) lower than in control conventional fields, whereas arthropod diversity is generally higher in AES than in conventional fields. Our primary interest in task 3.1 is to clarify under which conditions yield is similar or even higher in AES without compromising farmland biodiversity compared to conventional control.

We performed a literature-based systematic review. We found a total of 3434 potential arthropods' studies. After screening these studies by title, 258 studies remained, and after reading the abstracts, 64 studies remained for full-text filtering. Altogether, we found 24 studies with 107 data points, which fulfilled our study inclusion criteria for a meta-analysis. We extracted from each study biodiversity (arthropods species richness and/or abundance) and yield data for AES management and conventional control group.

We classified studies based on arthropod functional group, landscape structure, crop type and AES type (productive or non-productive areas). We used a log response ratio as a measure of effect size for arthropods and yield between AES and conventional farming. Additionally, we calculated the compatibility index from conventional to AES as an additive effect of the biodiversity gain and yield loss. A positive value of compatibility index implies a positive additive effect of biodiversity gain and yield loss from conventional to AES. A higher compatibility index value refers to a higher biodiversity gain as compared to the yield loss for AES, and thus AES achieves higher biodiversity relative to its yield loss and is the preferred option for biodiversity conservation.

Our results showed that the majority of the studies reported that arthropods had higher species richness and abundance on AES than conventional farms, but with yield, it was *vice versa*. We found evidence that it is possible to produce crops in environmentally-friendly ways (AES conditions) and concurrently farmers can get an even higher yield than in current conventional agricultural practice. However, the biodiversity is also safeguarded. Additionally, our results showed that AES is very effective for pollinators, but also for yield in AES compared to conventional farming conditions. On the contrary, the compatibility index was significantly below the zero line for natural enemies, indicating that the trade-off between biodiversity (natural enemies) vs. yield is inclined to conventional farming. Thus, there is evidence that there are winners and losers also among arthropod functional groups. We found that in-production AES vs. out of production, organic farming vs. others AES type and producing in complex vs. simple landscape conditions had a smaller trade-off between AES and conventional farming. Still, future research need to invest more effort to clarify what is the optimal trade-off between biodiversity and yield in European agricultural landscapes. There is more and more new evidence that it is possible to produce crops under AES conditions without losing yield in comparison to conventional farming and thereby also safeguarding biodiversity and maintaining ecosystem services.

2 List of abbreviations

EU	European Union
AES	Agri-environment schemes

3 Introduction

It is well known that worldwide agricultural biodiversity decline has been directly related to production intensity since the Second World War (Mazor et al., 2018, Grass et al., 2021). During the last four decades, agri-environment schemes (AES) such as wild flower strips or areas, grassy field margins, etc. have been developed to combat the negative influence of agricultural production on biodiversity (Batáry et al., 2015). Yet, the effectiveness of these different AES varies enormously. There are many positive examples of AES effects on arthropods (Boinot et al., 2020, Gallé et al., 2020, Sidemo-Holm et al., 2021), but several studies report no apparent positive AES effects on this organism group (Winqvist et al., 2011, Mei et al., 2021). In meta-analyses, positive effects of AES on arthropod richness and abundance in cropland dominate, but with low effectiveness in complex landscapes, as intensively managed cropland may also benefit from arthropod spillover from the landscape matrix (Batáry et al., 2011, Marja et al., 2019).

The majority of previous AES studies have mainly focused on biodiversity. On the contrary, agricultural production and yield studies often do not consider the biodiversity aspect. Therefore, the majority of previous studies about the topic have taken into account only "one side of the coin". Only a limited number of studies (for instance, Gabriel et al., 2013, Beckmann et al., 2019, Katayama et al., 2019, Albrecht et al., 2020) have concurrently studied AES effectiveness on biodiversity and yield in agricultural landscapes.

Beckmann et al. (2019) conducted a global meta-analysis to investigate how production intensification is related to species richness and yield. The authors found worldwide that across investigated production systems (food, wood, fodder), production intensification increased yield (approximately 20%), but this leads to a loss of species richness (approximate decline -9%). However, yield increase and biodiversity loss were intensity related. Areas of the medium intensity of land use showed the highest increase in yield (85%), but they also had the most significant loss of species richness (23%). In contrast, areas that already had high production intensity did not reveal any considerable loss of species richness but showed an increase in yield (15%). The latest result can be explained because in high productivity areas, there was not much biodiversity left. A case study from Indonesia smallholder cacao farms showed that species richness of fungi, trees, invertebrates, and vertebrates did not decrease with yield (Clough et al., 2011). However, these studies did not take into account AES effectiveness for biodiversity.

Katayama et al. (2019) researched organic and conventional farming comparisons between biodiversity and yield only in orchard and vineyard landscapes. The authors conducted a series of meta-analyses to compare biodiversity among different management regimes and fruit/nut yield. The study indicated that combined abundance and richness over the studied taxa were greater in organic farms (+51% and+16%, respectively), but the yield was also lower (−18%).

Recently Albrecht et al. (2020) made a quantitative synthesis focused on the effectiveness of flower strips and hedgerows on agricultural pest control, pollination services, and crop yield based on Europe, North America, and New Zealand studies. The authors found that flower strips, but not hedgerows, increased pest control services in adjacent crop fields by 16% on average. Relationships between crop pollination and yield were more variable. The authors also demonstrated that pollination services decreased exponentially with distance from plantings, and older flower strips with higher flowering plant diversity increased pollination more effectively. The limitation of this study was that the authors focused only on two common treatments of AES (wildflower strips and hedgerows).

AES effectiveness for biodiversity can vary. AES effectiveness can be even different for common arthropod diversity measures, such as species richness or abundance (Marja et al., 2022). Additionally, it can be also dependent on which arthropod functional groups are studied. Finally, AES effectiveness can be related to ecological contrast between AES and control habitats (Marja et al., 2019), as well as whether is it implemented on productive or non-productive land (Batáry et al., 2015).

Landscape structure can be measured by its habitat composition and configuration. Landscape composition is characterised by a mixture of landscape elements (managed and semi-natural habitat types), whereas landscape configuration focuses on their spatial arrangements (typical measures: habitat size, edge length, etc.) (Leitão et al*.,* 2006, Fahrig et al*.,* 2011). Many studies have found that higher landscape complexity (i.e. a landscape composed of high amounts of semi-natural habitat) supports higher arthropods species richness and/or abundance (Rundlöf et al*.,* 2008, Scheper et al*.,* 2015). This is explained by the larger species pool in these habitats. In contrast, in simple landscapes, local improvements, such as organic farming, may promote only the abundance of the limited number of species available (Schmidt et al*.,* 2005, Tscharntke et al*.,* 2012). One meta-analysis synthesising the topic showed that landscape complexity at local and landscape scales had, in general, positive effects on both pollinators and natural enemies, but effects varied among different taxa. Effects on spiders and bees were positive, but effects on predatory beetles and parasitoids were inconclusive (Shackelford et al*.,* 2013).

Landscape complexity may affect both species richness and abundance of target taxa, but these two response variables need not be correlated with each other and maybe valued differently. Recent studies highlight that it is not species richness but rather the abundance of the most common species that drive ecosystem services such as crop pollination (Kleijn et al*.,* 2015, Winfree et al*.,* 2015). However, others argue that increasing species richness, including rare and specialised species, is crucial for healthy ecosystem resilience and functioning (Senapathi et al*.,* 2015). Recently, Dainese et al. (2019) also showed that relatively rare and not only dominant species contribute positively to pollination and pest control and thus increase crop yield. Hence, both arthropods species richness and abundance can be important ecosystem service determinants.

Common AES in Europe are implemented in the agricultural landscape to increase ecosystem services (for instance, pollination, pest control). However, their effectiveness in achieving these goals are still poorly studied (Albrecht et al., 2020). In task 3.1, we performed a literature-based systematic review to investigate the effectiveness of AES for arthropods and agricultural yield on cropland concurrently. We tested the recent hypothesis by Seppelt et al. (2020): yield in AES fields are often (but not always) lower than in control conventional fields, whereas arthropod diversity is generally higher in AES than in conventional fields. We selected arthropods since they are important pollinators or natural enemies related directly to crop yield. Our primary interest in task 3.1 was to clarify under which conditions is yield similar or higher in AES without compromising farmland biodiversity compared to conventional control? We focused only on AES studies and did not consider other management options since AES are still an essential legal and political tool at the EU level to support biodiversity. To obtain the target of task 3.1, we completed a literature-based systematic review about current evidence of studies, which concurrently investigate biodiversity and yield in AES and conventional control in European agricultural landscapes. The results of this task fill the knowledge gap about trade-offs of AES effectiveness for biodiversity and agricultural yield.

4 Methods

4.1 Data collection and exclusion/inclusion criteria

For task 3.1, we conducted literature searches using ISI Web of Science Core Collection and Elsevier Scopus databases between the years 1945–2021 (last search date: 26 February 2021). We used the following keyword combinations according to the PICO (Population, Intervention, Comparator and Outcome) combination of search terms (Higgins & Green 2008), which linked with logical operators to include the maximum number of relevant studies covering the effect of AES on arthropod diversity. PICO: Population (arthropods); Intervention (European agri-environment schemes); Comparator (conventional management); Outcome (species richness, abundance). We used the following keywords combinations for literature search: TOPIC: arthropod* OR insect* OR pollinat* OR beetle* OR carabid* OR spider* OR hoverfl* OR syrphid* OR "natural enem*" OR predator* OR parasitoid* OR bee OR butterfl* OR pest*) AND TOPIC: (agri-environment* OR organic OR integrated OR hedge* OR "field margin" OR "beetle bank" OR "flower strip") AND TOPIC: (richness OR diversity OR abundance OR density). We filtered out only English language studies. We selected only EU country studies, but also included previous EU member United Kingdom and potential studies from Norway and Switzerland, since in these countries several different AES have been developed that are similar to those in EU. We used only the following categories for including studies: Agricultural and Biological Sciences, Agriculture Multidisciplinary, Biodiversity Conservation, Ecology, Environmental Sciences and Entomology. Our literature searches confirm the common review guidelines for a comprehensive literature review (Koricheva et al., 2013, Collaboration for Environmental Evidence 2018).

We combined the two searches of Web of Science (n=1906) and Scopus (n=2644) databases in Mendeley (Mendeley 2021) and removed duplicates. We found a total of 3434 potential studies. After screening these studies by title, we omitted studies, which were clearly not related to our study topic. 258 studies remained, and after reading the abstracts, 64 studies remained for full-text filtering. Additionally, we used previous meta-analyses (Beckmann et al., 2019, Katayama et al., 2019, Marja et al., 2019, Albrecht et al., 2020) with similar topics and unpublished datasets to include all potential data. Searching additional, including unpublished data, is necessary to reduce potential publication bias (Ahmed et al., 2012). Furthermore, we contacted authors of potential studies which fulfilled our research criteria, via e-mails, and requested yield data if it was not reported in the study. The PRISMA flow diagram representing the detailed selection process (i.e. the number of studies identified, rejected and accepted) is presented in the supplementary material (Figure. S1).

We used only European studies in our research since the majority of EU member countries have been under the same agri-environmental policies, and most studies examining the effectiveness of AES have been carried out in Europe. In North America and Australia, agri-environmental policies differ from Europe, complicating comparisons. We set up the following criteria for inclusion and exclusion to filter out only European (EU27 + United Kingdom + Switzerland + Norway) AES arthropod studies, which included also yield comparison between AES and control group. Inclusion criteria were: 1.) only European AES studies; 2.) only studies focusing on arthropod diversity (species richness or diversity index, abundance or density); 3.) only crops (including fruits, vegetables and cultivated berries); 4.) only studies where mean, standard deviation (or standard error) and sample size are clearly reported or provided raw data; in case of non-production AES (hedgerow, flower strip), inclusion of only those studies, which contain data directly next to the non-productive AES (i.e. the field itself). We excluded 1.) all grassland studies because yield is usually not measured or measured differently; 2.) studies with a number of replicates less than three in AES or in the control group; 3.) studies with single field experiments (blocks within fields or field margins), i.e. only taking studies at the landscape level, since AES management actions are more relevant at this scale. In total, we found 24 studies with 107 data points for analysis (List S2). The list S2 gives overview about the excluded studies.

4.2 Classification of moderators

We used four moderators to test our hypotheses: arthropods functional group, landscape structure, AES type in or out of production, and organic vs. other AES. We used the following procedures to classify selected moderators.

As functional groups, we classified bees, bumblebees, butterflies, hoverflies, social bees, solitary bees and wild pollinators as pollinator group. We classified beetles, predatory ground beetles, rove beetles, carnivorous carabids, omnivorous carabids, spiders and wasps as natural enemies. Leafhoppers, mealybugs and granivorous carabids were classified as herbivores. We treated epigeal arthropods as an independent, unclassified group.

We used the original GIS dataset from the authors to determine study areas. If GIS data was not available, we identified the study areas based on their description in the study text (published coordinates) or map of study areas in original studies, similar to a previous meta-analysis (Tuck et al., 2014, Marja et al., 2019). After we identified a study area, we placed five random 1000 m transects per study area in order to estimate representative landscape complexity. The positions of the five transects were defined by sets of three randomly generated numbers. First, we generated the random number between zero (central study area measuring point) and the radius of the study area, which denoted how many metres from the central point the starting point of each transect would be situated. Second, we randomly generated the angle degree defining the direction of the study area's central point for which the start point of the transect should be placed. With these two random numbers, we were able to define the transect location. Third, we randomly selected numbers between 0–360 degrees to specify the angle at which the transect should be drawn, 500 m to each side of the start point. Transects were not allowed to cross or be closer to each other than 2000 m to avoid pseudo-replication in the landscape structure information. In each of the five random transects, we collected landscape data in a buffer area of 1 km.

For landscape structure, we used the Coordination of Information on the Environment Land Cover databases from the years 2006–2018 (hereafter CORINE database, Büttner et al., 2004). Since case studies are from the last two decades, we used landscape structure information based on the version of CORINE closest to the year of study. The 17 categories starting with CORINE database codes three or four indicated semi-natural habitats and were used to calculate the proportion within a radius of 1000 m (Batáry et al., 2011). We classified landscape structure as simple and complex landscapes (Tscharntke et al., 2005). In simple landscape, the proportional area of semi-natural habitats was less than 20%, in complex landscapes, more than 20%. We did not consider the classification of a cleared landscape (<1%) since we did not find such studies.

Since AES effectiveness for biodiversity and yield can also depend on whether it is applied within or outside crop fields, we classified AES type as in-production and out of production (Batáry et al., 2015). AES targeting non-productive areas included hedgerows, wildflower strips or wildflower areas (out of production schemes). In contrast, in-production schemes support environmentally sensitive approaches to the management of land that is used to grow crops and the producer gets yield. We classified organic farming and environmentally friendly management (see details in Marja et al., 2014) as in-production schemes. We classified organic farming as one group against to the other AES, which fulfilled our studies selection criteria (wildflower strips/areas, environmentally friendly management, and hedgerows).

4.3 Effect size and compatibility index calculation

We used the log response ratio as a measure of effect size. The log response ratio has several advantageous features as an effect size measure. First, the log response ratio is directly connected to the metric of percentage change between AES and the control group. A second advantage of the log response ratio is that the magnitude of this effect size is relatively insensitive to how the outcome variable was measured, such as the use of different arthropod study methods or different monitoring intervals. For instance, some studies used a two-week study period, while others used a several-month study period. The magnitude of the log response ratio is unaffected by such variation, making it possible to compare studies that use different monitoring methods. Thus, selected effect size depends only on the mean levels of the outcome in each group (Pustejovsky, 2018).

We calculated effect sizes and their variance for all data points based on the mean, standard deviation and sample size of arthropods diversity and yield of AES and control groups separately. The effect size was positive if arthropod diversity or yield were higher in the AES than in the control group. To calculate the log response ratio, we obtained (from tables, graphs, text or raw data) the mean values, sample sizes and some variability measures of AES and control groups (SD, SEM or 95% CI).

The log response ratio is biased when quantifying the outcome of studies with small sample sizes. This can yield erroneous variance estimates when the scale of study parameters is near zero. Therefore, we used variance correction based on Lajeunesse (2015).

We used the following formulas for calculating the log response ratios of the biodiversity R_b and yield R_y (separate calculations, but based on the same treatment groups) between AES ($\overline{X}_T$) and conventional ($\overline{X}_C$) farming. Following are the R_b formulas as an example:

$$R_b = \frac{\overline{X}_T}{\overline{X}_C}$$

The effect size of biodiversity and yield of AES to the conventional field can be expressed as the logarithm of R_b,

$$ln(R_b) = \ln(\frac{\overline{\mathrm{X}}_\mathrm{T}}{\overline{\mathrm{X}}_\mathrm{C}})$$

Correction for effect size

$$lnR^{\Delta} = ln(R_b) + 0.5\left[\frac{(SD_T)^2}{N_T\ \overline{X}_T^{\,2}} + \frac{(SD_C)^2}{N_C\ \overline{X}_C^{\,2}}\right]$$

The variance is

$$SD_{pooled} = \sqrt{\frac{(N_T - 1)SD_T^2 + (N_C - 1)SD_C^2}{N_T + N_C - 2}}$$

$$Variance\ ln(R_b) = \frac{SD_{pooled}^{\ \ 2}}{N_T\ \overline{X}_T^2} + \frac{SD_{pooled}^{\ \ 2}}{N_C\ \overline{X}_C^2}$$

Corrections for the variance for small sample size (based on Lajeunesse, 2015)

$$Variance\ lnR^{\Delta} = Variance\ ln(R_b) + 0.5\left[\frac{(SD_T)^4}{N_T^2\ \overline{X}_T^{\,4}} + \frac{(SD_C)^4}{N_C^2\ \overline{X}_C^{\,4}}\right]$$

4.3.1 Compatibility index

Additionally, we calculated a compatibility index (developed by Jenny Hodgson and Yi Zou for another study) from conventional to AES as an additive effect of the biodiversity gain and yield loss, which can be expressed as,

$$T_{C-T} = ln\,(R_b)\; +\; ln(R_y)$$

The variance of T_{C-T} is

$$\sigma^2(T_{C-T}) = \sigma^2\;(\,R_b) + \;\sigma^2\;(R_y)$$

Where $\sigma^2_{R_b}$ and $\sigma^2_{R_y}$ are the variance of R_b and R_y.

A T_{C-T} > 0, implies a positive additive effect of biodiversity gain and yield loss from conventional to AES. A larger T_{C-T} > 0 value refers to a higher biodiversity gain as compared to the yield loss for AES, and thus AES achieves higher biodiversity relative to its yield loss and is the preferred option for biodiversity conservation.

4.4 Statistical analysis

For performing the meta-analysis models, we used the "metafor" package (Viechtbauer, 2010) for R (R Core Team, 2021). We used hierarchical models with country and study ID as nested factors (R syntax in all models: method="REML", random=list(~1|country/study)). We used nesting factors since some studies were carried out in different countries. Different studies might also include several taxa (for instance, butterflies and spiders); therefore, we also used study ID as a nesting factor.

For testing the moderators' effect for compatibility index, we fitted different models with moderator: 1) arthropods community measure (species richness or abundance), 2) arthropods functional group (pollinators, natural enemies, herbivores or others), 3) landscape heterogeneity (simple or complex), 4) AES production type (in-production AES or out of production), and 5) organic or other AES type.

We inspected a potential publication bias using a rank correlation test for funnel plot asymmetry separately for biodiversity and yield effect sizes. The rank correlation test for funnel plot asymmetry indicated no sign of publication bias in the biodiversity dataset (tau=0.077, p = 0.24). Since studies might contain several arthropod groups (for instance, butterflies and spiders), but the yield was always measured only once. Therefore, to avoid yield pseudo-replication in the dataset, we used yield only once for each study to estimate publication bias. The rank correlation test for funnel plot asymmetry indicated no sign of publication bias in the yield subset dataset (tau=0.25, p = 0.09).

We searched for outlier effect sizes in our dataset. Based on the method of Habeck & Schultz (2015), we evaluated the sensitivity of our analyses by comparing fitted model without effect sizes that we defined as influential outliers. We defined influential outliers as effect sizes with hat values (i.e. diagonal elements of the hat matrix) greater than two times the average hat value (i.e. influential) and standardised residual values exceeding 3.0 (i.e. outliers; from (Habeck & Schultz 2015). We found no outliers in our datasets.

5 Results

5.1 Arthropods vs. yield effect sizes

Prevalently we found studies where AES had higher arthropods values than in the control group, but with yield higher in control than in the AES group (Figure 1). We found same percentages for abundance (34.6% of the dataset) and species richness (34.6% of the dataset). Cases where arthropods as well yield had lower values in AES than in control were rarer (9.3% abundance and 5.6% of species richness of dataset). In a few cases, arthropods and yield had higher values in AES than in the control group (6.5% abundance and 2.8% of species richness of dataset). We also found some cases where arthropods had lower values in AES than the control group, but on the contrary, had higher values of yield in AES than in the control group (5.6% abundance and 0.9% of species richness of dataset). In Figure 1 we present log response ratio values between arthropods and yield based on abundance and species richness.

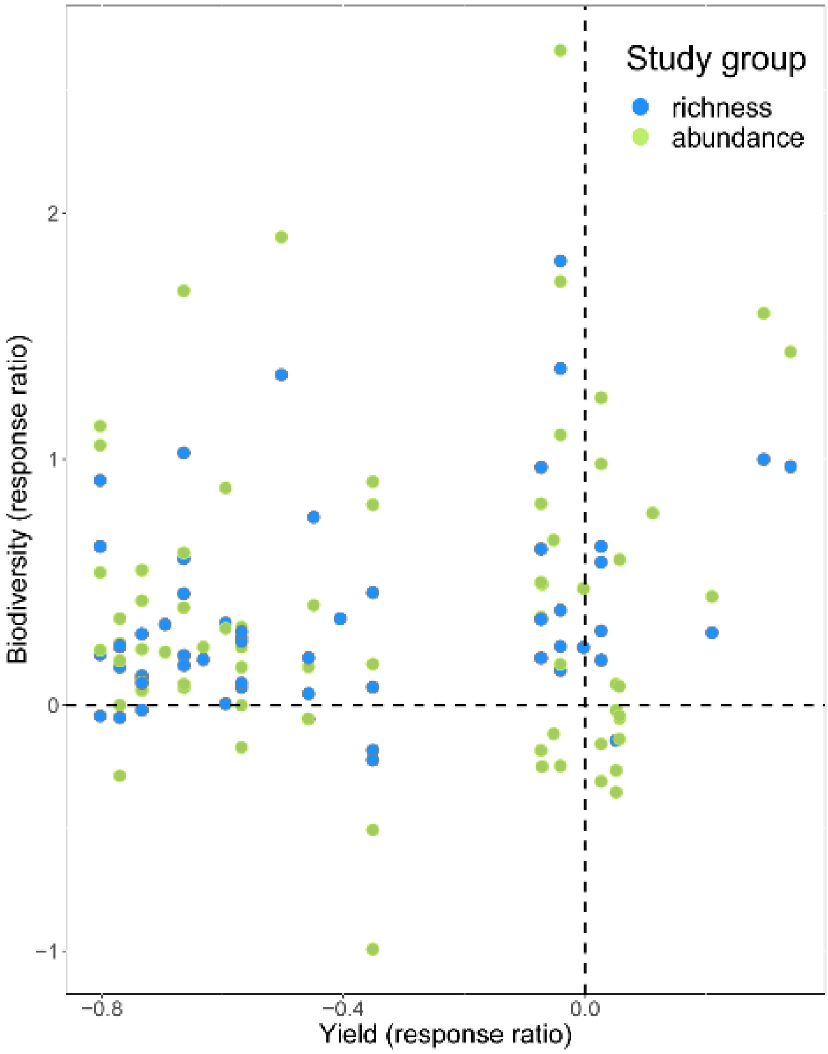

Figure 1. Biodiversity (arthropods) response ratio against yield response ratio between AES and control group. If biodiversity or yield response ratio value is higher than zero, this represents the situation of higher arthropods or yield values in AES than in the control group.

5.2 Effects of moderators on compatibility index

5.2.1 Study group

The mean compatibility index had similar values in both investigated study groups (abundance or species richness), representing standard biodiversity measures (Figure 2). Both groups' mean compatibility index values were a bit below the zero line, while confidence intervals crossed the zero line. Since both abundance and species richness show that compatibility index values were a bit below zero, these results refer to a lower arthropod diversity gain than the yield loss in AES; however, these were both non-significant.

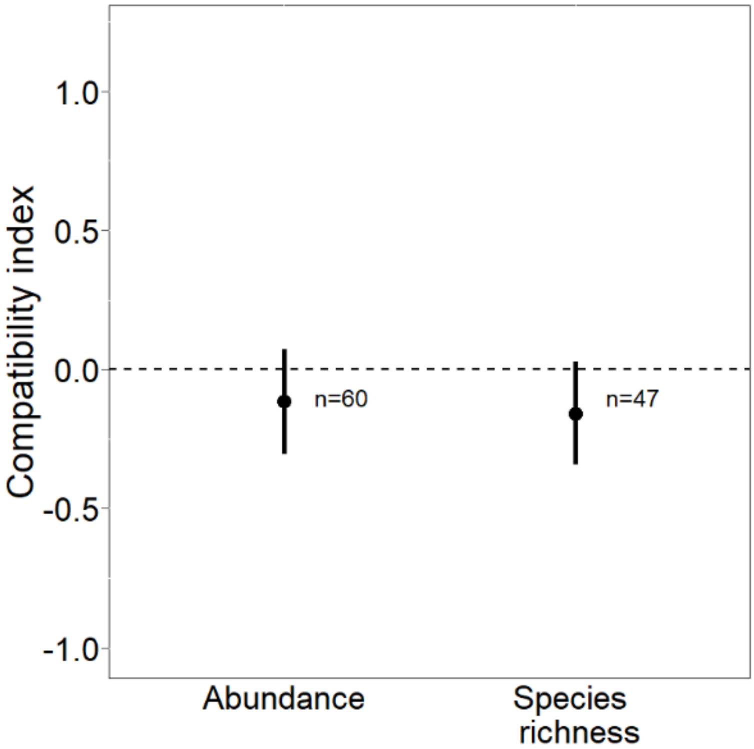

Figure 2. Mean compatibility index of arthropod diversity (abundance and species richness). Numbers indicate sample size. Dots present mean group values with 95% CIs range.

5.2.2 Functional group

We found significant differences in compatibility index values of arthropod functional groups (Figure 3). Natural enemies had significantly lower compatibility index values than pollinators, who had very close to significantly (p=0.06) positive compatibility index values. Herbivores and epigeal arthropods sample sizes were limited to confirm clear patterns.

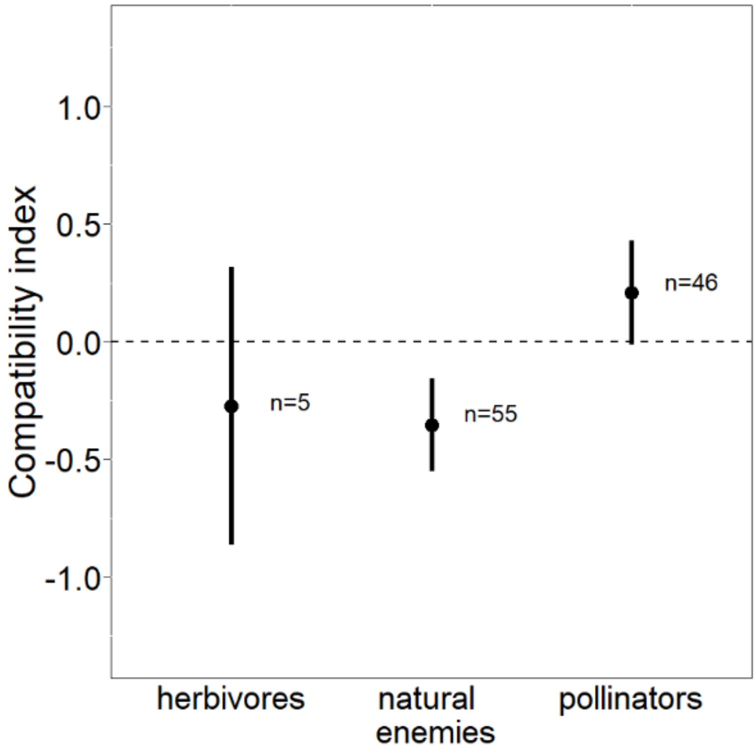

Figure 3. The mean compatibility index based on arthropods functional group (herbivores, natural enemies, and pollinators). Numbers indicate sample size. Dots present mean group values with 95% CIs range. The epigeal arthropods (constitute the bulk of herbivore, predator, and decomposer species in soil and litter ecosystems) is excluded from this figure (n=1).

5.2.3 Production type

Out of production AES had significantly lower compatibility index values than in-production AES compatibility index mean values, which was close to zero (Figure 4).

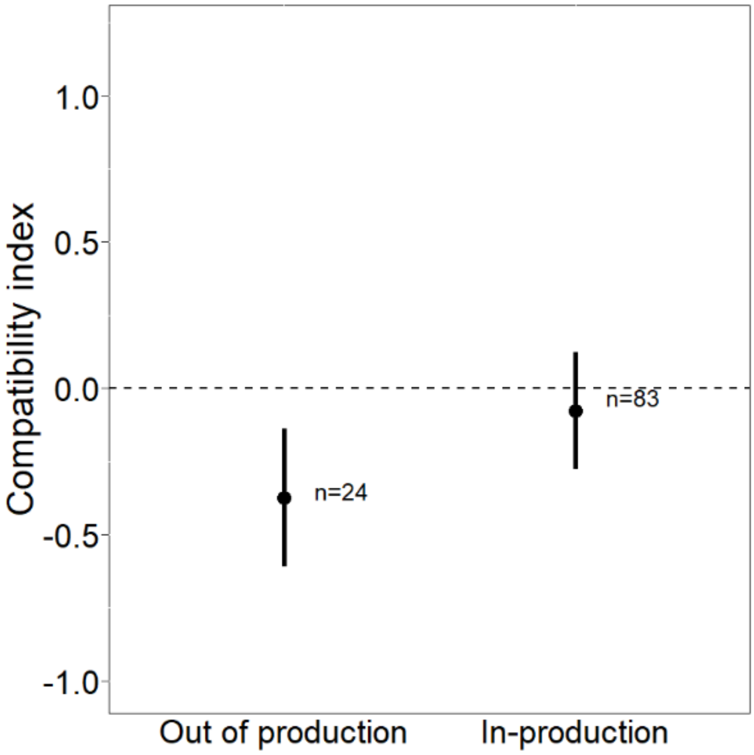

Figure 4. The mean compatibility index based on agri-environment schemes (AES) production type (in-production vs. out of production). Numbers indicate sample size. Dots present mean group values with 95% CIs range.

5.2.4 Agri-environment scheme type

Non-organic AES had significantly lower compatibility index values, whereas organic farming had a non-significant effect (Figure 5). Organic farming's mean compatibility index value was close to zero, indicating a minimal trade-off between diversity of arthropods and yield loss.

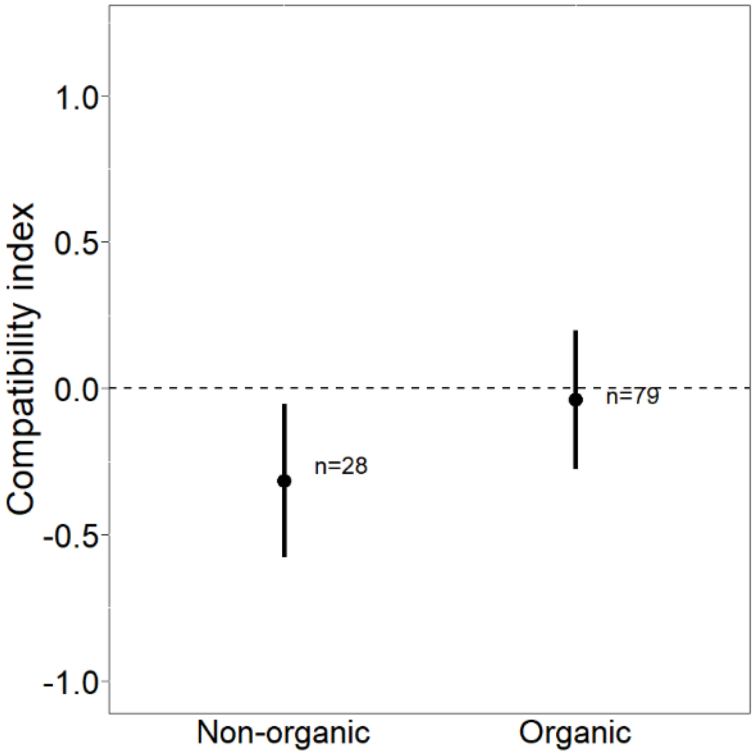

Figure 5. The mean compatibility index based on non-organic agri-environment schemes vs. organic farming. Numbers indicate sample size. Dots presents mean group values with 95% CIs range.

5.2.5 Crop type

In cereal fields had significantly lower compatibility index values than in other non-cereal habitats. In other habitats, we did not discover significant compatibility index values different from zero (Figure 6).

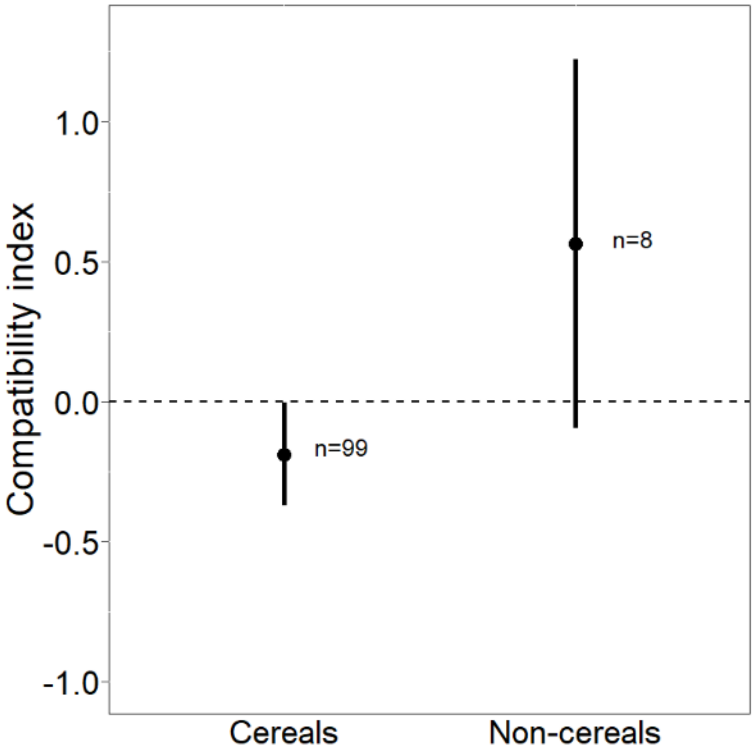

Figure 6. The mean compatibility index based on habitat type (cereals vs. non-cereals). Numbers indicate sample size. Dots presents mean group values with 95% CIs range.

5.2.6 Landscape type

The compatibility index was significantly lower in simple landscapes, while in complex landscapes, the index confidence intervals crossed the zero line (Figure 7). This indicates that biodiversity gain and yield loss from conventional farming are smaller in complex landscapes than in simple ones.

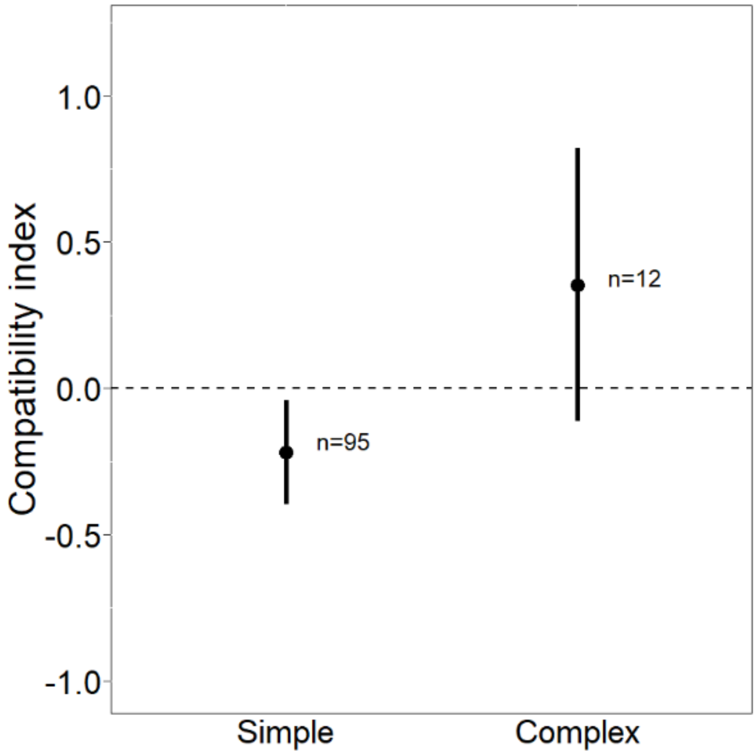

Figure 7. The mean compatibility index based on landscape type (simple vs. complex). Numbers indicate sample size. Dots presents mean group values with 95% CIs range.

5.3 Studies geographical coverage

The studies, which fulfilled our search criteria were carried out in the following countries: England, Estonia, France, Germany, the Netherlands, Sweden and Switzerland. The map of geographical coverage is presented in the supplementary material.

6 Discussion

Our results show, as current evidence, that the majority of the studies reported that arthropods had higher values on AES farms compared to conventional farms, but with yield, it was *vice versa*. This evidence was similar for arthropods abundance and species richness. Additionally, we found that arthropods functional group, production, crop and AES type, and landscape complexity moderated the compatibility index results. Our results showed evidence that it is possible to produce environmentally-friendly ways under different AES conditions where at least some biodiversity is protected, and the farmers get an even better yield than in current common conventional agricultural practice. Therefore, more effort is needed to clarify the optimal trade-off between biodiversity and yield in European agricultural landscapes.

6.1 Study and functional group

Our results showed that, in general, AES support strongly arthropods diversity (both abundance and species richness similarly). Still, the yield is often lower in AES compared the conventional farms. However, the trade-off between biodiversity and yield is relatively minimal since the mean compatibility index was slightly below the zero line for both abundance and species richness. This indicates that if the producers accept the minimal yield loss, AES is an effective tool in the EU to increase biodiversity status. Our results give evidence, and strong hope that producing with different AES conditions across the EU is sustainable for biodiversity and yield.

Additionally, our results indicated that AES are very effective, especially for pollinators as the producers get satisfactory yield in AES compared to conventional farming conditions. On the contrary, the compatibility index was significantly below the zero line for natural enemies, indicating that the trade-off between biodiversity (natural enemies) vs yield is inclined to conventional farming. Thus, there is evidence that there are winners and losers between arthropod functional groups. AES for pollinators are more effective as well the producers get profit from the yield.

One possible explanation of such functional group differences might be related to arthropods' mobility. For instance, bumblebees and other wild bees, hoverflies, and butterflies are all essential pollinators increasing crop yield. They are also very mobile taxa compared to natural enemies (spiders or beetles) who mostly dwell on the ground. A similar pattern was found recently in Marja et al. (2022) study where AES were more effective for aerial- than ground-dwelling arthropods. Thus, the effectiveness of AES for aerial- vs ground-dwelling arthropods might vary; therefore, compatibility index results showed controversial evidence. A recent case study from England (Campbell et al., 2017) also confirmed this pattern. The authors found that pollinators benefitted from AES as well yield was higher in apple orchards with flower strips than in conventional ones.

Mei et al. (2021) showed that in the Netherlands the presence of wildflower strips did not directly affect ground-dwelling natural enemies or crop yield. However, the richness and availability of flowers across the wildflower strips and control margins were positively related to the abundance of the pooled arthropods' number of examined natural enemies (carabid beetles and spiders). Thus, the ecological quality of the wildflower strip (flowers richness and cover) is an essential factor of arthropods diversity and influences the crop yield, as shown by the authors. Thus, there is also opposite evidence of arthropods' functional group relations with AES and crop yield contrary to our results.

6.2 Production and AES type

Out of production AES had significantly lower compatibility index mean value than in-production AES. The in-production AES compatibility index mean value was close to zero. This indicates that the producers lose less yield with in-production AES and AES enhance biodiversity status and biodiversity gain is smaller than yield loss. However, we could not take into account the yield loss due to area under out of production, where grassy field margins, wildflower strip, or hedgerow were established, i.e. the land actually taken out from production. This can also have an effect on the results.

AES such as grassy field margins or wildflower strips are established to enhance biodiversity status *per se* and not directly to increase crop yield. These agri-environmental measures help to increase native plant species diversity and contribute to ecosystem services. However, according to Albrecht et al. (2020), farmers are often reluctant to accept these AES due to concerns of negative effects on crop yield, for instance, because of spillover of pests to crop. Albrecht et al. (2020) findings did not confirm such concerns since the authors found a generally positive effect of flower strips on pest control services. Still, these effects did not have a negative impact on higher yields.

Although our results indicated that out of production AES had lower compatibility index values and therefore showed potential higher yield loss than in-production AES, also out of production schemes have prospective for stabilising biodiversity loss with the conditions where produces do not lose the yield. Therefore, a better understanding of the mechanism is needed how to develop further these schemes that producers will get in the future profitable yield. For instance, Pywell et al. (2015) demonstrated no significant loss of yield of arable crops when up to 8% of cropped land was removed from production to create a wildlife-friendly habitat. The authors' results indicated that wildlife-friendly and out of production farming increased crop yield, but the effect appeared over the years where crop rotation has an important role. Pywell et al. (2015) provided evidence that the concept of ecological intensification of agriculture is achievable. Ecological intensification means to achieve environmentally sustainable increases in crop yields by enhancing ecosystem functions that regulate and support production. They demonstrated that yields at the field scale were maintained and enhanced despite the loss of cropland for wildlife-friendly habitat creation. Their results suggested that over a 5-year crop rotation, there would be no negative impact on yield in terms of monetary value. This study provides clear evidence that wildlife-friendly management, which supports ecosystem services in the agricultural landscape, is compatible with crop yields. The authors emphasized the importance of out of production AES supporting higher abundances of pollinators and natural enemies of aphids, thus increasing multiple ecosystem services.

Non-organic AES had a significantly lower mean compatibility index value, whereas organic farming had a non-significantly effect, where the mean value of the compatibility index was close to zero. This indicates a minimal trade-off between arthropods diversity and yield loss and is the evidence that production in organic farming conditions is sustainable, the producers lose rather a minimal yield and biodiversity status (arthropods species richness and abundance) is in good condition. This is very important finding since one of the biggest challenges globally, in the conditions where the human population is still growing, is to safeguard global food production. In a recent study by Knapp and van der Heijden (2018), the authors performed a global meta-analysis to assess temporal yield stability between organic and conservation farming. The authors found that organic agriculture has, per unit cropland yield, −15% lower temporal stability compared to conventional farming. However, organic farming supports more biodiversity (including arthropods) and is a more environmentally friendly farming practice in general. The authors highlight that future efforts should reduce organic farming yield variability and improve the quality. This helps to reduce the trade-off between biodiversity and yield and would probably be a win-win situation. According to Knapp and van der Heijden (2018), one option to reduce yield variability in organic farming is to use more organic fertilisers (including manure). However, the authors emphasise that this can negatively influence ground and surface water quality as well biodiversity as showed (Kleijn et al., 2009). Thus, well-planned organic practices are needed to support biodiversity, crop yield (quantity and quality), and environmental conditions.

There are also other possibilities to increase crop yield production in organic farming conditions. Ponisio et al. (2015) found that organic yields were 19.2% (±3.7%) lower than conventional farming yields. However, more importantly, the authors found different effects of management practices on the yield. Two agricultural diversification practices, multi-cropping and crop rotations, substantially reduced the yield gap (to 9 ± 4% and 8 ± 5%, respectively) when the methods were applied in only organic systems. These results also suggest that organic management systems could significantly reduce the yield gap compared to conventional farming.

In Ponisio et al. (2015) study, cereal crops exhibited the most remarkable difference in yield of the crop types between organic and conventional systems. The finding that cereal productivity (including common crops such as wheat, barley, maise, and rice) is lower in organic farms need more research because of its central importance in the human diet and predominance in cultivated land area. Historically, the research and development of organic farming have been extensively understudied compared to conventional farming. Also, our results confirmed this pattern since previously, in general, agroecological studies did not investigate the yield effect, and we had to exclude several potential studies. Thus, research priorities need to shift to fulfil this knowledge gap. Additionally, Ponisio et al. (2015) bring forth that only a few modern varieties have been developed to produce high yields under organic conditions. Hence, generating such new breeds would be an essential step towards reducing yield gaps between organic and conventional farming.

Sidemo-Holm et al. (2021) pointed out another aspect of yields in organic farms. The authors demonstrated that organic farming in cereals supports arthropods (bumblebees) by allowing more flowering weeds as food resources but, at a cost of lower crop yield. However, adjusting crop sowing density offers the chance to attain improved floral resources without negatively affecting crop yields. Thus, by increasing floral resources for pollinators as it is target in several out of production AES, and adjusting crop sowing density, may contribute to supporting pollinators densities, which enhance pollination services to wild plants as well insect-pollinated crops, such as oilseed rape, pea, beans, clover in agricultural landscapes.

6.3 Crop type

Seufert et al. (2012) performed meta-analysis to examine the relative yield performance of conventional and organic farming globally. Their analysis showed that, organic farms yields are typically lower than conventional farms yields, but yield differences are highly contextual, depending on crop type, local site and farming system characteristics (range from 5% to 34% lower yields in organic farms). However, under good management practices, particular crop types and growing conditions—organic farming can nearly match conventional yields. The cereal fields showed a higher yield gap, while forage crops, such as hay, tend to have smaller yield gap or even higher yields under organic farming (Seufert, Ramunkutty, 2017). Seufert et al. (2012) emphasize that organic farming as an important tool in sustainable food production and the factors limiting organic yields need to be more fully understood, alongside assessments of environmental, economic, and social benefits of organic farming.

Our results showed that on cereal fields compatibility index was significantly lower than in other investigated habitats (non-cereal fields). The majority of the studies, which fulfilled our study protocol, were carried out in cereal fields, and we found only a limited number of studies conducted in organic and conventional vineyards or apple orchards (Boinot et al., 2020, Campbell et al., 2017, Muneret at al., 2017, Porcrel et al., 2018). All these studies showed positive compatibility index mean values, which indicate that producing under AES conditions it is possible to get a similar or even better yield compared to conventional farming while arthropod diversity is safeguarded. The important findings of these studies are presented below.

Muneret et al. (2017) studied biological pest control in conventional and organic vineyards. The authors' results indicated that policies promoting the development of organic farming in conventional vineyard landscapes would not cause higher pest and disease infestations but rather will reduce the pesticide treatment intensity and maintain organic vineyards' crop productivity. Additionally, their results showed that increasing the area under organic farming did not cause the increase of pest infestation levels at the landscape scale. Moreover, the study showed that the interaction between semi-natural habitats in local and landscape farming practices suggests that organic farming deployment should also be adapted to landscape contexts. Our study indicated a similarly important landscape complexity effect (see below).

Porcel et al. (2018) carried out a diversity and yield study of arthropods in organic and conventional apple orchards. The authors evaluated the effect of organic farming on two ecosystem services provided by arthropods (biological control and pollination). They found that organic farming in apple orchards preserves the local natural enemy community (specifically predatory bug populations), essential for early aphid colony suppression. The study results indicated that local management options to eliminate or decrease pesticide use early in the season in conventional farming apple orchards would increase the biological control of aphids. This leads to a reduction in apple damage at harvest time. However, the authors' results on pollination success indicate that implementing organic farming at a local scale does not enhance pollination services for apple growers.

In contrast to our general finding, the compatibility index was not always lower in the cereal field and indicated "business as usual"– where biodiversity was higher in AES farms and yield in conventional farms. We also found several opposite examples (Geppert et al., 2020, Holzschuh et al., 2007, Marja et al., 2014, Sutter et al., 2018) where the compatibility index was higher than 0.5 in cereal fields. Thus cereal production in AES conditions is possible to get a similar yield as in conventional farming.

6.4 Landscape type

We found evidence that the compatibility index was significantly lower in simple landscapes, than in complex landscapes, where the index confidence intervals crossed the zero line. This indicated that biodiversity gain and yield loss from conventional farming are smaller in complex landscapes than in simple ones. Batáry et al. (2017) found a similar pattern in Germany, where the authors compared small-scale agriculture with a large one. Small-scale agriculture was presented with smaller fields, and therefore more complex landscape in former West Germany than larger area fields and a simpler landscape in former East Germany. The farmer's profit and revenue values and biodiversity status were higher in organic compared to conventional farms. Thus, our and previously Batáry et al. (2017) results indicate that there is evidence that in more complex landscapes, AES support biodiversity status, and the producers do not lose their yield. Highly likely in the more complex landscape where more edge habitats and semi-natural areas are available, this supports both pollinators as well other species, which provide biological control; hence both functional groups might support higher yields. On the contrary, Boetzl et al. (2020) results showed that edge effects significantly reduce yields, especially in small fields. Thus, the landscape structure effect for yields is not straightforward and needs more research based on the results of these two earlier studies.

Birkhofer et al. (2016) found lower aphid numbers and higher predation rate on aphids in organic farms, independent of landscape complexity, which directly contributed to higher yields in Sweden. Both farms that had been under organic management for shorter and longer times showed the expected higher yields with increasing predation on aphids. Still, conventional farms showed a decline in yield with raising predation on aphids. The authors' results indicate that higher predator abundances and changes in predator community composition may be related to the absence of synthetic pesticides under organic farming. Thus, natural biological control may compensate for the modern pesticide usage in conventional farms.

Dainese et al. (2019) did not directly investigate the AES effect for biodiversity and yield but also showed the importance of landscape structure effect for crop yield. The global synthesis (89 studies with 1475 locations) showed that delivery of pest control ecosystem services in agricultural fields depends on the composition of the surrounding agricultural landscape. The landscapes containing less semi-natural habitats provide lower pest control services and this consequence lower crop yield (Dainese et al., 2019). The authors emphasised that up to 50% of the negative effects of landscape simplification on ecosystem services was due to richness losses of service-providing natural enemies, with direct negative effects for crop yields.

The importance of the landscape structure was found also in earlier case study from England. Gabriel et al. (2013) emphasised that some aspects should be born in mind when interpreting

AES, arthropods, and yield results. The crop yield and biodiversity are affected by processes at different scales. Crop yield may depend more on local conditions, management type, crop variety, local climate, and soil conditions. Biodiversity is affected by wider spatial scale processes, for instance, surrounding landscape structure and longer temporal scales (for example, land-use history). The authors pointed out that there is the possibility to underestimate the negative impacts of conventional farming on local and larger-scale biodiversity.

A recent study from Switzerland showed that local establishments such as wildflower strips and hedgerows, combined with landscape-scale greening measures in agricultural landscapes, can promote multiple ecosystem services in conventional production systems (Sutter et al., 2018). Benefits to biodiversity from such local and landscape-scale measures may be maximised when these measures are combined. However, the authors found that enhanced natural pest regulation and pollination seem to contribute relatively little to crop yield improvement than common agricultural practices in the high-input conventional production system. Still, the study indicates that fields in landscapes with a higher share of greening measures had stronger natural pest control. The authors emphasise that additional research is needed to understand better local AES measures combined with landscape-level greening to promote multiple ecosystem services.

6.5 Indirect AES effects

AES can also have indirect positive effects on arthropods and yields. For instance, recent studies showed that AES reduces the spatiotemporal resource fluctuations for pollinators (Carrié et al., 2018, Marja et al., 2021). These studies indicated that AES could also indirectly affect the yield because AES increases floral resources and reduces food resource bottlenecks, thereby supporting pollinators who provide pollination services. Similarly, AES supports positively natural enemy richness and abundances (Gallé et al., 2020, Gayer et al., 2021, Porcel et al., 2018). Thus, AES increases the availability of floral resources in the agricultural landscape and therefore contributes to maintaining the within and between-year food resources stability of arthropods. AES areas can also be essential source areas where pollinators disperse to neighbour conventional farming areas providing better pollinator services as expected of the resource spillover hypothesis (Tscharntke et al., 2012).

6.6 Studies geographical coverage

Our study gave direct evidence about the knowledge cap between biodiversity and yield statuses in AES studies. We found only a limited number of studies with limited geographical coverage from Europe, which concurrently measures biodiversity and yield. Future agroecological studies will likely fill this knowledge gap more. Agricultural biodiversity is impossible to study outside productive areas (i.e. protected areas). Therefore, the yield aspect in future agroecological studies is highly needed. It is a significant future direction if the target is to support biodiversity status globally and stop its drastic decline, which occurred in the last half-century.

6.7 Future. Recommendations.

New AES studies must also consider yield besides the biodiversity aspect in further research. Currently, several effective AES are developed around the EU to support biodiversity. Still, if the yield amount (as well quality, profit or revenue) is not acceptable for producers, these schemes are highly likely unpopular. Also, better understanding and new research are needed between biodiversity and yield relationships. Undoubtedly, biodiversity conservation must also occur in agricultural landscapes, where, however, the main target is safeguarding food production. Therefore, directly comparing biodiversity (including ecosystem services) and food production across different agricultural management in the same locality would be necessary to develop future regional conservation planning (Katayama et al., 2019).

Beilouin et al. (2021) performed a meta-analysis to summarise the impacts of crop diversification, amongst others, for biodiversity and crop yield. Their study showed that crop diversification had a positive effect on biodiversity while having a neutral impact on crop yield. Thus, one potential AES or one requirement in AES can be a simple but effective tool to reduce biodiversity and crop yield trade-off. Chen et al. (2021) showed that increasing crop plant diversity due to intercropping (the simultaneous cultivation of more than one crop species on the same land) from monocultures over two- to four-species mixtures increased seed yield in mixtures compared with monocultures. Thus, if one AES requirement is growing multiple crops on the same field (three crops or more), it is possible to increase the yield. Tamburini et al. (2020) performed a second-order meta-analysis based on 5160 original studies globally to investigate agricultural diversification and its effects on biodiversity and yield. The authors found that, generally, diversification improves biodiversity, pollination, and pest control without compromising crop yields. Their results also indicated that agricultural diversification practices often resulted in win-win support of ecosystem services, including pollination and pest control as well concurrently crop yields. Thus, there is a lot of evidence on how to increase the yield in the agricultural landscape, including in AES farms as also indicated by our results.

7 Conclusion

Our compatibility index results indicated that AES and conventional farms had minimal trade-off between biodiversity and yield for both arthropods abundance and species richness. Therefore, there is a need for the area under AES to increase continuously in the future. In this way, highly likely biodiversity status will increase gradually, and the producers will accept more of the different methods and novel agricultural approaches to producing under AES or environmentally friendly conditions.

Further research is still needed on how agricultural production intensity is linked with biodiversity (including arthropods) as well as production yield. We have limited understanding and evidence between biodiversity, agricultural production, land-use intensity, and yield. The only sustainable solution for the future is to ensure that modern farming practices do not harm so drastically biodiversity as happened in the last half-century, and at the same time, the producers get profitable yields. After all, biodiversity conservation must also occur in agricultural landscapes, where the main target is to produce food.

We studied only yield quantity between AES and conventional farming. Future studies should also consider the yield quality between AES and conventional agriculture. There is currently very limited evidence about AES biodiversity studies where yield quality is also considered. In the majority of the cases, we found that yield was lower in AES than conventional farming. Similar results were also found in Batáry et al. (2017) in Germany in comparison of small- vs large-scale agriculture. The latest study also investigated farmers' profits. The authors found that revenue and profit were consistently higher in organic than conventional farms (small vs large-scale agricultural conditions). Thus, the yield quantity might not be the best indicator compared to agricultural profit for the producers and additional indicators might be needed.

Finally, better engagement, communication, and training of farmers will also be essential for delivering new and effective AES and wildlife-friendly approaches. Indeed, recent studies suggest that the training of farmers is highly effective in improving the agricultural habitat quality for biodiversity. This may translate to more significant benefits to crop yield (Pywell et al., 2015).

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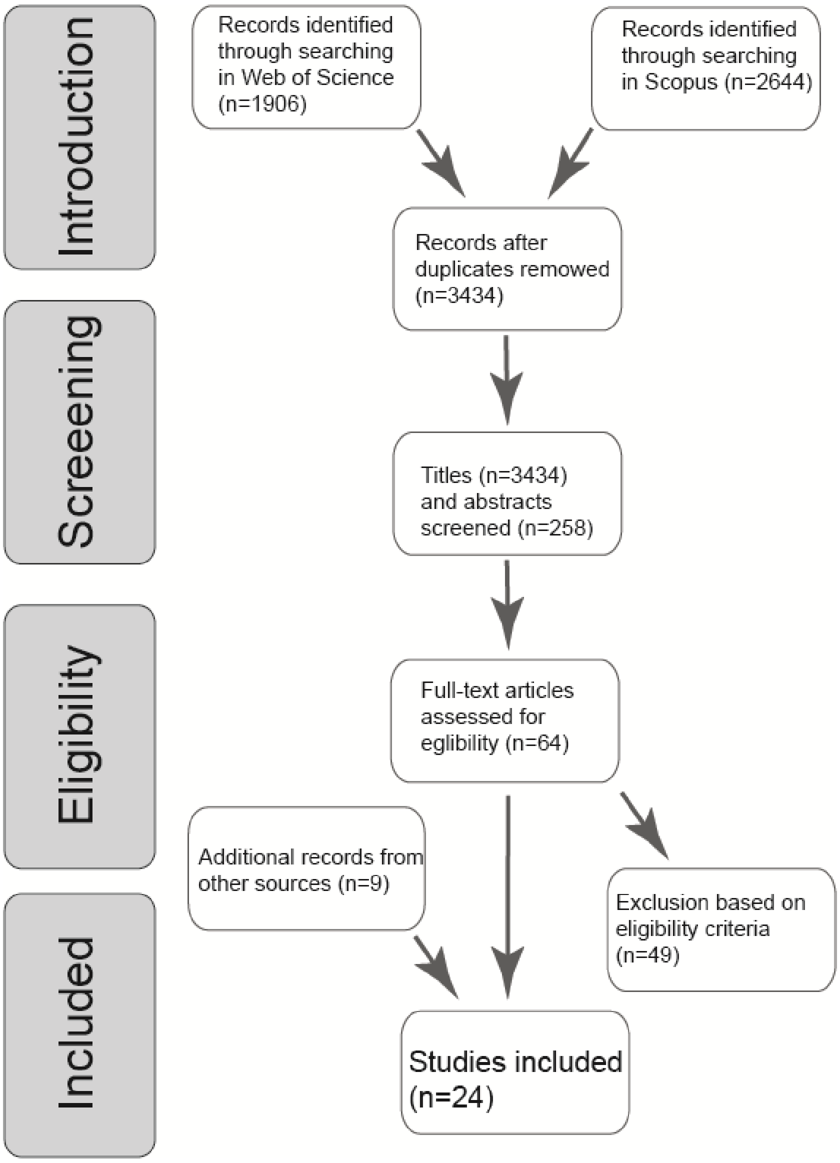
10 Supplementary data

Figure S1 PRISMA flow diagram representing the flow of information through the decision process (i.e. the number of studies identified, rejected and accepted).



List S2. The list of used studies for systematic review.

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Figure S2 Geographical coverage of used studies