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Geographic, Taxonomic and Metric Gaps in Biodiversity Research Limit Evidence-Based Conservation in Agricultural Landscapes: An Umbrella Review

Jonathan Bonfanti[1,2,3,4] | Joseph Langridge[3] | A. Avadí[5,6] | N. Casajus[3] | A. Chaudhary[7] | G. Damour[8,9] | N. Estrada-Carmona[10] | S. K. Jones[10] | D. Makowski[11] | M. Mitchell[12,13] | R. Seppelt[14,15,16,17] | Damien Beillouin[1,2,18]

[1]CIRAD, UPR HortSys, Montpellier, France | [2]HortSys, Univ Montpellier, CIRAD, Montpellier, France | [3]FRB-CESAB, Fondation pour la Recherche sur la Biodiversité–Centre de Synthèse et d'Analyse sur la Biodiversité, Montpellier, France | [4]Eco&Sols, Univ Montpellier, CIRAD, INRAE, Institut Agro, IRD, Montpellier, France | [5]CIRAD, UPR Recyclage et risque, Yamoussoukro, Côte d'Ivoire | [6]Recyclage et risque, Univ Montpellier, CIRAD, Montpellier, France | [7]Department of Civil Engineering, Indian Institute of Technology (IIT), Kanpur, India | [8]CIRAD, UPR GECO, Montpellier, France | [9]GECO, Univ Montpellier, CIRAD, Montpellier, France | [10]Bioversity International, Parc Scientifique Agropolis II, Montpellier, France | [11]Université Paris-Saclay, INRAe, AgroParisTech, Palaiseau, France | [12]Department of Forest Resources Management, Faculty of Forestry, University of British Columbia, Vancouver, British Columbia, Canada | [13]Faculty of Land and Food Systems, University of British Columbia, Vancouver, British Columbia, Canada | [14]Luxembourg Centre for Socio-Environmental Systems (LCSES), University of Luxembourg, Belvaux, Luxembourg | [15]Department of Computational Landscape Ecology, Helmholtz Centre for Environmental Research–UFZ, Leipzig, Germany | [16]Martin Luther University Halle-Wittenberg, Institute of Geoscience & Geography, Halle (Saale), Germany | [17]German Centre for Integrative Biodiversity Research (iDiv), Halle-Jena-Leipzig, Leipzig, Germany | [18]Cirad, UPR HortSys, Le Lamentin, Martinique, France

Correspondence: Jonathan Bonfanti (jonathan.bonfanti@gmail.com) | Damien Beillouin (damien.beillouin@cirad.fr)

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ABSTRACT

Agriculture is fundamentally dependent on biodiversity, yet unsustainable management practices increasingly threaten various organisms and ecosystem services. Confronting the global crisis of biodiversity loss requires a thorough understanding of the gaps, clusters and biases in existing knowledge across various management practices, spatial scales, and taxonomic groups. We undertook a comprehensive literature review, synthesising secondary data from 200 meta-analyses on agricultural management impacts on biodiversity in croplands. Our systematic map covers 1885 comparisons (mean effect sizes), from over 9000 primary studies. In the latter, seven high-income countries prevail (notably the USA, China and Brazil), with particular focus on fertiliser use, phytosanitary interventions and crop diversification. This emphasis on individual practices overshadows research at the farm and landscape levels. In secondary evidence, arthropods and microorganisms are most frequently studied, while annelids, vertebrates and plants are less represented. Evidence predominantly stems from averaged abundance data, revealing substantial gaps in studies on functional and phylogenetic diversity. Our findings highlight the need to analyse combinations of multiple practices to accurately reflect real-world farming contexts, and covering a wider range of taxa, biodiversity metrics and spatial levels, to enable evidence-based conservation strategies in agriculture. Given the uneven evidence on agricultural impacts, caution is required when applying meta-analytical findings to public policies and global assessments.

1 | Introduction

Human alteration of the Earth's land surface is substantial and growing (Winkler et al. 2021). Therefore, managing sustainably agricultural land—the world's largest managed biome—is crucial for preserving biodiversity and its vital contributions to people at local and global scales (Campbell et al. 2017; IPBES 2019). While conservation-focused practices such as habitat preservation and low-input approaches generally yield positive biodiversity impacts (Beillouin et al. 2021; Estrada-Carmona et al. 2022; Newbold et al. 2015; Tamburini et al. 2020), evidence suggests that unsustainable agricultural management practices continue to threaten the long-term conservation of various species globally, in particular, vertebrates (Rigal et al. 2023), invertebrates (Raven and Wagner 2021), and plant species (Biesmeijer et al. 2006; Dorrough and Scroggie 2008). Agriculture's negative impacts can occur at localised or broader scales and may vary depending on the species, biome, and specific practices employed (Cozim-Melges et al. 2024; Rocha-Ortega et al. 2021; Troudet et al. 2017). Ensuring that areas under agriculture are managed through the sustainable use of biodiversity and innovative agroecological approaches (in line with Target 10 of the Global Biodiversity Framework—GBF) is a major societal challenge. Actions planned to achieve the GBF targets should be based on robust and comprehensive scientific evidence.

Political and economic incentives can lead to rapid changes in agricultural land use, providing a means for decision-makers to improve conditions for biodiversity relatively quickly. However, poorly designed incentives, including those based on inaccurate estimates of biodiversity benefits, can fail to achieve desired environmental outcomes (Piñeiro et al. 2020). Illustrating the dynamics of land-use change and management practices across scales is critical in order to enable the design of effective incentives for halting biodiversity loss and restoring ecosystem functioning. But with thousands of primary research papers published each year documenting land use and agricultural management effects on biodiversity, expecting stakeholders to assimilate such extensive information for more informed decision-making is unrealistic. Attempts to address this issue are evidenced by a surge in first-order meta-analyses focused on agricultural practices effects on biodiversity in recent years (e.g., Beckmann et al. 2019; Estrada-Carmona et al. 2022; Jones et al. 2023). Policy decisions can benefit from such meta-analyses, as they offer expedited access to synthesised findings from a significant body of literature on specific topics (Kavale and Forness 2000; Miteva et al. 2012; Haddaway et al. 2020).

Although the number of meta-analyses on the effect of agricultural practices on biodiversity continues to increase, substantial variability in their scope—for example, taxonomic focus, intervention type, and geographical coverage—makes it challenging to draw clear and reliable conclusions (Koricheva and Gurevitch 2014; Beillouin et al. 2021). This diversity in study design and methodology often leads to conflicting results, undermining the ability to synthesise evidence effectively. Furthermore, certain taxa (Troudet et al. 2017), management practices, or regions may be over-represented in the literature, while others remain underrepresented, creating an imbalanced knowledge base. This skewed representation may fail to reflect the practical realities faced in the field. Ultimately, this impedes the communication of actionable insights and makes it difficult for policymakers and practitioners to implement informed, evidence-based decisions.

To provide a comprehensive perspective of current biodiversity research in croplands, we present a systematic map of secondary research that organises and visualises the distribution and extent of meta-analyses across agricultural practices, taxonomic groups, and geographical regions. Systematic maps prioritise comprehensiveness by following rigorous guidelines and standards developed by review coordinating bodies (see Collaboration for Environmental Evidence 2022). Therefore, unlike other forms of evidence synthesis, such as meta-analyses or scoping reviews, they exhaustively highlight trends, gaps, and biases, reliably identifying underexplored areas and objectively offering clear insights to guide future research and inform policymakers (Arksey and O'Malley 2005; Colquhoun et al. 2014).

We hereby present a detailed and comprehensible overview of the existing research landscape through a dataset that is over seven times larger than that of Babin et al. (2023), while favouring objectivity, transparency, and reproducibility to ensure reliability. As evidence-informed decision-making is our end goal, this synthesis identifies five key priorities for future research, offering essential guidance for policymakers and researchers to direct funding and shape future primary studies, while encouraging a more nuanced interpretation of existing meta-analytic evidence.

2 | Material and Methods

2.1 | Literature Search and Study Selection

We conducted a comprehensive systematic literature search in Web of Science Core Collection (WOS), Scopus, Ovid, and Google Scholar to retrieve peer-reviewed meta-analyses on the impacts of agriculture on biodiversity published in English or French, in September 2022 (see PICOC framework used in Table S1, the search strings used in Table S2). The search yielded 4154 records after removing duplicates (Figure S1).

All agricultural management practices (i.e., interventions) impacting biodiversity (i.e., study populations) at the field, farm, or landscape level (i.e., context) were retained (for intervention definitions, see Table 1). All relevant biodiversity metrics (e.g., abundance, biomass, richness), from which the impacts of an intervention can be reliably demonstrated, were retained. Lastly, all effect size indices (e.g., odds ratio, Hedges' g, Cohen's d) that quantify the magnitude and direction of the effect of an intervention on the study population were retained.

We undertook a two-stage screening process on all records in Abstrackr (Wallace et al. 2012). Firstly, article titles and abstracts were screened, and any clearly irrelevant articles were removed. Secondly, the full texts of all remaining articles were screened. Articles were retained based on the following eligibility criteria: (i) the article qualifies as a meta-analysis, defined here as a quantitative synthesis of experimental results (paired-data)

TABLE 1 | A list of agricultural management definitions used in the review process for post-classifying interventions.

Intervention group	Intervention	Definition(s)
Individual practice	Agroforestry	A farming practice in which at least one woody perennial (e.g., trees, shrubs) species is deliberately grown on the same land-management units as crops (Beillouin et al. 2019).
	Crop diversification	Agricultural practices leading to increasing crop diversity in a field in space and/or time. This could include longer rotations, addition of cover crops, multiple cropping, cultivar mixtures, or intercropping (Beillouin et al. 2019).
	Fertilisers and Soil amendments	Methods used to improve the supply of essential elements (mainly nitrogen, phosphorus, and potassium) to plant growth by chemical or organic external inputs (FAO 2024).
	GMO	Genetically modified organisms, here a crop in which one or more changes have been made to the genome, typically using high-tech genetic engineering (e.g., Bt-Bacillus thuringiensis - maize) (FAO 2024).
	Pest and disease management	Any chemical, physical, or other type of agricultural practice that aims to directly prevent pests and diseases from affecting a crop (FAO 2024).
	Residue management	Any agricultural practice that relates to the fate of materials remaining in the field after crop harvest (e.g., residues retention) (FAO 2024).
	Tillage management	Any soil mechanical cultivation practice (e.g., low-till) (FAO 2024).
	Water management	Practices used for maintaining crop water supply.
Agricultural system	Combined practices	Combination of at least two individual practices used simultaneously in the same field.
	Conservation agriculture	A farming system based on the simultaneous maintenance of a permanent soil cover, minimum soil disturbance, and diversification of plant species (FAO 2024).
	Organic agriculture	A farming system defined by official standards based on agricultural practices which, among others, exclude the use of synthetic biocides and fertilisers, and the use of genetically modified organisms (GMOs) (FIBL and Forschungsinstitut für biologischen Landbau 2021).
Landscape	Landscape complexity management	Specific landscape patterns and characteristics encompassing configuration, heterogeneity, or composition of an agricultural landscape (Estrada-Carmona et al. 2022).
	Land-use change	Any modification of the purpose or function for which a particular area of land is used over time. Here, any conversion from cropland to any other land-use (e.g., forest land, grassland, wetlands, settlements) and vice-versa (IPCC 2003).

from multiple primary studies that applies established meta-analytic methods (e.g., estimation of effect sizes, weighting by inverse variance or sample size)—secondary research using only descriptive aggregation or unweighted averages without statistical synthesis were excluded-, (ii) the meta-analysis quantifies the effect of any agricultural management practice in croplands on biodiversity, (iii) the article is written in English or French. Lastly, no date or geographical restrictions were applied. The final database, its structure as well as the systematic review methodology were extensively described in Bonfanti et al. (2023).

2.2 | Data Coding and Evidence Mapping

We characterised the evidence based on the number of (i) meta-analyses, (ii) effect sizes (i.e., overall estimate of an intervention's impact on a specific outcome compared to a control,

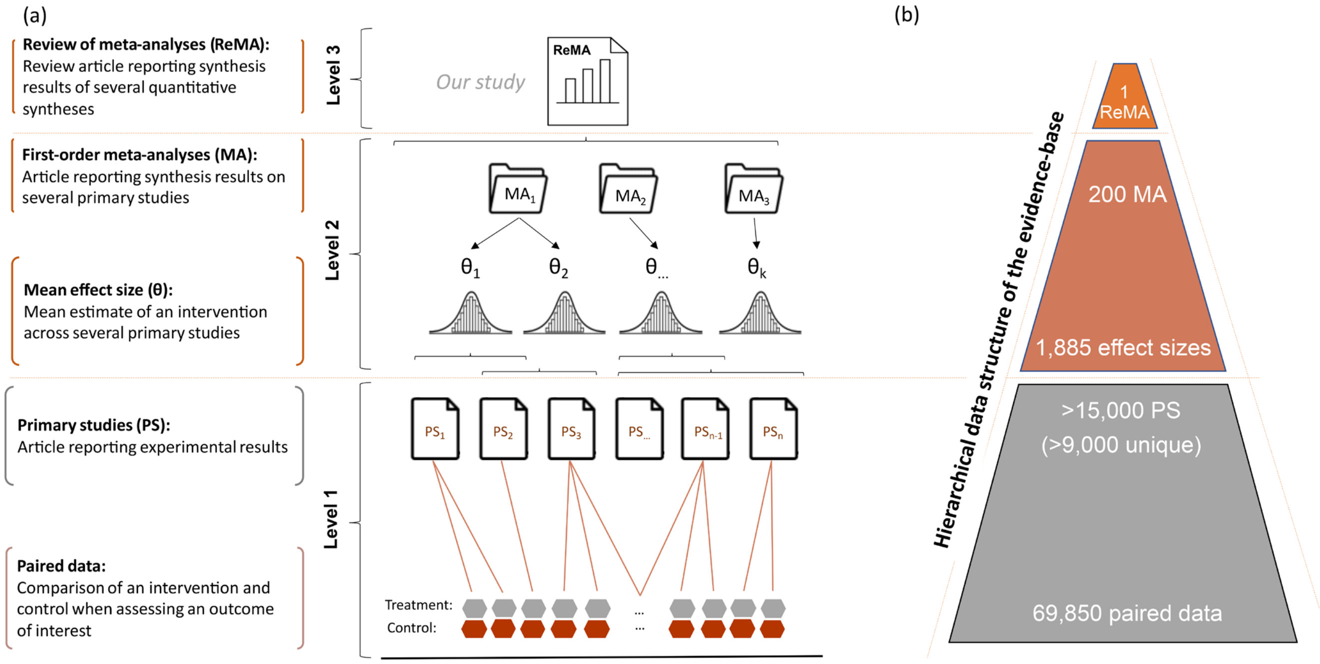

FIGURE 1 | A conceptual representation of (a) our umbrella review and (b) the multi-level nature of the evidence base. At the lowest level (level 1), the individual primary studies report one or several paired data comparisons on an outcome of interest. At level 2, meta-analyses report one or several mean estimates (i.e., effect size) of an intervention across several primary studies. Level 3 is a descriptive state of the art (i.e., a systematic map) of 200 meta-analyses quantifying a measure of impact of an agricultural practice on biodiversity. These meta-analyses presented 1885 effect sizes from 69,850 paired data reported in > 15,000 total primary studies, of which > 9000 primary studies are unique (i.e., one primary study could be used in several meta-analyses).

derived from multiple primary studies), (iii) paired data (i.e., comparative outcome data obtained from a matched control and treatment group) and (iv) primary studies (Figure 1).

We extracted and assigned the highest available taxonomic resolution to each effect size based on the information in the retained meta-analyses, and using the Catalogue of Life (COL) classification (Bánki et al. 2024). We thus mapped study populations first to (1) kingdom (e.g., *Animalia*), (2) phylum (e.g., *Arthropoda*), (3) class (e.g., *Insecta*) and (4) order level (e.g., *Hymenoptera*). When authors mentioned an ecological group *sensu lato* (e.g., feeding guilds within nematodes), this information was coded (Figure S4). We compared taxonomic group occurrences in our dataset against those reported in biodiversity-focused scientific literature reported in Mammola et al. (2023). The latter analysed a randomly sampled subset (ca. 10%) of all articles listed in Web of Science mentioning 'biodiversity' in their title, notably in terms of geographical focus and biodiversity facets investigated. To perform the comparison, we mapped Mammola et al. (2023) occurrences of terrestrial taxa to a comparable taxonomic resolution (according to COL), that is, at a kingdom level for microorganisms and plants, and at a phylum level for animals.

Each effect size was assigned a biodiversity metric: abundance, activity, biomass, phylogenetic diversity, taxonomic diversity, taxonomic richness, trait-based, or 'multiple metric'. If a meta-analysis quantified the biodiversity response using more than one metric, we extracted data for each metric. When a meta-analysis presented subgroup analyses by taxa or other moderators (e.g., climate type, soil parameters), we extracted the effect size with the highest taxonomic resolution to avoid redundancy in our database. The interventions associated with each extracted effect size were coded and categorised into three main groups: (i) individual practices, (ii) agricultural systems and (iii) landscape-level practices (Table 1). We categorised the various effect size indices into six main types (Borenstein et al. 2009): mean difference, standardised mean difference (e.g., Hedge's g), response ratio (e.g., Ln(RR)), odds ratio, and correlation regression (see Figure S6).

We extracted the references of all primary studies used in each meta-analysis. The unique digital object identifier (DOI) associated with each primary study was used to identify the list of unique primary studies. For each primary study, we extracted information using text-mining techniques, based on a predefined keyword list, on the study location (i.e., country) and the type of agricultural management practice. The results were then checked manually to ensure the reliability of the extracted information. Country names and agricultural practices were extracted either from the title, the abstract, or the material and methods section. Agricultural practices were coded and categorised using the same method as the effect sizes (Table 1). Among the 9080 unique primary studies, 5600 provided enough information to code the location.

All graphical representations were performed in the R environment (version 4.3.1, R Core Team 2021), notably using the packages tidyverse (Wickham et al. 2019), ggplot2 (Wickham 2016) and in RAWGraphs (Mauri et al. 2017).

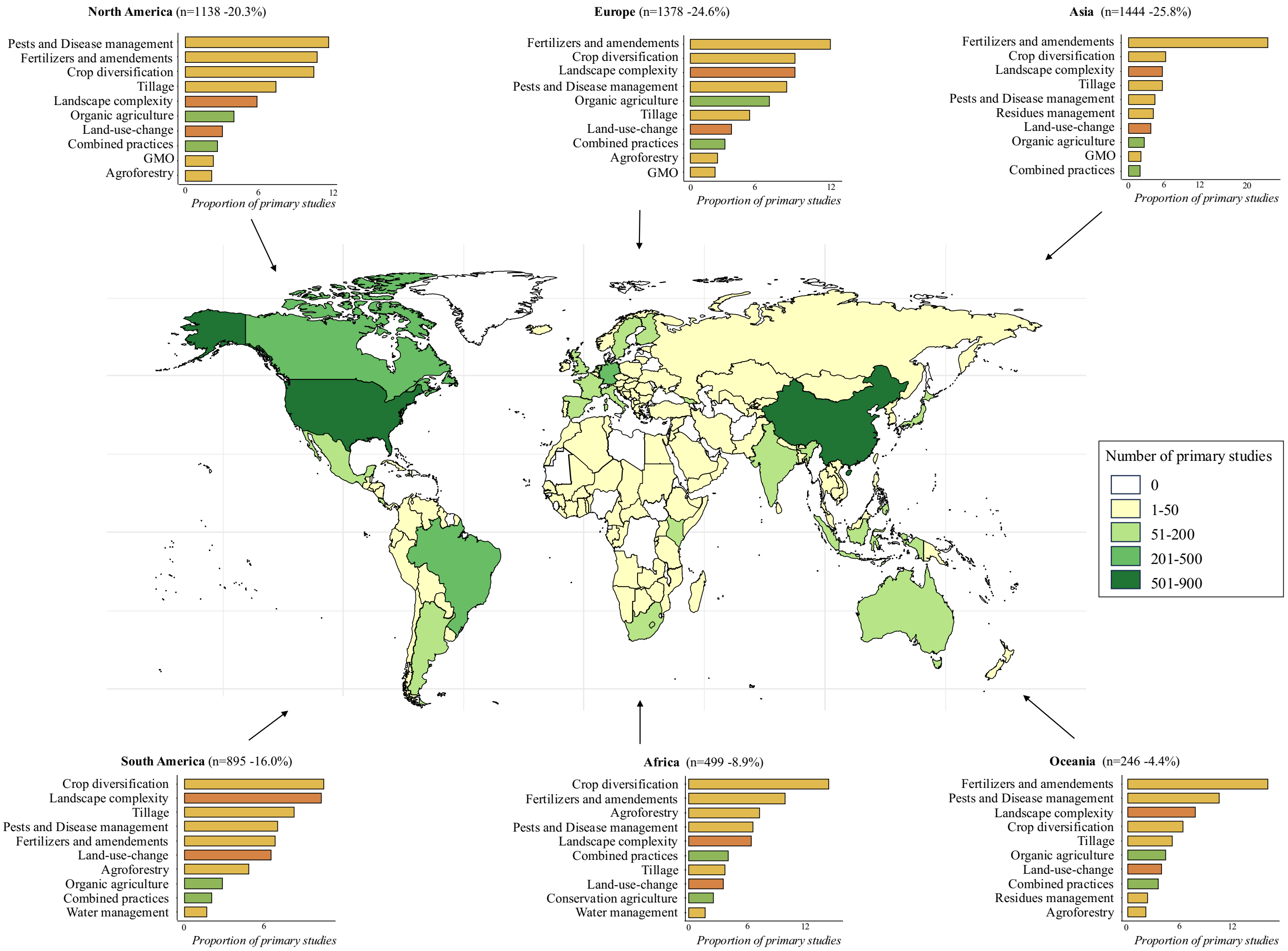

FIGURE 2 | Locations of the primary studies included in the 200 meta-analyses and the top 10 agricultural interventions analysed by world region. Some meta-analyses did not provide the references of their original studies, and the full text or locations of some primary studies were not available, thus not accounted for. Among the 9080 unique primary studies, 5600 provided enough information to code the location. In the barplots, yellow bars: Field-level practices; green bars: Farm-level practices; orange bars: Landscape-level practices (see Table 1 for definitions).

3 | Results

3.1 | High-Income Countries Dominate Primary Studies of Agricultural Impact on Biodiversity

Our review identified 200 meta-analyses published between 1994 and 2022 covering *ca*. 9000 unique primary publications (and ca. 15,000 non-unique references) resulting in 1885 effect sizes (Figure 1). The primary data synthesised in the meta-analyses originate from studies conducted all over the world (Figure 2), but evidence is uneven. For instance, Asia contributed 25.8% of the primary studies with accessible information on location, followed by Europe (24.6%), North America (20.3%) and South America (16.0%). Less than 10% of the primary studies originate from Africa and Oceania. Seven high-income countries contributed to more than 50% of the primary studies with information on locations from the USA (891 studies), China (845), Brazil (347), Canada (266), Germany (244), Australia (197) and Spain (190). Fertilisers and organic amendments emerge as the most extensively prevalent practices studied, featuring as the top two most studied practices in five out of six world regions. Crop diversification consistently ranks among the top four most studied practices, with cover crops, crop rotations, and intercropping being the main practices, comprising approximately 50%, 25% and 7% of studies, respectively. Tillage is in the top four practices in four out of six world regions. Globally, more primary studies have assessed landscape complexity than land-use change, and organic agriculture is more frequently studied than combined practices or conservation agriculture across regions. Our review uncovers regional specificities in agricultural research. For instance, the effects of agroforestry systems are more frequently investigated in Africa and South America than in other regions, while pest and disease management receives more attention in North America and Oceania.

3.2 | Agricultural Inputs, Phytosanitary Interventions, and Crop Diversification Dominate in Evidence Syntheses

Our study shows that evidence from synthesis research is skewed towards studying the effect of individual practices at field scale, with these representing six times (×6.4) more effect sizes than agricultural system-level interventions, and

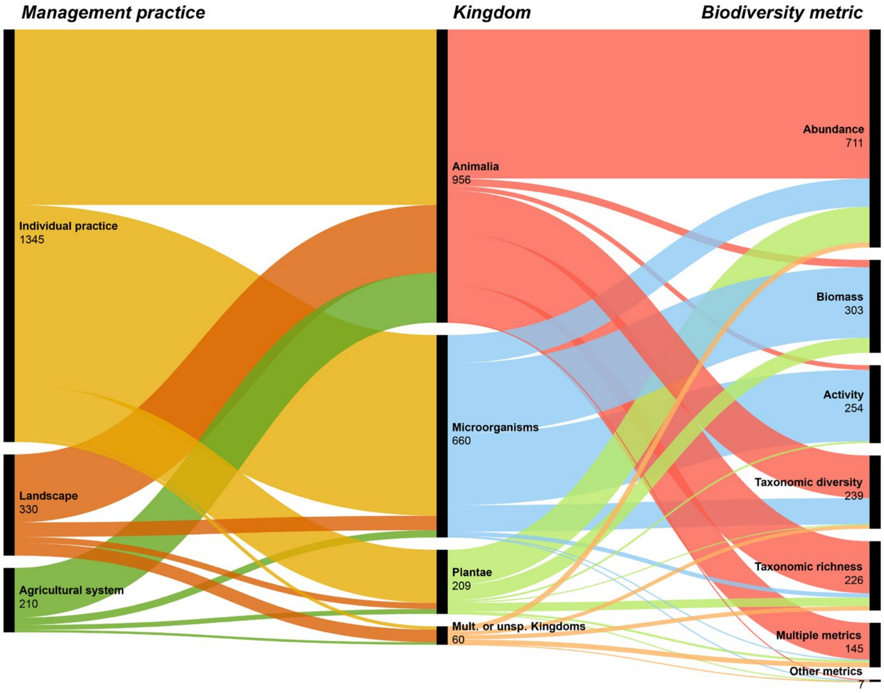

FIGURE 3 | Alluvial diagram showing the distribution of effect sizes across agricultural interventions (left bar), taxa at the kingdom level (middle bar), and biodiversity metrics (right bar) for the 200 meta-analyses studying the effects of agricultural interventions on biodiversity. Each bar represents the 1885 effect sizes of our database, subdivided into categories whose width is proportional to the number of data it contains. The width of the flows between the categories is proportional to the number of primary studies examining each combination of agricultural interventions, taxa, and biodiversity metrics. For example, 1345 effect sizes focus on 'individual practices,' from which 572 examined impacts on Animalia, 589 on microorganisms, and 173 on Plantae. For clarity, on the middle bar: 'Archaea' ($n=3$) were grouped within 'Bacteria', and 'Chromista' ($n=3$) were grouped within 'Fungi'. On the right bar: 'Other metrics' refers to 'Phylogenetic diversity' ($n=3$) or 'Trait-based' ($n=4$) metrics. 'Multiple metrics' indicates effect sizes aggregating multiple or unspecified biodiversity metrics.

four times (×4.1) more than landscape-level (Figure 3). The gap in evidence is even larger when we look at the number of primary studies rather than the effect sizes: we observe 11.4 times more studies focused on individual practices compared to agricultural systems, and 4.92 more compared to landscape factors. In meta-analyses focusing on individual practices, the spotlight is on practices related to inputs such as fertilisers and amendments, and residue retention (440 effect sizes in total, accounting for 32% of the effect sizes data related to individual practices). Following closely are phytosanitary interventions, including pest and disease treatments and GMOs represented by 369 effect sizes in total (27%). Practices related to on-farm diversification strategies, for example agroforestry and crop diversification, represent almost one third of the total effect sizes assessed (373 effect sizes in total; 28%). Less studied practices include tillage, represented by one-tenth of effect sizes (161 effect sizes, 12%) (Figures 2, 3). Regarding landscape-level interventions, syntheses focus primarily on the effect of land-use change (273 effect sizes) and less commonly on landscape complexity (57 effect sizes). We show an inverted hierarchy when focusing only at the primary studies level, that is, more studies focus on landscape complexity than land-use change (Figure 2). Finally, agricultural-system level practices are mainly represented by organic agriculture interventions (142 effect sizes), followed by combined practices (57 effect sizes) and conservation agriculture (11 effect sizes). Water management is scarcely addressed.

3.3 | Insects, Birds, and Abundance Outcomes Prevail in Evidence Syntheses

Synthesis research reveals a strong taxonomic bias. Animalia accounts for half of the available effect sizes (50.5%) (Table 2, Figure 3). Within this group, arthropods represent 46.5% of effect sizes, of which 61.0% are insects, 10.0% arachnids, and 26.8% other or unspecified arthropods (Table 2). Nematodes, Vertebrata, and Annelids are significantly underrepresented compared to Arthropods, by factors of 2.2, 4.7 and 18.5, respectively; similar trends exist for paired data. Moreover, 67% of effect sizes within vertebrates concern only birds. Among other kingdoms, Plants contribute 11.1% of all effect sizes, followed by Fungi at 5.6% and Bacteria at 4.7%, with the remaining one-quarter of the available effect sizes (24.3%; 459 effect sizes) not assigned to a single kingdom because the data concern several or unspecified taxa (Table 2).

The taxonomic resolution of the effect sizes largely differs between Kingdoms (Figure 4). Microorganisms had low taxonomic resolution, often summarised through non taxa-specific

TABLE 2 | Distribution of evidence in terms of taxonomic structure (Kingdom and Phylum levels).

Kingdom	Phylum	Groups used in Figure 3	Groups used in Figure 5	# effect size	# paired-data	# meta-analyses[a]
Animalia	Annelida	Animalia	Annelids	24	530	6
	Arthropoda		Arthropods	445	12,184	56
	Chordata (Vertebrata)		Vertebrates	138	1220	27
	Nematoda		Nematodes	195	6798	11
	ND		Mult. or unsp. Animals	155	6599	35
Archaea	ND	Microorganisms	Bacteria	3	52	1
Bacteria	Actinobacteria			19	637	8
	Acidobacteria, Bacteroidetes, Chloroflexi, Firmicutes, Proteobacteria			9	593	3
	ND			61	2893	18
Chromista	Oomycota		Fungi	3	27	2
Fungi	Ascomycota			10	1055	2
	Basidiomycota			6	193	3
	ND			90	3183	26
ND (microorganisms)	ND (microorganisms only)		Mult. or unsp. microorganisms	458	23,172	70
Plantae	Tracheophyta	Plantae	Plants	92	2043	7
	ND			117	3789	31
ND	ND	Mult. or unsp. Kingdoms	Mult or unsp. Kingdoms	60	4873	19

Note: Mult.or.unsp.: Multiple or unspecified, that is, some effect sizes could not be attributed to a single taxonomic group.
[a]One meta-analysis may provide several effect sizes belonging to several taxonomic groups.

metrics (e.g., microbial biomass carbon). When Bacteria or Fungi kingdoms were identified, few effect sizes were characterised at a higher resolution. Taxonomic resolution of plants was also generally low, with 44% effect sizes classified at phylum level, and the majority of all plants falling under the 'weeds' functional group designation (80%) (Figure S4). Animalia was the most detailed kingdom, with 84% of effect sizes detailed at phylum, 51% at class and 32% at order level. Note that for animals, when the taxonomic resolution was very low (i.e., kingdom level), an ecological group was given in 76% of the effect sizes (e.g., 'feeding guilds' in different groups, 'functional groups' such as pollinators, natural enemies).

We identified eight metrics used in the assessed reviews. Abundance was the most frequently used metric for biodiversity (38% of all effect sizes), especially for plants, unspecified or multiple invertebrates, nematodes, and insects (Figures 3, 5). Biomass (16%) and activity (13%) metrics were dominant for microorganisms. Taxonomic diversity and richness were less frequently used (13% and 12%, respectively), but were common for animal taxa, such as insects and nematodes. Phylogenetic diversity and trait-based indices were rarely employed (< 1% each) in the retained meta-analyses.

In addition, our results on taxa occurrences align somewhat with global biodiversity patterns, that is, Mammola et al. (2023) concerning animals in general (Figure 6). However, within animals, arthropods and nematodes are over-represented in syntheses on biodiversity in agroecosystems (our database) by approximately a factor of 2 and 10, respectively, while vertebrates are under-represented by a factor of 2 relative to Mammola et al. (2023). In general, microorganisms are over-represented in agrobiodiversity syntheses (×3)

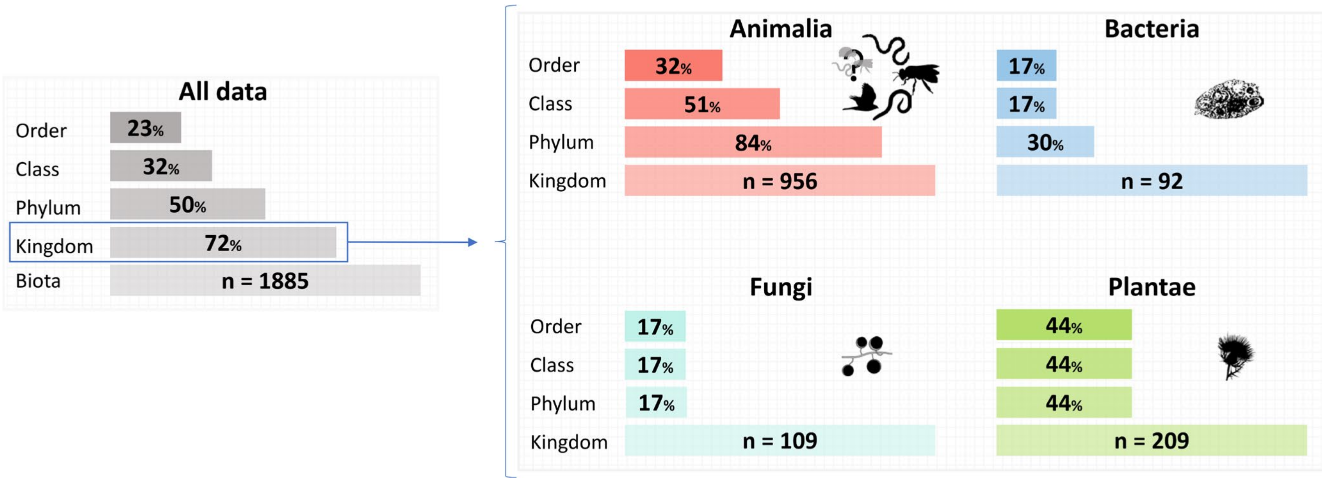

FIGURE 4 | Taxonomic resolution for each major Kingdom and for the total 1885 effect size data. The total number of effect sizes per Kingdom is depicted at the bottom of each plot, while the available information at lower taxonomic ranks is represented as a percentage of the total effect sizes.

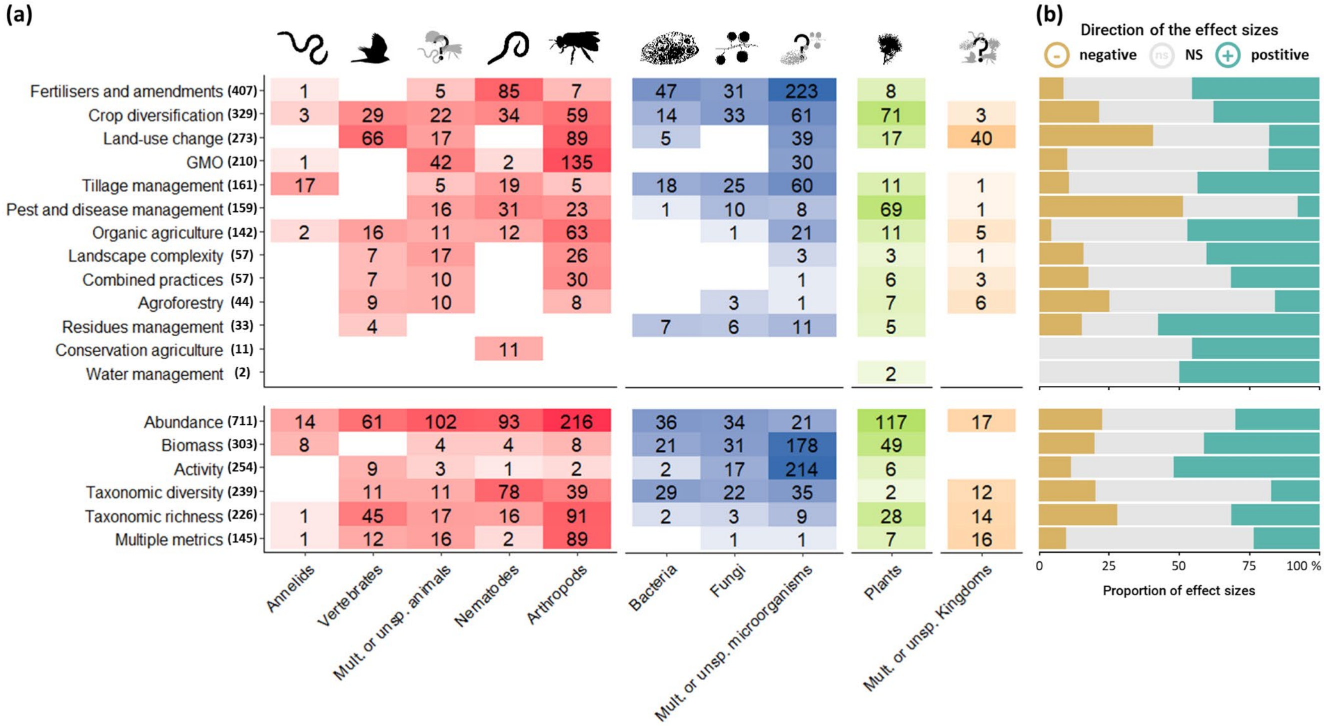

FIGURE 5 | Evidence map of the 1885 effect sizes extracted from the 200 meta-analyses: (a) heatmap representing the number of effect sizes by agricultural management practice (*y*-axis, top) and biodiversity metric (*y*-axis, bottom), and for each taxonomic group (*x*-axis); (b) stacked bar chart (in %) representing the direction of the effect sizes by agricultural management practices and biodiversity metrics (*y*-axis, as in panel a), for all taxonomic groups (see also Figure S7 for min-max range of the mean effect size values). In panel a, tile labels and colour intensity represent the number of effect sizes. Taxonomic groups are presented at Kingdom level, except animals at Phylum level (see Table 2). For clarity, Archaea are grouped with Bacteria, Chromista are grouped with Fungi, and effect sizes depicting phylogenetic and trait-based metrics ($n = 7$ in total) are not shown. The number in parentheses on the x-axis represents the total number of effect sizes for each management practice and biodiversity metric. Tile colours: Red for animals, blue for microorganisms, green for plants, orange for multiple or unspecified kingdoms.

and plants receive much less focus (4 times less). Other taxa such as Mollusca, Platyhelminthes, and Protozoa are absent from our dataset but are the focus of respectively 0.7%, 0.1% and 0.1% of the primary studies in the general biodiversity literature; Chromista is characterised in 3 effect sizes in our dataset but absent in Mammola et al. (2023).

3.4 | At Least Half of the Evidence Is Missing on Agricultural Intervention Impacts on Biodiversity

Combining results on agricultural practices and biodiversity outcomes, our study reveals that 47 out of 130 theoretically possible combinations between agricultural interventions' effects

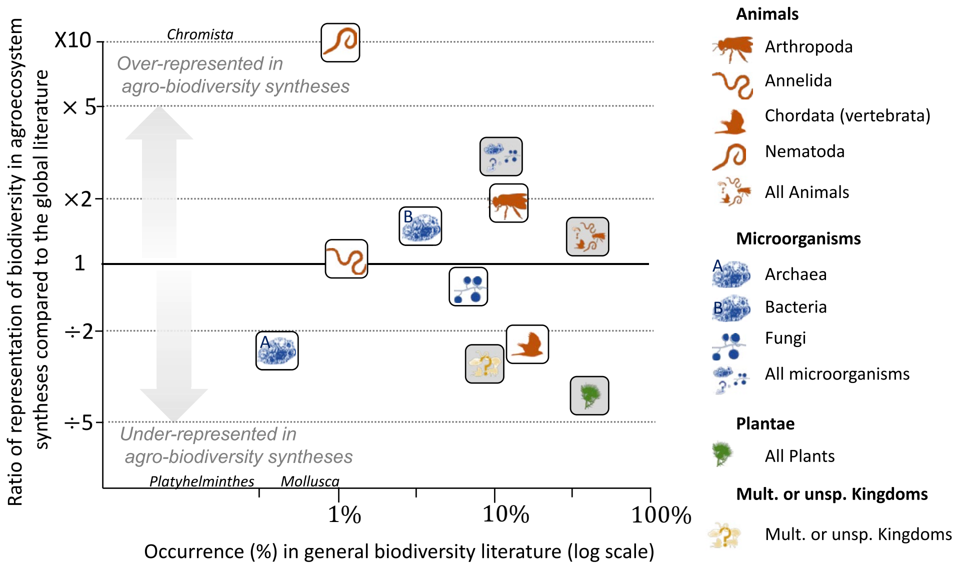

FIGURE 6 | Over- or under-representation of taxonomic groups in syntheses on biodiversity in agroecosystems (our study) compared to the general biodiversity literature (data from Mammola et al. 2023). The y-axis represents the ratio between the percentage of occurrence of each taxonomic group in both studies, the *x*-axis represents the percentage of occurrence of taxonomic groups in Mammola et al. (2023) after harmonisation with respect to the Catalogue of Life classification. The four major groups (see Figure 3, Table 2) are presented with grey background boxes, and detail is given with white background boxes. Microorganisms are detailed at Kingdom level and animals at Phylum level. When no box is drawn, the group is absent from one of both studies, that is, Chromista is absent from Mammola et al. (2023), Mollusca and Platyhelminthes are absent from our study. For clarity, Protozoa and Algae are hidden behind Platyhelminthes and Mollusca, respectively. Raw data are given in Table S3.

on specific taxonomic groups have not been studied in any meta-analysis, while 18 combinations are filled with three or fewer effect sizes (Figure 5a). Most effect sizes represent the same intervention-outcome combinations, for example, the effect of fertilisers and amendments on microorganisms, crop diversification on plants and microorganisms, or genetically modified organisms on insects (Figure 5a). As a result, almost no information is available on some potentially important agricultural drivers of biodiversity loss, for example, the effect of land-use change on underground biodiversity, or of crop diversification, tillage, agroforestry, and organic agriculture on herptiles, mammals. Water management impacts on all taxa are considerably understudied.

Furthermore, the analysis of the direction of the effect of the different intervention categories revealed considerable variability and a mixed distribution of effects (Figure 5b, Figure S7). Each category consistently included a combination of positive, neutral, and negative outcomes, often in proportions that hinder straightforward conclusions about the overall average effect, likely reflecting the complex, dynamic and context-dependent interactions between species, functions and ecosystems. The observed effects may also vary depending on the statistical power of the data, which is directly influenced by the number of studies or data points included in the meta-analyses. A larger sample size generally enhances statistical power, reducing uncertainty and yielding more precise effect estimates. Conversely, meta-analyses with fewer studies (i.e., smaller sample sizes) may result in higher variability and less robust conclusions, potentially biasing the interpretation of effect sizes (Figure S8). This variability underscores the need for a more nuanced exploration of regional contexts, taxa-specific responses, and subcategories of interventions. Among the categories, pest and disease management and residue management represent two contrasting cases: the former showed the highest proportion of negative effects (50%), while the latter exhibited the highest proportion of positive outcomes. The diversity of effects, coupled with the disparity in data availability across categories, highlights the challenges in drawing clear, generalisable conclusions.

4 | Discussion

The 200 meta-analyses identified in this study on the effect of agricultural practices on biodiversity could serve as a resource in addressing the urgent need to mitigate biodiversity loss, which has declined by 68% globally since 1970 (WWF 2024). Aligning agricultural research efforts with growing demand for evidence-based policymaking is not only a gateway to finding and implementing more biodiversity-friendly agricultural systems (Semenchuk et al. 2022; Sutherland et al. 2004), but also a vital step towards preserving ecosystem services valued at over a trillion of dollars annually (TEEB 2010), upon which the very existence and well-being of humanity depend. This scientific literature can provide insights on how to re-design heavily intensified agricultural systems and landscapes towards biodiversity-friendly agriculture (e.g., Stein-Bachinger et al. 2022), particularly in the world's top agricultural producers (USA, Brazil, China, Canada and France), which collectively account for 13% of global cropland area and constitute 44% of total pesticide use (FAO 2023). It may also allow for constructing objective arguments to develop primary research to conserve traditional or highly biodiversity-friendly practices (Herrero et al. 2017; Hutchins et al. 2024) in less-studied areas that face political and economic pressure—especially tropical and subtropical—to transition towards conventional and intensified systems (e.g., Perfecto et al. 1996; Tscharntke et al. 2012). Our systematic map reveals gaps in knowledge that may hinder evidence-based decision making for certain regions (Figure 2), intervention types (Figure 3) and taxa (Figure 4). Unbalanced knowledge and persistent research gaps on the relation between agricultural practices, species functions, ecological processes, and ecosystem services, coupled with the absence of adapted and/or localised knowledge, constitute two primary factors that constrain the practical application of biodiversity-based agriculture (Duru et al. 2015).

Consequently, based on our review, we identify five critical shortcomings that must be addressed through future research to effectively enhance biodiversity in agricultural systems:

1. The prevalent reductionist approach in meta-analytical studies examining the effects of agricultural practices on biodiversity must be complemented with systems-based approaches, which are better suited to address the complexities of farming systems. This is especially important given that 70% of the studies focus on single practices in isolation (Figure 3). While understanding the performance of individual practices is crucial for managing local biodiversity impacts, comprehending the effects at whole farm and landscape levels is paramount for effective agricultural management, enabling alignment with the Global Biodiversity Framework's post-2020 goals, which aim to reverse biodiversity loss by 2030. Given that farmers rarely adopt singular practices in isolation, more studies are needed to monitor the outcomes of combined practices, such as intercropping with cover crops and organic amendments, to accurately reflect the complexities and dynamics of real-world agricultural systems. Research indicates that combining multiple practices or implementing integrated agricultural systems yields more positive outcomes for biodiversity and ecosystem services (Beillouin et al. 2019; Rosa-Schleich et al. 2019). In our database, system-level agricultural land management practices, such as conservation agriculture, are significantly underrepresented (Figure 3), accounting for approximately 20% and 10% of the evidence, respectively, compared to individual practices like fertilisation alone. Additional research is essential to identify the most effective practice bundles, which would help minimise potential trade-offs between biodiversity and food production (Jones et al. 2023). Additionally, the limited quantification of landscape-level interventions, particularly land use change in Africa—where fewer than 3% of studies focus on these issues—highlights the need for landscape-level monitoring. Multi-level research designs are essential to capture the impacts of management decisions from field to landscape. Both field- and landscape-level interventions are critical for restoring biodiversity, as effective management at one scale enhances outcomes at the other (Estrada-Carmona et al. 2022; Lichtenberg et al. 2017; Kremen and Miles 2012). While landscape-level studies and meta-analyses may face practical challenges, recent advances or examples in systematic reviews and meta-analysis (e.g., Estrada-Carmona et al. 2022; Sánchez et al. 2022) show a growing focus on these areas. We believe the low number of such studies reflects both technical difficulties and a late scientific investment in these topics. Current research and policy discussions often overlook the diversity of agricultural systems, from smallholder agroecological practices to large-scale mixed systems, underrepresenting their unique contributions to biodiversity, ecosystem services, and livelihoods: This results in generalised recommendations that fail to address the complexity of real-world challenges (Tittonell et al. 2016; HLPE 2019). The present review challenges the notion that agricultural effects are thoroughly studied (e.g., Ortiz et al. 2021).

2. An overemphasis on practices aimed at increasing efficiency or substituting inputs—representing over 50% of the evidence in the literature—risks limiting innovation and comprehensive assessments of whole-system performance, thereby reinforcing the *status quo* of conventional agricultural practices (Figure 3). The predominance of studies on fertiliser impacts in croplands (over 15% of total evidence) is unsurprising, given their role in enhancing global food security by boosting yields and productivity, particularly for staple crops like cereals (Falconnier et al. 2023). However, the heavy use of fertilisers has significantly disrupted the geophysical global cycles of major nutrients (Penuelas et al. 2023; Robertson and Vitousek 2009), failed to ensure global food security, thereby exerting alarmingly high pressure on planetary boundaries (Rockström et al. 2017). The ecological restoration of agricultural landscapes, along with the emulation of natural principles in agricultural practices, is increasingly advocated to enhance system performance (Wezel et al. 2020). This shift from prioritising efficiency to improving habitat quality may necessitate different or more intricate experimental designs and research focusing on cascading effects and on the various facets of biodiversity. For instance, reducing soil tillage (representing 8% of the evidence) to enhance soil health can lead to improved soil structure and fertility, thereby reducing inputs (Willekens et al. 2014). This transition is already evident in scientific research, as shown by the increasing focus on crop diversification in our study: $<5\%$ of studies addressed diversification before 2015, compared to over 20% after 2020. Yet our analysis of primary studies suggests that the majority (i.e., 54%) of crop diversification strategies primarily focus on cover crops. While these require less extensive system redesign and yield positive outcomes for ecosystem services, other diversification strategies may have more significant positive effects (Beillouin et al. 2021). Advancing our understanding of the relationship between agricultural practices and biodiversity requires not only additional studies or syntheses but also a more effective accounting of actual farmer practices, ultimately aiming to align policies with the needs and realities of farmers (Tyllianakis and Martin-Ortega 2021).

3. Our analysis shows that agriculture impacts a broad spectrum of species. However, 50% of research remains concentrated on only two groups (i.e., arthropods and unspecified microorganisms), underscoring a significant knowledge gap for other groups (Figures 4 and 5). Our analysis highlights taxonomic biases in agricultural evidence, for

example: Vertebrates are both understudied (Figure 5) and underrepresented in our study (Figure 6), nematodes are highly studied and overrepresented, while more surprisingly annelids are rarely studied, yet matching their regular representation in the literature. Precisely, while nematodes and earthworms are extensively studied in relation to tillage practices in our database, other soil fauna taxa and vertebrates receive comparatively less attention, despite their crucial role in microhabitat modifications (Rosenberg et al. 2023; Anthony et al. 2023). Furthermore, plants reveal two levels of knowledge gaps: (i) they are both understudied (Figure 5a) and underrepresented (Figure 6) in our evidence base, and (ii) they are predominantly studied at a low taxonomic resolution and under the angle of 'weeds' (i.e., 80% of the Plantae kingdom), thus overlooking the broader implications for untargeted plant species. Such biases result in the exclusion of rare taxa in our dataset and an overrepresentation of charismatic species (Enquist et al. 2019), particularly Animalia, or birds when a study focuses on vertebrates (Figure 5). While charismatic species may garner greater attention, their effectiveness as umbrella species in conservation efforts is debated (Davison et al. 2021; Simberloff 1998; Williams and Araéjo 2000), underlining the need for a more balanced research approach across taxa. In contrast, over 70% of pest and disease management studies focus on non-targeted pest species. This mirrors the biases observed at the primary study level or societal preferences, which are now perpetuated in meta-analyses as well (Troudet et al. 2017; Davison et al. 2021). Agricultural landscapes and biodiversity, shaped by crop type, climate, and management, differ from natural ecosystems. While the focus has largely been on taxa directly impacted by farming, broadening biodiversity conservation efforts is crucial. Maintaining a threshold of at least 20% of natural habitats (Mohamed et al. 2024) and promoting natural habitat elements such as agroforestry, riparian zones or semi-natural margins in agricultural landscapes can support a wide range of species, rarely to highly interacting with agricultural production systems. Future research must thus address the underrepresentation of taxa like fungi (currently making up less than 6% of the evidence), molluscs, and various-sized vertebrates (from e.g., hedgehogs and mustelids to foxes, boars, or deer) whose ecosystem contributions—through ecological functions (e.g., nutrient cycling, soil aeration) and ecological networks—are vital for understanding croplands functioning in a perspective of sustainability.

4. Although some of them are partly correlated, numerous metrics (Magurran 2013) are available for monitoring the taxonomic, functional and phylogenetic facets of biodiversity. However, our analysis reveals that over 40% of agricultural evidence at the meta-analytical scale predominantly relies on averaged abundance metrics (and 16% on biomass). This indicates a significant bias in biodiversity assessments and provides an incomplete understanding of biodiversity dynamics in agricultural systems (Figure 5a). Abundance metrics provide a clear indication of the decline or recovery of specific taxonomic groups, making it appealing for researchers (Santini et al. 2017). In agricultural-related studies, they are frequently employed to analyse key functional groups, such as pests, pathogens, and their natural enemies, as well as pollinators, essential for crop productivity. Furthermore, using the abundance metric may reduce time and cost since it can be applied to broad taxonomic groups and doesn't require huge effort in terms of taxonomic identification, thus allowing a wider use of this indicator by non-specialists. Nonetheless, other community-level metrics are crucial for understanding how various biodiversity facets respond to agricultural changes. For instance, taxonomic diversity metrics are not commonly used in our evidence base. Furthermore, metrics describing functional diversity—yet used in $<1\%$ of the evidence base—provide a more accurate representation of ecosystem function and stability, demonstrating sensitivity to changes at the community level (Lamb et al. 2009; McGill et al. 2006). Similarly, phylogenetic diversity metrics—used in $<1\%$ of the evidence base—are increasingly recognised for their ability to capture critical ecosystem functions and their interconnections with crop performance (Grab et al. 2019). The Essential Biodiversity Variables (EBVs) framework provides a more comprehensive approach by integrating species distribution, population size, ecosystem function, and phylogenetic diversity. Adopting EBVs in agricultural biodiversity assessments could offer a more holistic view of biodiversity impacts, using complementary metrics and aligning research with global monitoring standards (Pereira et al. 2013). Therefore, measuring the performance of agricultural systems that actively contribute to maintaining 'life on earth' (SDG15) needs a more comprehensive use of biodiversity metrics (capturing impacts at the species and the community levels) to reflect the multidimensional nature of organisms' responses.

5. Building multifunctional agricultural landscapes requires reviewing evidence in an objective, rigorous, and meaningful way to better guide decision-makers and research agendas. The annual publication of synthesis papers globally has risen significantly, with over 22 per year since 2020 focused specifically on the impacts of agriculture on biodiversity. This surge makes it increasingly challenging for stakeholders to digest such extensive and complex information effectively. Our findings reveal that agricultural practices can have positive, negative or negligible effects on biodiversity, depending on the study considered and the amount of primary studies synthesised (Figure 5b, Figure S8). This variability underscores the risk of misinterpretation when relying on individual studies or averaged outcomes. Instead, these results point to the intricate interplay of factors such as climate, soil characteristics, and species traits, which collectively shape biodiversity responses. While meta-analyses remain a powerful and often essential tool to inform policy, their interpretation must account for this complexity, and for between-study heterogeneity and validity of the meta-analyses. Recognising and addressing this complexity is essential for developing accurate, context-sensitive strategies that can advance sustainable agricultural practices worldwide. Capturing the true complexity of biodiversity responses in agricultural systems requires synthesis approaches that move beyond simple averages. Meta-regression is indispensable for quantifying the role of numerical moderators such as climate, soil, and

management intensity, but it should be embedded within a broader analytical toolbox—including multilevel modelling, Bayesian inference, and causal methods like propensity score analysis. Only by embracing this methodological diversity can we generate reliable, context-sensitive insights that reflect the ecological reality and truly inform sustainable transitions in agriculture. Our global umbrella review, that is, multi-level systematic map of secondary research, serves as a foundational step in providing a higher-level perspective to critically assess the vast empirical evidence related to biodiversity. But the strength of secondary research depends on the quality of the underlying primary evidence. Our work identifies key limitations, offering a framework to refine future research and enhance its impact. In particular, it highlights frequent mixed or contradictory results that call for deeper contextual interpretation. Timely access to scientific up-to-date evidence for decision-makers by continually updating existing evidence syntheses is also a main challenge (Skinner et al. 2023). Living reviews offer a pertinent strategy for bridging the gap between science and action and would benefit from cross-institute collaboration to mobilise and utilise resources from across evidence synthesis research teams to streamline efforts. Such approaches could support policy-makers in making informed decisions based on reliable, up-to-date evidence (Martin et al. 2023; Chang et al. 2025), while also helping to identify knowledge gaps and data limitations, thus preventing overinterpretation. Further, this could facilitate communication and collaboration between scientists and agricultural stakeholders through, for example, evidence-based platforms, which are essential for fostering open dialogues and promoting more targeted conservation schemes (Maas et al. 2021; www.impact4soil.com). These flexible syntheses could be complementary to other global tools assessing the impact of policy or management practices such as life cycle assessments (LCA) (Leclère et al. 2020), and footprint analyses, which often rely themselves on parameters derived from the scientific literature.

5 | Conclusion

Our work represents a comprehensive multi-level systematic map of quantitative syntheses about agricultural impact studies on associated biodiversity in croplands, at the global scale. We provide a characterisation of 200 meta-analyses and of 1885 pooled experimental results (effect sizes) from over 9000 unique primary studies assessing farming practices at the field, farm, and landscape level. Innovating, re-designing, and valuing agricultural farms and landscapes to positively contribute to biodiversity conservation while remaining resilient to changing conditions would be facilitated by closing key evidence gaps. More than 27% of the estimated effect sizes focused on chemical fertilisers, GMO, or chemical pest and disease management, whereas conservation-oriented and certain diversity-enhancing practices such as conservation agriculture, agroforestry, and water management are rarely represented in the synthesis literature, despite their potential for achieving win-win outcomes (Jones et al. 2023). A large part of the evidence is focused on animals (51%) and the impact of an intervention on animal and plant biodiversity is mostly measured with the abundance metric (52%), whereas richness and diversity metrics, *a fortiori* on the functional and phylogenetic facets, are much less used despite their benefits for describing community-level changes. We provide five recommendations to improve the coverage and utility of knowledge syntheses and primary studies for science to contribute to achieving the Global Biodiversity Framework goal of transitioning to biodiversity-friendly croplands.

Author Contributions

Jonathan Bonfanti, Joseph Langridge, N. Casajus, D. Makowski and Damien Beillouin conceptualised the work and defined the methodology. Jonathan Bonfanti, N. Casajus and Damien Beillouin undertook data extraction and constitution of the evidence base. Jonathan Bonfanti and Damien Beillouin produced visualisations. Jonathan Bonfanti, Joseph Langridge and Damien Beillouin wrote the original draft. All authors reviewed, edited and approved the manuscript.

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Data Availability Statement

Our data consists of an Excel file database, composed of 6 sheets, that is freely accessible online (https://doi.org/10.18167/DVN1/RIRTOT) and described in Bonfanti et al. (2023, DOI: https://doi.org/10.1016/j.dib.2023.109555). The present study notably results from the analysis of the ‘ES_qualitative data’ worksheet.

Peer Review

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/ele.70220.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Data S1:** ele70220-sup-0001-DataS1.docx.