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Unveiling the Bounty: A Systematic Synthesis of Biodiversity and Ecosystem Services in Mediterranean Lentil and Chickpea Cultivation Through Alternative Pulse Systems

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ABSTRACT

Pulses get increasing awareness not only for their nutritional value but also for their multifunctionality in sustainable agri-food systems. Although having a long tradition in Mediterranean regions, their share of arable land is very low. Knowledge about pulse cropping, considering nonmarket outputs in alternative cropping systems, is scarce. To this end, we conducted a systematic literature research. We synthesized the current quantified state of knowledge about associated biodiversity in pulse systems and ecosystem services, specifically food/feed provision and soil quality, in lentil and chickpea cropping systems using alternative management practices in the Mediterranean and analysed their impact compared to conventional practices employing a meta-analysis. As alternative practices, we considered practices frequently proposed to be sustainable and more ecologically oriented than conventional cropping. Most studies examined soil quality, especially chemical quality, followed by grain yield. Very few studies surveyed biodiversity, most of which used arable flora as an indicator. Mean lentil and chickpea grain yields were 1484.4 ± 665 kg/ha under alternative practices, and flora richness was on average 10.9 ± 4 species during the pulse phase. We found significant positive impacts of organic farming on biodiversity, no tillage on soil quality and diversified rotations on yield. In multiservice trials, no tillage tended to be synergistic for both, yield and soil quality. In conclusion, organic and conservation agriculture elements seem promising techniques for ecosystem service-enhancing pulse management. Anyhow, the current evidence base on ecosystem service performance in alternative pulse systems is empirically not yet robust to conclude sound data-driven management recommendations—especially with a focus on biodiversity. However, we can draw justified hypotheses that can focus future research and can be tested in the field.

1 | Introduction

Multiple current and impending stressors pose challenges to sustainable Mediterranean agriculture. Presently, it is challenged by either abandonment, marginalization and decline of traditional extensive farming or specialization and intensification processes with market orientation (Caraveli 2000; Debolini et al. 2018; López-Iglesias, Sineiro-García, and Lorenzana-Fernández 2013). Although not in the same intensity as in the 'Northern Model', that is, northern Europe, in terms of

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intensification, we can observe similar agrarian trends and resulting environmental consequences (Arnalte-Alegre and Ortiz-Miranda 2013). Agricultural holdings give up mixed farming and narrow their crop rotations, meaning a simplification and decrease in duration of rotations and often replacement of the fallow phase by cereal as well as increase external inputs such as fertilizers, pesticides and irrigation (Arnalte-Alegre and Ortiz-Miranda 2013; Nainggolan et al. 2012; Ryan 2011; Ryan, Singh, and Pala 2008; Sokos et al. 2013; Zalidis et al. 2002). Both trends, marginalization and specialization, lead to environmental degradation and, consequently, a decrease in ecosystem services (ESs) other than provisioning services or even to the flow of disservices (Kremen and Miles 2012; Power 2010; Watson et al. 2021), as well as species decline, especially affecting segetal communities (Blondel et al. 2010; Cuttelod et al. 2008; Meyer and Bergmeier 2020; Recasens et al. 2020; Tarifa et al. 2021). Moreover, Mediterranean ecosystems are likely to be strongly affected by climate change. Farmers will need to cope with an increased likelihood of extreme droughts and general water shortage in agroecosystems, increasing land-use and resilience challenges in this region even more (Cramer et al. 2018; Giorgi and Lionello 2008; Iglesias et al. 2011; Trnka et al. 2011).

In light of ongoing pressure on natural resources and emerging environmental crisis, pulse crops are getting increasing attention for their multifunctionality in sustainable agri-food systems. The United Nations has emphasized pulses by celebrating the International Year of Pulses in 2016 (FAO 2016a) and proclaiming 10 February as World Pulses Day since 2019 (United Nations 2019). Pulses are known as an important nutritional source for human consumption and alternative protein source to replace meat. Thus, they are considered an essential means to a transformation of current food consumption and production systems, especially in industrialized countries (Kwasny, Dobernig, and Riefler 2022; Röös et al. 2020). The increase in food legumes cultivation is crucial for reaching environmental and climate targets (IPCC 2019; Ruggeri Laderchi et al. 2024) as well as Sustainable Development Goals such as Goal 2, 'zero hunger, food security and improved nutrition' (United Nations 2023). Pulses have a considerably lower environmental footprint during production than meat (Clark et al. 2019; Di Paola, Rulli, and Santini 2017; Poore and Nemecek 2018; Semba et al. 2021). Their biological nitrogen fixation ability could reduce the high reliance on nitrogen fertilizers, which, in turn, would reduce greenhouse gas emissions caused by mineral fertilizer production. Also, pulses can improve the capacity of soils to sequester carbon and reduce on-field N_2O emissions if leaching after the legume crop is prevented by appropriate management (Nemecek et al. 2008; Peoples et al. 2019; Stagnari et al. 2017; Williams, Pappa, and Rees 2017; Zander et al. 2016). Hence, pulses can enhance ecosystem functions and, consequently, the delivery of ES via their specific traits (González del Portillo, Arroyo, and Morales 2022). Moreover, pulses offer great possibilities for biodiversity increase by rescuing old local landraces (genetic diversity) or by diversifying fields and landscapes (species and habitats diversity) (Everwand et al. 2017; Howieson, O'Hara, and Carr 2000; Redden et al. 2010; Siddique et al. 2012; Stagnari et al. 2017). All these benefits are not only provided during the pulse phase of the crop rotation but can also have positive residual effects on the subsequent crops (Guinet, Nicolardot, and Voisin 2020; Nemecek et al. 2008; Preissel et al. 2015).

In the Mediterranean, food legumes have a long tradition (Ryan, Singh, and Pala 2008; Sahyoun and Sankavaram 2016; UNESCO 2013). Lentil (*Lens culinaris* Medik.) and chickpea (*Cicer arietinum* L.) are the most important pulses for human consumption in this area (Ryan, Singh, and Pala 2008, 284) (share of total harvested area for pulses in the Mediterranean, effective 2021: ~16% lentil and ~23% chickpea; FAO 2022). However, the share of pulses on arable land is still very low, and cereals are the most dominant crop type (share of harvested area for all crop types, effective 2021: Europe: ~54% cereals and ~2% pulses; Mediterranean: ~64% cereals and ~4% pulses; FAO 2022). Apart from present dietary habits with a major focus on meat consumption (Tilman and Clark 2014), the reasons for the low cultivation of pulses mainly derive from growers' perceptions and market developments. Pulses are perceived as yield unstable and less competitive against weeds while having low herbicide resistance (Döring 2015; Rawal and Kalamvrezos Navarro 2019). However, data on proofing or falsifying yield instability are scarce, and advances in agronomy and breeding, especially through exploiting the varietal diversity, have increased productive performance, yield quality and drought resistance (Döring 2015; Khatun et al. 2021; Millán et al. 2015; Sarker and Erskine 2006). In terms of weed suppression, there are voices in literature stating that lentil and chickpea have a low competitive ability with weeds, especially in periods of cooler temperatures (Brand et al. 2007; Materne and Amarender Reddy 2007; Stefan, Engbersen, and Schöb 2021). Other literature reports good weed competition ability, especially from chickpea against annual broad leaves, grasses, monocotyledonous and dicotyledonous weeds (Pradhan et al. 2022). Again, other bodies of research indicate that the cropping practice is decisive for weed competition, highlighting either the overall benefit or reduced weed infestation through the break of pest cycles in crop rotations including pulses (Stagnari et al. 2017) or intercropping of lentil or chickpea with cereal, leading to reduced weed occurrence (Banik et al. 2006; Pradhan et al. 2022; Stefan, Engbersen, and Schöb 2021). Whether this is due to the cereal or the lentil/chickpea crop is reported inconsistently (Banik et al. 2006; Pradhan et al. 2022; Stefan, Engbersen, and Schöb 2021). Pulses show substantially lower gross margins as against the regionally most profitable crop (typically cereal) (Stagnari et al. 2017; Zander et al. 2016). However, comparing crops with similar functions within the agroecosystem and the factoring in of nonmarket outputs and savings from long-term effects of pulse crops (e.g., biodiversity increase and precrop effects) would be more appropriate. Additionally, subsidizing competing crops, such as bioenergy crops, impacted the pulse share on agricultural land (Zander et al. 2016). Moreover, Murphy-Bokern (2022) argues that for the successful and long-term establishment of legume systems, a particular focus needs to be put on balancing diversification and specialization and mediating trade-offs as much as possible, urging the need to optimize the performance of pulses and overall farm-level resource use. Thus, environmental, agronomic and economic concepts and policies for multifunctional pulse cropping are needed to increase the production of pulses and, subsequently, for the remuneration of the above-named multiple benefits. For pulses, recently proposed sustainable cropping systems already consider some of the mentioned economic and biophysical limitations as well as precautions against unwanted nitrogen leaching after and during the pulse phase or measures that enhance CO_2 sequestration (Peoples et al. 2019;

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Siddique et al. 2012). Much less attention has been paid to the role of pulses for noncrop biodiversity in the field (Everwand et al. 2017). The latter is very much endangered because of the extensive use of pesticides and fertilizer in intensive farming systems (Albrecht 2003; Albrecht et al. 2016). Furthermore, the support of higher (functional) biodiversity and natural species interactions is often an important approach for ES provision in alternative farming systems (i.e., integrated management approaches) (Altieri 1999; Duncan, Thompson, and Pettorelli 2015; Kazemi, Klug, and Kamkar 2018; Malézieux 2012; Vanbergen et al. 2020; Wezel et al. 2015).

Recently, some reviews about alternative farming practices in the Mediterranean and their ES have been conducted (Balzan, Sadula, and Scalvenzi 2020; Lee et al. 2019; Palomo-Campesino, González, and García-Llorente 2018; Shackelford et al. 2017). These reviews offer a good first overview of possible alternative farming practices. However, they do not differentiate between the broad spectrum of farming systems (e.g., agroforestry, annual cropping and silvopastoral systems) and crop types delivering the ES. Crops, in general, and pulses differ in their ES delivery–related traits and their interaction with the agroecosystem and associated species (Bredemeier et al. 2015; Everwand et al. 2017; Faucon, Houben, and Lambers 2017; Suso et al. 2016).

This study aims to synthesize and quantify the hitherto published empirical evidence about the effects of different alternative management practices on associated biodiversity, provisioning and regulating ES in pulse-based Mediterranean cropping systems. We put special regards to lentil and chickpea, being the most important food legume crops in this area (Ryan, Singh, and Pala 2008, p. 284). Thus, we exclusively reviewed the literature on lentils and chickpeas for provisioning and soil-regulating ES. However, for biodiversity, all pulse crops were considered in this synthesis due to highly limited data availability.

We specifically address the following research questions:

1. What are the effects of alternative management practices on biodiversity, food/feed provision and soil quality in pulse cropping systems in the Mediterranean compared to conventional practices?
2. Which of the alternative management practices show evidence to be multibeneficial?

We use the term alternative practices to frame a range of management practices proposed as sustainable or more ecologically oriented alternatives compared to conventional cropping (cf. Section 2.1 for more details).

2 | Methods

We followed a two-step approach using different methods (Figure 1). Firstly, we conducted systematic literature research to obtain primary data from field experiments. Each ES was addressed independently in the research process. Secondly, these databases were analysed. Depending on the characteristics of the experiment, either the whole database was synthesized using descriptive methods or a subset of data that stemmed from experiments with comparators was processed in meta-analysis. Comparators are 'either a control with no intervention/exposure or an alternative intervention or a counterfactual scenario' (Collaboration for Environmental Evidence 2013, 20).

Literature management was done using Citavi 6.10. Data management, statistical analysis and graphical representations were done using Excel 2019 combined with XLSTAT 2021.3.1 (XLSTAT 2021). In all statistical analyses, a critical level of $\alpha = 0.05$ was set. Maps were compiled in ArcMap 10.7.

2.1 | Systematic Literature Research

Literature research was conducted following the PRISMA 2020 statement (M. Page, Mckenzie, et al. 2021; M. Page, Moher, et al. 2021) in combination with suggested amendments of the ROSES standard (Haddaway et al. 2018) to adapt the PRISMA protocol to environmental science. The literature research was run as topic search during February–July 2021 within the Core Collection of the Web of Science (Clarivate 2021). The search was restricted to primary studies assigned to the document type 'Articles' in English. Our keywords and Booleans are listed in Supporting Information S1. In literature reviews, dissemination

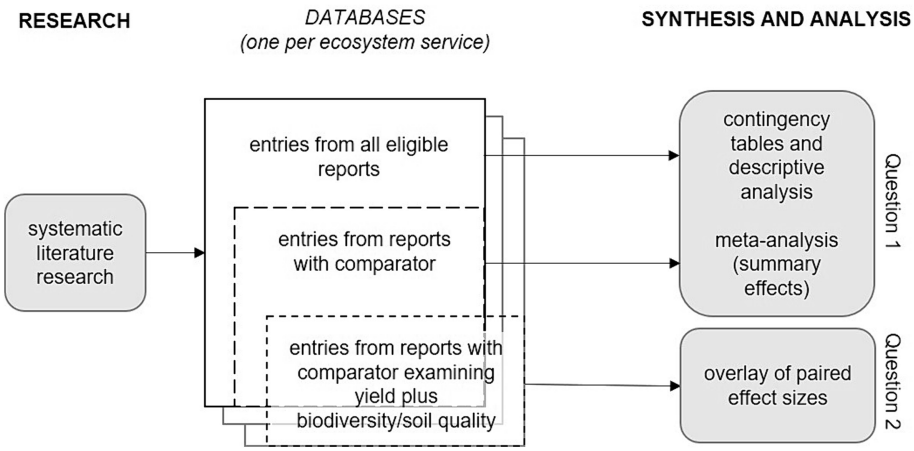

FIGURE 1 | Workflow for knowledge synthesis and further analysis.

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bias often occurs, which covers possible errors related to the occurrence of reports in the search hits (according to Jennions et al. 2013). To keep this as low as possible, we used an extensive list of keywords for the literature research. They represent a combination of two searches per ES, as well as combinations of words and synonyms representing the different eligibility criteria (Table 1):

- Search #1: An AND combination of keywords and a wide range of synonyms of the eligible location, crop types and studied service in combination with (agricultur* OR farm* OR farmland OR field* OR crop* OR arable OR plot* OR patch)
- Search #2: An AND combination of keywords and a wide range of synonyms of the eligible location, crop types, alternative practices, studies services
- Full list of records without duplicates: #1 + (#2 NOT #1)

For screening, we applied the inclusion criteria given in Table 1. We included articles reporting primary data on biodiversity, yield and soil quality from open-air field trials under rain-fed conditions in Mediterranean climate regions testing alternative management practices, at best compared to conventional practices. As alternative practices, we encompassed various practices stated in the literature, for example, integrated management, elements of agroecological, organic or conservation farming and diversification practices (further details are given in Table 1 and Supporting Information S1). For yield and soil quality, trials using lentil or chickpea were included. Due to a limited number of studies for biodiversity, all pulse crops were included. One reviewer screened and extracted data. However, critical cases were discussed amongst all authors (group of three). Screening was done in two stages, first by abstract and then by full text. The articles were checked for similar underlying studies to reduce the risk of bias in the eligible records. If several papers reported results from the same study with the same intervention, subjects and time period, only the paper that provided the most detailed results was included. Besides, we applied a snowball search for biodiversity by screening the reference list of all eligible reports after full-text screening and checking for additional eligible reports to include.

After full-text screening, bibliographic information of the report, details about the study site, trial and management practices, as well as the impact on the studied ES, were extracted from all eligible reports. For soil quality and biodiversity, we also extracted yield information, if also examined in the trials, to detect possible multifunctional practices. If the study took place over several years, we calculated the means of the data to avoid pseudoreplication. But if more than one practice was tested as a factor in the same trial, these results were treated independently, eventuating in more than one database entry. We tried to keep selective reporting bias (Jennions et al. 2013) as low as possible by analysing all data available in the reports, including supplementary material, raw data tables and figures. If relevant data were presented only in graphs, numbers were extracted using WebPlotDigitizer Version 4.4 (Rohatgi 2021). Agroecosystems are inherently ecologically complex (Altieri 1999, 2002; Gomiero, Giampietro, and Mayumi 2006; Vandermeer and Perfecto 2017) and can be analysed multiscalarly (Wezel et al. 2014). Therefore, in our study, we included both temporal dimensions and immediate and residual effects as eligible evidence of impact. Thus, residual measurements cannot preclude the effect of the following crop(s). However, we want to point out that in the case of biodiversity (mainly related to segetal flora) and especially soil quality, the stabilized real influence of management shifts often occurs with a time lag (Bai et al. 2016; Duval et al. 2016; Restuccia et al. 2020; Richner et al. 2015). Due to the sparse research or insufficient reporting of details in the studies, we could, in some cases, not conduct further distinctions and subsequent analysis on aspects such as exact practices under the umbrella of organic farming, crop types and their share within the (diversified) crop rotations, amount of retained residues after tillage or biophysical attributes of the study sites (soil type and pH) and weather variables.

2.2 | Synthesis and Analysis

The whole literature research and data extraction resulted in three different databases to be further analysed, one per ES. Each ES and its respective database were analysed independently throughout the synthesis.

2.2.1 | Descriptive Analysis

Longitude and latitude of the study locations were imported into ArcMap and joined with the databases. To provide an overview of the eligible reports and their findings, we used contingency tables and performed descriptive analysis of all databases. For soil quality, the parameters were assigned to harmonized indicators, which in turn were allocated to categories: biological, chemical or physical soil quality based on Bünemann et al. (2018) (Supporting Information S2). Additionally, for biodiversity and yield, means, ranges and standard deviations were calculated from the primary data after unifying units where necessary. We refrained from doing this for all soil quality entries, as the parameters examined in the studies were too heterogeneous. Here, soil quality parameters could thus only be compared using standardized scores, which, in our opinion, then lose their informative content for the descriptive synthesis.

2.2.2 | Effect Estimation

Meta-analysis was applied to all database entries with a comparator. We applied a nested approach at two different hierarchical levels. Consequently, sample sizes differ according to the hierarchical level on which the meta-analytical method was applied. The impact of alternative management practices on ES delivery was meta-analysed by calculating the overall effect size of each ES (hierarchical level 1) and via subgroup analysis, where we distinguished between the different practices that have been intentionally tested in the field and were indicated as the intervention in the database (hierarchical level 2). Effect sizes are commonly used in meta-analysis to express 'the outcome of each study on a common scale' (Koricheva and Gurevitch 2013, p. 8), including the direction and magnitude of the measured outcome or

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TABLE 1 | Eligibility criteria.

Criterion	Description
I. Document type	Articles reporting primary data (no reviews or meta-analysis)
II. Study type	Open-air field trials under normal site conditions (no pot or greenhouse trials, model or simulation studies and rigged fields, such as heavily disease- or pest-infested sites)
III. Location	The experimental site is within the Mediterranean area; this includes all regions from the overlay of areas that are classified as Mediterranean Biogeographical Region (European Commission 2021) under the Habitats Directive (Council of the European Union 1992, Council Directive 92/43/EEC) and all regions with a Mediterranean climate (Csa and Csb) according to updated Köppen–Geiger classification (Rubel and Kottek 2010).
IV. Farming system	Rainfed annual cropping system (no irrigated systems, silviculture, plantations or agroforestry)
V. Crop types	For food/feed provision and soil quality: chickpea or lentil For biodiversity: pulse crops according to the list of FAO (1994) The pretest of the search strategy showed that the strict restriction to chickpea and lentil yielded too few eligible records. Therefore, here, this criterion was softened.
VI. Intervention/exposure	Alternative sustainable farming practices, such as integrated management, agroecological, conservation, organic practices, biodiversity-based agriculture (Duru et al. 2015; IPBES 2016; IPES-Food 2016; Therond et al. 2017; Vanbergen et al. 2020; Wezel et al. 2014, 2015) and/or those that are already especially recommended for sustainable legume cropping, such as cover cropping and diversification practices, for example, rotations or intercropping, should be tested (Meena et al. 2018; Mikić et al. 2015; Murphy-Bokern, Stoddard, and Watson 2017; Siddique et al. 2012). This could be done with or without comparator. Eligible comparators are respective contrasted conventional practices (monocropping of another crop, conventional tillage and use of mineral fertilizer or pesticides) of the tested intervention/exposure.
VII. Studied population/subject	For biodiversity: noncrop diversity as associated biodiversity (in the sense of Duru et al. 2015) by means of species richness (exclusion of selective surveys of dominant species) of segetal flora, arthropods, amphibians, reptiles, birds, mammals or soil macrofauna or mesofauna (cf. Albrecht 2003; Billeter et al. 2008; Bockstaller et al. 2011; Herzog et al. 2012; Lange-Kabitz et al. 2019; Marshall et al. 2003) For food/feed provision: grain yield or biomass from cultivated crops to be used for food/fodder (cf. Haines-Young and Potschin 2018, CICES V5.1 Group 1.1.1) For soil quality: chemical, biological and physical indicators of soil quality and fertility (cf. Arshad and Martin 2002; Bünemann et al. 2018; Haines-Young and Potschin 2018, CICES V5.1 Group 2.2.4; Muñoz-Rojas 2018)

effect, respectively (Koricheva and Gurevitch 2013). For the effect size index, we used the response ratio computed on a natural logarithmic scale ($\ln R$). The response ratio is the ratio between a pair of means and is recommended when the aim is to compare two groups (here, intervention and control). It is typically ln-transformed to have a symmetrical effect size and zero indicating no effect (Borenstein et al. 2009; Gates 2002; Hedges, Gurevitch, and Curtis 1999; J. P. T. Higgins, Li, and Deeks 2019; Rosenberg, Rothstein, and Gurevitch 2013). The computation of $\ln R$ was done for each study by calculating the ratio of the mean of intervention $\overline{X_I}$ and the mean of the comparator $\overline{X_C}$ (Borenstein et al. 2009) (see Equation 1).

$$\ln R = \ln\left(\overline{X_I}/\overline{X_C}\right) = \ln\left(\overline{X_I}\right) - \ln\left(\overline{X_C}\right) \quad (1)$$

Next, the studies were weighted to account for differences in precision. Typically, this is done using the inverse variance of the studies or the sample sizes (Borenstein et al. 2009; Mengersen et al. 2013). In our case, many articles did not report information about variance, and/or sample sizes could not be determined clearly due to very different study designs. To nevertheless account for higher precision of studies with larger sample sizes, as this decreases variance, we used the product of the number of replicates (NR) of the field design and the overall study duration (D) as a proxy for the sample size. We also decided to factor in the study duration because long-term experiments can provide reliable evidence of changes in slow variables (e.g., soil) or stability processes (cf. Grosse et al. 2020). The computation of the weights (W_i) of study i followed Adams, Gurevitch, and Rosenberg (1997) and Hedges (1982) (see Equation 2):

$$W_i = 1/V_i = 1/\left(\frac{2\left(NR_iD_i\right)}{\left(NR_iD_i\right)^2} + \frac{\ln R_i^{\,2}}{2\left(NR_iD_i + NR_iD_i\right)}\right). \quad (2)$$

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To obtain information about the overall effect of sustainable practices compared to conventional comparators, summary effects were computed. Summary effects generally express the weighted mean of the effect sizes of all studies considered at the respective level of analysis and are used to provide synthesis and information about the consistency of the single effects (Borenstein et al. 2009). We chose a random-effects model a priori for summary, as it generally better accounts for ecological questions and studies with much less comparability in terms of experimental conditions. Random-effects models assume the existence of two sources of variance: within-study variance (due to sampling error) and between-study variance (due to other influential factors such as different site conditions) (Mengersen et al. 2013). Between-study variance was included in the summary effect via the parameter τ^2, which we calculated following the DerSimonian and Laird (1986) method (cf. also Veroniki et al. 2016). If $\tau^2 \leq 0$, we went back to fitting the summary effect to a fixed-effect model, which, in contrast to a random-effects model, assumes only within-study variance. This often happens and is a better choice if sample sizes of the individual studies or the total number of datasets used in the meta-analysis are relatively small (Mengersen et al. 2013). Summary effects in fixed- and random-effects models for k number of studies were calculated following Borenstein et al. (2009) (see Equations 3 and 4).

$$SE_{FE} = \sum_{i=1}^{k} W_i \ln R_i \Big/ \sum_{i=1}^{k} W_i \tag{3}$$

$$SE_{RE} = \sum_{i=1}^{k} W_i^* \ln R_i \Big/ \sum_{i=1}^{k} W_i^*, \quad \text{where: } W_i^* = 1/\left(V_i + \tau^2\right) \tag{4}$$

For the summary effects, we also calculated 95% confidence intervals by bootstrapping ($n = 10{,}000$ bootstrap samples) with simple percentile intervals (Lee et al. 2019). Especially when the dataset for the meta-analysis is very small and/or the primary data do not report sufficient information, resampling is powerful to nevertheless gain a robust parameter. If the confidence interval did not overlap with zero, the effect was assumed to be significantly different from zero (Adams, Gurevitch, and Rosenberg 1997; Dixon 2000; Rosenberg 2013; Van den Noortgate and Onghena 2005). For subgroups that consisted of $n < 5$ datasets, we only displayed a summary effect in the forest plot but did not calculate any confidence intervals and levels of significance, though they were included in the combined summary of the overall ES. Moreover, a heterogeneity test was performed for all summary effects to test the null hypothesis of a common effect size across groups (Pigott 2012). We applied the Q-test, as explained in J. P. Higgins and Thompson (2002), and calculated p-values by comparing the obtained value to a χ^2 distribution (degrees of freedom $= k - 1$). Response ratios of multiservice trials were plotted against each other to analyse potential multibenefits or trade-offs.

3 | Results

3.1 | Overview of Eligible Reports and Studies

The full PRISMA flow chart and list of included reports are given in Supporting Information S3. All three compiled databases, on which the following synthesis is based, are listed in the Data Availability Statement. The literature search with the given keywords (see Supporting Information S1) resulted in 3634 reports for biodiversity (+3 identified through citation screening), 1505 for yield and 569 for soil quality. All articles were screened for eligibility based on the abstract. From these, 202 reports for biodiversity, 350 for yield and 177 for soil quality were screened in full text. For biodiversity, all eligible pulse studies were considered, whereas for yield and soil quality, only lentil and chickpea trials were included (Table 1). For our research questions, a total of 13 (11 with comparator) reports were eligible for biodiversity (Table 2). Here, mostly pea (eight reports), vetch (six reports), broad bean (three reports) or lupin (one report) were examined. Only two (both with comparator) reports investigated biodiversity in chickpea. None were surveying lentil cropping. The soil quality search yielded 25 (22 with comparator) eligible reports. In the case of food/feed provision, 35 (28 with comparator) reports were included in the database. Here, one study (one report and three database entries) reported only relative data (Campiglia, Radicetti, and Mancinelli 2018) and absolute yield data could not be acquired for further analysis. Additionally, one report (one study and two database entries) was excluded from descriptive analysis (Research Question 1), as it reported implausibly high wheat yield data (27.01–32.15 t/ha) (Montemurro and Maiorana 2015). Nevertheless, we included this study in the meta-analysis, where only relations are analysed.

TABLE 2 | Overview of the number of eligible reports and database entries per ecosystem service.

Ecosystem service		Total database		Database entries with comparator (meta-analysis)	
		Included reports (studies)	Database entries	Reports with comparator (studies)	Database entries
Biodiversity	All pulses	13 (13)	33	11 (11)	20
	Chickpea	2 (2)	4	2 (2)	4
Food/feed provision[a]		35 (28)	101	30 (22)	56
Soil quality		25 (15)	157	22 (15)	136

[a]One study reporting implausibly high cereal yield and one study not reporting precise numbers were excluded from descriptive analysis, resulting in two reports, two studies and five database entries being substratced from the eligible results.

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The earliest reports were published in 1991 and examined productive performance. Studies covering yield have been more or less consistently published since the early 1990s. Soil quality studies and biodiversity gained increasing attention from the 2000s onwards. Most trials were short- to medium-term experiments with a duration of 1 (minimum biodiversity) to 7 (median soil quality) years. Experiments of 1 or 2 years compromise half of this category. Only about 10% of all included reports ($n = 291$ total database entries) were from long-term experiments of more than 15 years, mostly yield stability or soil monitoring trials (Figure 2).

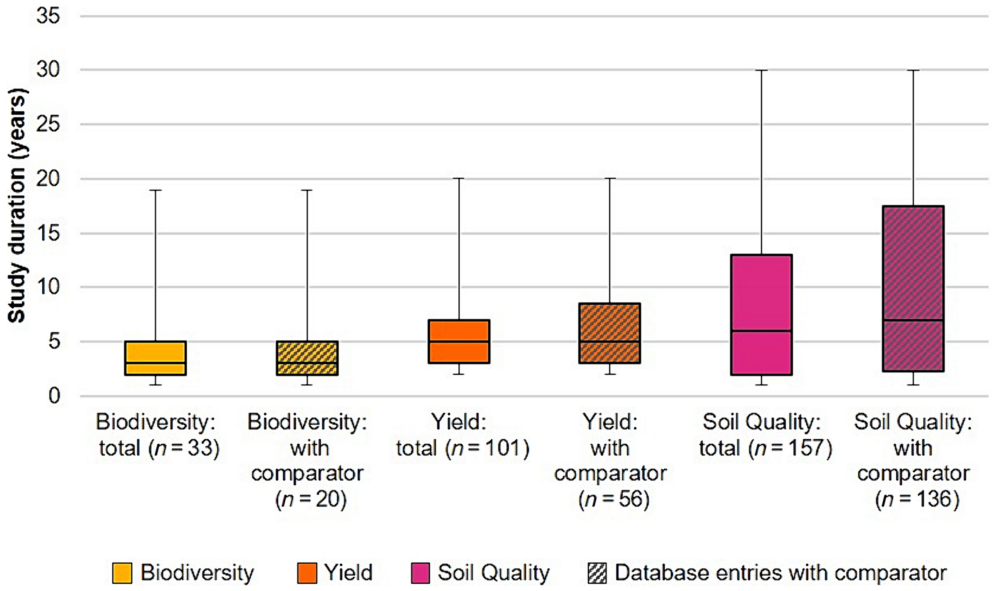

FIGURE 2 | Study duration (in years) of the eligible field experiments, where n = number of database entries.

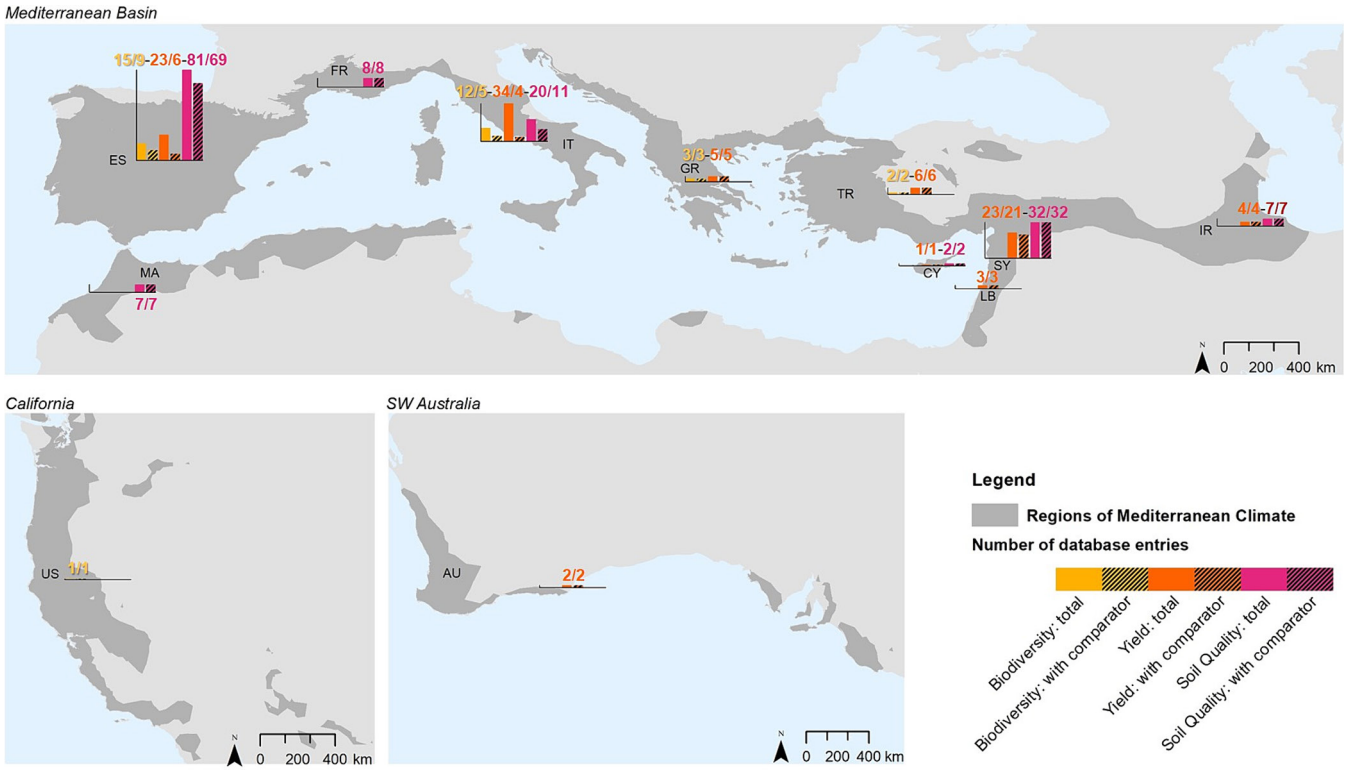

FIGURE 3 | Spatial distribution of the primary data differentiated by services. The letter code follows the ISO 3166 international standard Alpha-2 Codes (International Organization for Standardization 2021). The numbers label the bars in the symbology charts, which indicate the number of database entries (n) per service. The colour of the numbers follows the colour coding given in the legend. Within each colour group, the order of the numbers refers to the number of database entries retrieved in total and the number of database entries with a comparator; for example, the yellow number code 15/9 for ES indicates that in Spain, for biodiversity, $n = 15$ database entries were retrieved in total, and of those, $n = 9$ were with comparator.

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In terms of the location of the experimental sites, most trials were located around the Mediterranean Basin (Figure 3). Hotspots of research can be found in Europe in Spain and Italy for all three ESs, as well as in the Near East in relation to yield and soil quality, predominantly in Syria at ICARDA's research station 'Tel Hadya' in Aleppo.

3.2 | Current State of Quantified Knowledge and Effects of Alternative Compared to Conventional Practices

3.2.1 | Descriptive Synthesis of All Reports

As a metric for biodiversity, the vast majority of studies surveyed arable wild flora and reported species richness. In the whole dataset ($n = 28$ database entries), mean species richness was 9.7 (± 3.4) wild plants. The reported flora richness (from $n = 15$ database entries) was on average higher under alternative management practices (10.9 ± 4) compared to conventional techniques (9.1 ± 4). This can also be observed as a residual effect in cereals, whereby it needs to be mentioned that the effect of organic (including pulses in rotation) was compared to conventional management (including none or only a low share of pulses in the rotation). In a few cases (5 out of 20 database entries with comparator), the conventional comparator had higher segetal flora richness. This was measured once for organic management (difference of 0.155 in the Simpson index, Ntatsi et al. 2019) and four times for reduced or no tillage (average difference of one flora species, Bilalis, Efthimiadis, and Sidiras 2001; Mas 2003; Ozpinar and Ozpinar 2011). Moreover, two studies did not examine arable flora species richness as a measure of biodiversity. One study surveyed arable flora but reported only the Simpson index. Two other studies evaluated nematode and arthropod species richness (Table 3).

For food/feed provision, most studies have examined lentil, chickpea or cereal grain yield. From all studies ($n = 76$ database entries), average lentil or chickpea grain yield under alternative management in the Mediterranean was 1307.5 (± 674.9) kg/ha. Synthesizing those studies with a comparator ($n = 41$ database entries), we see that lentil or chickpea grain yield was slightly lower under conventional management (1415.5 ± 611.7 vs. 1484.4 ± 655 kg/ha under alternative management). Looking at the yield of the subsequent crop (cereal), we see stronger evidence for this tendency (from $n = 11$ database entries): With an average difference of 435.8 kg/ha, cereal grain yield was higher after a pulse phase (alternative practice, 2139.8 ± 766.7 kg/ha) than under repeated cereal cropping (comparator practice, 1704.0 ± 941.1 kg/ha). The same trend has been observed in one study in relation to cereal biomass (Table 3).

Within the reports eligible for soil quality (25 out of 569 reports found), a total of 76 different parameters (72 from the subset of comparator studies), resulting in 29 different harmonized indicators, could be identified. Nine database entries (all with conventional comparators) are from studies measuring immediate effects. In 144 (123 with comparator) cases, residual effects were examined after a cereal phase, the end of the growing season or the whole trial. Biological soil quality was a research topic in 44 total cases and 38 times compared with conventional control practices. The vast majority surveyed either enzymatic activity ($n = 20$ total entries, 20 with comparator) or microbial biomass ($n = 17$ total database entries, 11 with comparator). With 31 total database entries, all with comparator, physical soil quality was least studied in the eligible reports. Indicators were relatively diverse, where aggregate stability and aggregation (each $n = 8$ total database entries, eight with comparator) were investigated less than other indicators (Table 4). Most reports examined chemical properties ($n = 82$ total database entries, 71 entries with comparator). Here, more frequently analysed indicators were organic carbon ($n = 18$ total entries, 10 with comparator), soil organic matter ($n = 14$ total entries, 14 with comparator), total nitrogen ($n = 11$ total entries, 6 with comparator) and mineral nitrogen ($n = 10$ total entries, 10 with comparator) (Table 4).

The results of soil nitrogen measurements were varied. A lentil- or chickpea-inclusive crop rotation was compared with wheat monocropping, and the following results in relation to soil nitrogen were reported: Ammonium nitrogen and mineral nitrogen were higher within the diversified rotation (25.29 g/kg ammonium nitrogen compared to 14.64 g/kg and 7.8–7.95 mg/kg residual mineral nitrogen compared to 6.93 mg/kg residual mineral nitrogen) (López-Bellido et al. 1997; Ryan et al. 2009). Nitrate content was reported to be higher in wheat monocropping (0.22 g/m^2) than in lentil- or chickpea-inclusive rotation (0.13 g/m^2) (Melero et al. 2011). Results for total nitrogen were indifferent, with one study reporting higher results for the pulse-inclusive rotation (Montemurro and Maiorana 2015) and another study reporting the opposite (Mrabet et al. 2001). In trials where no or reduced tillage was compared with conventional tillage, chemical soil quality parameters relating to nitrogen were ambivalent as well. Ammonium nitrogen content was higher with soil-inverting techniques (33.41 g/kg) than under no tillage (25.29 g/kg) (López-Bellido et al. 1997). Mineral nitrogen without tillage in lentil rotations was lower compared to conventional tillage (9.48 vs. 9.67 kg/ha) whereas the same trial utilizing chickpea resulted in higher residual soil mineral nitrogen under the alternative option (12.97 vs. 12.37 kg/ha) (Ruisi et al. 2012). Measurements of residual soil total nitrogen content were higher under alternative tillage regimes (no, minimum, subsoil) than under conventional tillage (0.549–0.763 vs. 0.547 g/kg) (González-Prieto et al. 2013).

3.2.2 | Effect Estimation

Overall, 10 different alternative management practices were found in the literature and tested against a conventional comparator (Table 1). The factors most frequently tested in the field trials in all ES categories were conservation tillage regimes, followed by cropping diversification mostly by means of a (wider) rotation.

Regarding biodiversity in pulse cropping, alternative management practices have rarely been examined and compared. Only the impact of organic management and no-/reduced-tillage regimes was tested in a few cases in the Mediterranean (Figure 4A). The combined summary effect was nonsignificant. Also, we did not find any overall significant impact of reduced- or no-tillage regimes on biodiversity. Organic management significantly positively impacts

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TABLE 3 | Overview of reported indicators and results of biodiversity and yield.

				Total dataset			Database entries with comparator (meta-analysis)				
		Effect dimension						Alternative practice		Conventional comparator	
	Indicator	Immediate	Residual (phase)	*n*	Range	Mean (SD)	*n*	Range	Mean (SD)	Range	Mean (SD)
Biodiversity	Arable flora species richness	x		28	5–18	9.7 (3.4)	15	5–18	10.9 (4.0)	3–16.6	9.1 (4.0)
			x (cereal)[a]	Same as for with comparator			2	8.2–27.2	17.7 (9.5)	3–13.8	8.4 (5.4)
	Arable flora Simpson index	x		Same as for with comparator			1	—	2.66	—	2.8
	Nematode species richness		End of growing season	Same as for with comparator			1	—	7.8	—	7.7
	Arthropod species richness		x (cereal)[a]	Same as for with comparator			1	—	72	—	70
Yield	Grain (kg/ha)	x		76	290–2930	1307.5 (674.9)	41	577–2930	1484.4 (665.0)	512–3140	1415.4 (611.7)
		Mixed (total yield from legume–cereal intercropping compared with cereal monocropping)		Same as for with comparator			1	—	1906.5	—	2277
			x (cereal)[b]	Same as for with comparator			11	1010–3322	2139.8 (766.7)	590–3700	1704.0 (941.1)
	Biomass (kg/ha)	x		7	600–1180	788.6 (178.9)			—		
			x (cereal)[b]	Same as for with comparator			1	—	3096		1502

Abbreviations: *n* = number of database entries; SD = standard deviation.

[a]Here, flora species richness was compared as follows: The intervention was organic management including a legume within the rotation compared to conventional management with a crop rotation without or only a very low share of legumes.

[b]Here, cereal yield was compared as follows: The intervention was a crop rotation with legumes compared to repeated cereal cropping.

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TABLE 4 | Overview of reported indicators for soil quality and their assigned groups.

Soil quality group	Harmonized indicator	Total number of database entries	Number of database entries with comparator
Biological	Enzymatic activity	20	20
	Index of biological fertility	1	1
	Metabolic quotient	1	1
	Microbial biomass	17	11
	Mineralization quotient	1	1
	Respiration	4	2
	Total	44	38
Chemical	Available phosphor	5	5
	Available potassium	1	1
	Cation exchange capacity	9	9
	Electrical conductivity	1	1
	Mineral nitrogen	10	10
	Nitrogen from rhizodeposition	1	1
	Organic carbon	16	10
	Organic phosphor	2	2
	pH	3	3
	Soil organic matter	14	14
	Total carbon	4	4
	Total nitrogen	11	6
	Total phosphor	2	2
	Water-soluble carbon	3	3
	Total	82	71
Physical	Aggregate stability	8	8
	Aggregation	8	8
	Bulk density	2	1
	Dispersion coefficient	2	2
	Hydraulic conductivity	3	3
	Infiltration	2	2
	Soil moisture	1	1
	Texture	1	1
	Water storage	4	3
	Total	31	31

biodiversity in pulse cropping systems (summary $\ln R = 0.25$, [0.01, 0.81], $n = 5$ database entries). Only one study (Ntatsi et al. 2019) resulted in a negative effect size (summary $\ln R = -0.06$), due to a slightly lower diversity index (Simpson index) under organic farming. Nevertheless, the authors reported the difference as nonsignificant (Ntatsi et al. 2019). However, heterogeneity of the effect sizes between the groups (practices) was nonsignificant ($Q = 1.356$, $p = 0.508$, three groups), indicating that practices' summary effects do not significantly differ from the overall summary effect for biodiversity.

The combined summary effect of alternative practices in pulse cropping systems on food/feed provision was not significant, neither positively nor negatively (Figure 4B). Many practices were also only sparsely tested as a factor in the eligible field trials (five groups with $n < 5$ database entries). A significant positive impact

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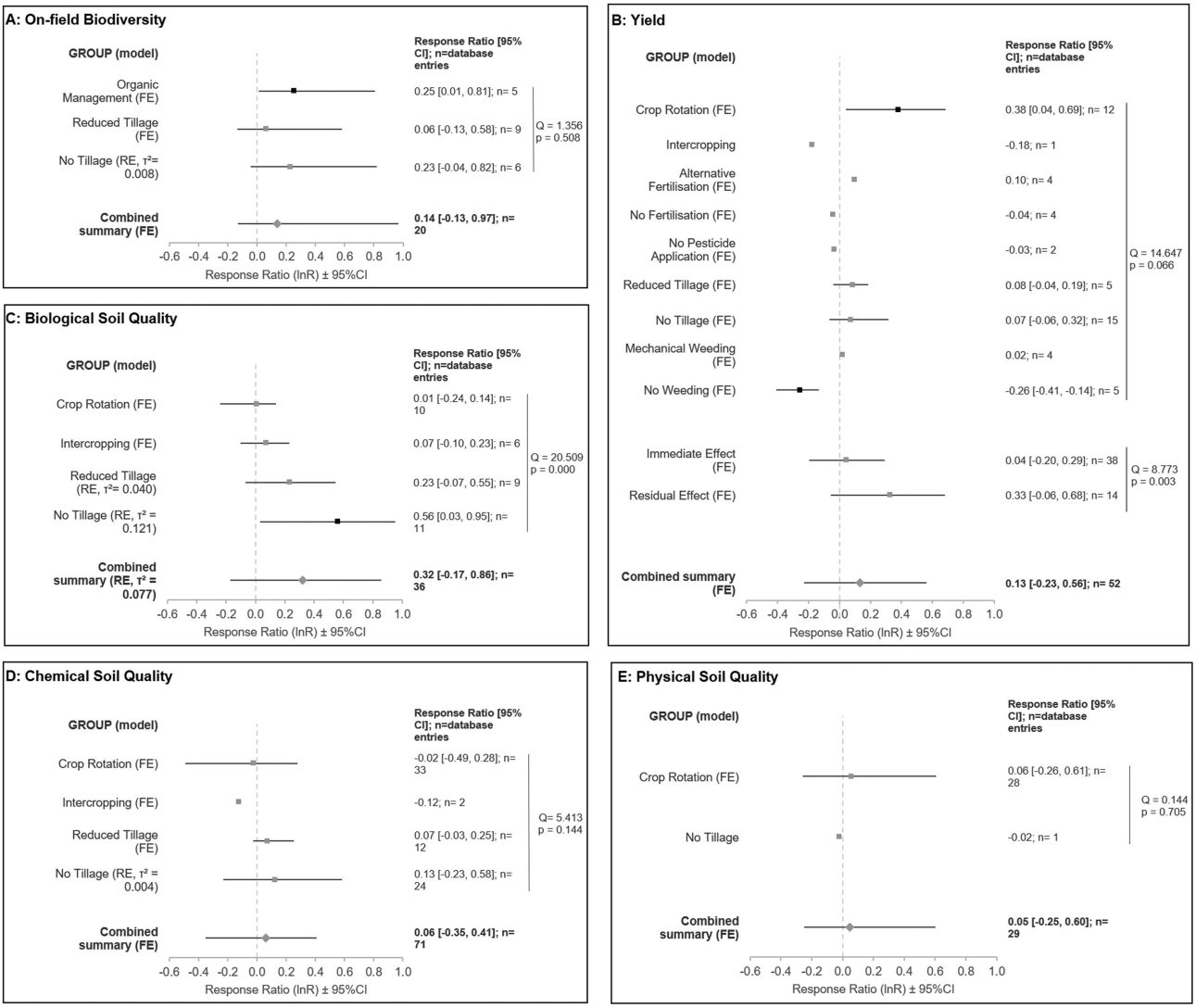

FIGURE 4 | Forest plots showing the effect ($\ln R$) of alternative management practices on (A) on-field biodiversity, (B) yield and (C–E) soil quality. Significant summary effects (CI does not overlap with zero) are displayed with black markers. The combined summary indicates the summary effect on the overall ecosystem service and is displayed by a diamond. The statistical model used for calculating the summary effect is given in brackets, whereas FE = fixed-effect model, RE = random-effects model, CI = confidence interval and n = number of database entries. Heterogeneity for the grouping(s) was tested with the Q-test. The vertical lines indicate the group to which the test results belonged.

on yield was found for crop rotation with pulses compared to cereal monocropping (summary $\ln R = 0.38$, [0.04, 0.69], $n = 12$ database entries). Only one study (Kayan et al. 2017) reported a slightly higher wheat yield in wheat monocropping than in wheat–chickpea–wheat rotation ($\ln R = -0.01$), but it was nonsignificant according to the authors. Moreover, no weeding reduced yield significantly as compared to chemical weed management (summary $\ln R = -0.26$, [0.04, 0.69], $n = 5$ database entries). This finding was consistent across all included trials. However, the Q-test did not result in significantly heterogeneous effect sizes between all practices ($Q = 14.647$, $p = 0.066$, nine groups). The implementation of alternative practices in pulse cropping systems showed ambivalent results for the yield of the grown pulse (immediate effect, summary $\ln R = 0.04$, [−0.20, 0.29], $n = 38$ database entries) but tends to have a positive effect on the yield of the following crop (residual effect, summary $\ln R = 0.33$, [−0.06, 0.68], $n = 14$ database entries). These effects were also significantly heterogeneous between groups ($Q = 8.773$, $p = 0.003$, two groups).

In the case of biological soil quality, we did not find an overall statistically significant effect (Figure 4C). Here, crop diversification practices and tillage regimes were tested in relation to this service in Mediterranean pulse cropping. The effect of rotation, intercropping and reduced tillage on soil biological indices was insignificant in either direction. However, we found a significant positive impact of no tillage on biological soil quality (summary $\ln R = 0.56$, [0.03, 0.95], $n = 11$ database entries). Also, the heterogeneity of the effect sizes between the groups (practices) was significant ($Q = 20.509$, $p = 0.000$, four groups). In relation to chemical soil quality, similar practices had been tested as factors in field trials as for biological quality (Figure 4C,D). In terms of physical soil quality, crop rotations were mostly tested as an alternative practice (Figure 4E). No tillage was examined once in a pulse system in the Mediterranean. For chemical and physical soil quality, our meta-analysis did not result in any significant effects, neither of the practices nor in an overall summary or heterogeneity test.

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FIGURE 5 | Site-specific paired effects (ln*R*) of alternative practices on two ecosystem services, either yield and on-field diversity ($N = 6$ studies, $n = 9$ database entries) or yield and soil quality ($N = 6$ studies, $n = 24$ database entries). The symbols in the scatterplot contain two pieces of information: The shape represents the tested practice and the colour the respective ecosystem service examined.

3.3 | Multibeneficial Practices

A total of 12 trials also examined the influence of a certain practice on more than one of the ESs we focused on. Six studies (resulting in $n = 9$ database entries) tested the effect of either organic management or a conservation tillage regime on biodiversity and yield in pulse cropping systems in the Mediterranean. The results of the biodiversity–yield multiservice trials were ambiguous (Figure 5). Some sites had trade-offs between biodiversity and yield under reduced tillage and organic management. Another six studies (resulting in $n = 24$ database entries) examined the effect of the integration of a pulse into the crop rotation or no-tillage operations in pulse cropping systems on soil quality and yield. In these trials, no-tillage operations tended to produce synergistic effects by increasing yield and biological/chemical soil quality on the experimental sites (Figures 4B,C and 5). For chemical soil quality and yield, crop rotation also tended to be synergistic on multiple sites. The paired effects of crop rotation on physical soil quality and yield were divergent and seem to depend on other factors. Overall, the summary effects and paired effects analyses indicated that from those practices up to now tested in field, no or reduced tillage tends to be the most synergistic practice for all three examined services in pulse cropping systems in the Mediterranean.

4 | Discussion

In total, we screened nearly 6000 English peer-reviewed articles, of which more than half were only for biodiversity, to synthesize current quantitative evidence of alternative farming systems in Mediterranean pulse or lentil and chickpea systems, respectively, on biodiversity, yield and soil quality. Most research focused on soil quality, primarily its chemical properties, whereby a variety of indicators, 29 in total, were used to evaluate soil services. Biodiversity studies in pulse systems were least common, with arable flora frequently used as an indicator. The eligible trials indicated that alternative farming practices generally resulted in higher yields for both the lentil or chickpea crops and subsequent cereal crops. Biodiversity, measured as arable flora richness, was also greater during the pulse and residual cereal phases under alternative farming methods. Significant benefits were noted from organic farming on biodiversity, no-tillage farming on soil quality and diverse crop rotations on lentil or chickpea yield or yield of the residual crop. Furthermore, in trials that assessed multiple services, no-tillage farming showed benefits for both yield and soil quality. Overall, using organic and conservation agriculture techniques appears to be effective for enhancing the ES delivery of pulse crops, especially in lentil and chickpea.

4.1 | Effects of Alternative Practices

4.1.1 | On-Field Biodiversity

We kept our literature search open to various species groups as possible indicators to describe associated diversity. However, most eligible studies surveyed arable flora. Effect sizes for reduced tillage were volatile, whereas no-tillage systems showed a more evident tendency towards positive effects, but both were nonsignificant in our summary. Soil tillage, in general, influences the floral seed bank and species occurrence (i.e., by soil inversion and presence/absence of disturbance) (Nichols et al. 2015). Several evidence-based studies summarize that changing tillage regimes certainly acts as a filter and induces (functional) changes in the community composition of arable plants, but whether they increase overall richness remains unclear. This uncertainty is

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mainly explained by the fact that other associated management decisions, such as crop rotation and fertilization as well as weather conditions, can also interact with tillage effects on arable flora (Armengot et al. 2016; Clements, Weise, and Swanton 1994; Gaba et al. 2017; Holland 2004; Nichols et al. 2015; Travlos et al. 2018).

Organic management of pulses shows a clear and significant increase in biodiversity compared to conventional farming. Our findings are similar to the results of other syntheses and cropping systems, which also revealed that agrienvironmental measures and specifically organic management induce considerable increases in plant species richness (Albrecht et al. 2016; Batáry et al. 2011; Bengtsson, Ahnström, and Weibull 2005; González del Portillo, Arroyo, and Morales 2022; Hole et al. 2005; Stein-Bachinger et al. 2021; Tuck et al. 2014). As we focused on plot-scale studies, the increase of plant species richness in organically managed pulse systems can most likely be explained by the nonuse of herbicides.

Although organic management in pulse systems has a significant positive effect on biodiversity, between-group heterogeneity is nonsignificant. This indicates that subgroup summary effects are homogenously distributed estimators around the combined summary effect in general, practically meaning that alternative management practices in pulse systems tend to influence biodiversity positively but do not show a statistically significant effect when fitted into a summarizing model. In agribiodiversity studies, the field history, the local seed bank and landscape contextual factors also should find consideration (Bredemeier et al. 2024). In the reports eligible for our study, this information was not reported and thus could not be taken into account as moderators. Findings from other studies in cereal agroecosystems in the Mediterranean about the role of the landscape context are ambivalent. While some studies did not find a significant influence of the landscape context on segetal flora (Armengot et al. 2011), others show the importance of landscape heterogeneity for arable flora diversity in agroecosystems (Solé-Senan et al. 2014), especially impacting rare segetal species (Rotchés-Ribalta et al. 2015). Moreover, the local field-specific characteristics, such as the species pool, seem important for rare wild flora emergence in croplands (Rotchés-Ribalta et al. 2015).

The existence of complex and scale-dependent interactions between agricultural land-use intensity (which correlates with yield) and biodiversity (conservation) and ES has been repeatedly demonstrated (Dullinger et al. 2021; Gebhardt et al. 2023; Kleijn et al. 2009; Maskell et al. 2019). Gonthier et al. (2014) particularly proved in relation to wild flora that management intensity has a stronger effect on flora biodiversity than landscape complexity. Following the intensity diversity matrix of López Rodríguez, van Bussel, and Alkemade (2024) for global modelling of ES and biodiversity, legumes can help enhance diversity at a medium intensity level. Thus, land-use intensity on a landscape scale needs to be addressed in agroecological research. However, our study has not addressed such impacts beyond the plot and farm scales.

4.1.2 | Food/Fodder Provision

Most studies measured the provisioning ES of lentils and chickpeas through grain yield as a parameter (Table 3). Two management practices significantly influenced the yield effect sizes in our meta-analysis: diversified crop rotations including lentil and chickpea (increasing yields) and no weeding (decreasing yields) (Figure 4B). Not surprisingly, crop rotations, including pulses, positively influenced yield compared to cereal monocropping, especially focusing on the residual effect on the subsequent crop. The positive effect of legumes on soil fertility due to their nitrogen fixation ability is widely known (González del Portillo, Arroyo, and Morales 2022; Stagnari et al. 2017). This enhances growing conditions for the subsequent crop in the rotation, if nitrogen leaching is properly prevented, as more readily available nutrients are accessible in the soil (Berrada, Shivakumar, and Yaduraju 2007; FAO 2016b; Kakraliya et al. 2018). This precrop effect has been demonstrated in several regions, not only the Mediterranean (Ditzler et al. 2021; Döring 2015; Liu et al. 2019; Preissel et al. 2015, 2017; Stagnari et al. 2017). Therefore, even in earlier times, legumes have been implemented in traditional Mediterranean cropping patterns (Buonincontri et al. 2017), and still, today, they are a main part of certain farming practices, such as organic farming (European Union 2018, Regulation 2018/848, annex II, part I, 1.9.2). Another expected result was a significant decrease in lentil and chickpea yields without weeding compared to chemical weed control. Lentil and chickpea are short in vegetative height and grow slowly in the early crop stage. For these reasons, they have a relatively low competitive ability against weeds. Without any active weed management, a high weed density in the fields results in a disadvantage of the pulses in the crop–weed competition for resources, poor crop establishment and lower harvestability, ultimately leading to yield reductions (Brand et al. 2007; Döring 2015; Yenish 2007). The frequently reported range of yield loss in lentil and chickpea due to weed competition ranges from 23% to 87% for chickpea (Yenish 2007) and from 37.7% to 58.8% for lentil (Kuber et al. 2016). With a summary effect of $\ln R$ $-0.26 \approx -23\%$ yield reduction of lentil and chickpea in no-weeding regimes, our results are at the lower bound of this range but still correspond with previous results.

4.1.3 | Soil Quality

The influence of different management practices on soil quality indicators in lentil or chickpea systems was diverse and overall not significant in combined summary effects for either biological, chemical or physical soil quality. We tie this to the fact that nearly half of all database entries stem from short-term studies (duration ≤ 5 years) and more than 20% of the overall dataset were annual trials. Many soil properties, especially chemical (i.e., organic matter) or physical, are typically slow variables. Therefore, short-term studies cannot be expected to properly show the effects on soil quality (Bai et al. 2016; Bünemann et al. 2018; Duru et al. 2015; Grosse et al. 2020). Biological soil quality indicators are reported to be more sensitive to changes in management practices (Aziz, Mahmood, and Islam 2013; Nunes et al. 2020), and conservation agriculture has been proven to be beneficial to microbial communities and activities (Lee et al. 2019; K. Page, Dang, and Dalal 2020; Zuber and Villamil 2016). From our analysis, we can now confirm that these findings are also true for the special case of pulse cropping.

Surprisingly, we did not find any significant influence of crop rotations diversified by lentils or chickpeas on soil quality, not

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even on chemical quality, although the biological nitrogen fixation ability of pulses is probably their most prominent trait, and several studies have demonstrated the positive effect of legumes on soil nutrients (Ditzler et al. 2021; Kakraliya et al. 2018; Yang et al. 2021). We explain this by the fact that only a very small amount of studies in the subgroup crop rotation measured nitrogen-related parameters (six studies resulting in eight database entries compared to a total of 33 database entries), and we did not interpret these studies separately within the chemical soil quality group. Another factor that could explain the absence of significant soil quality improvements when using lentil- and chickpea-inclusive rotations could be the overshadowing effect of other associated management decisions, especially soil cultivation techniques, which were reported by several authors (López-Bellido et al. 1997; López-Bellido et al. 2020; Melero et al. 2011; Montemurro and Maiorana 2015).

4.2 | Multibeneficial Practices for Biodiversity and ES Enhancement

From an overview of the trials dealing with several ES, we can deduce a first tendency that elements of organic and conservation agriculture seem promising techniques for service-enhancing pulse management. Also, other studies on aggregated ES level come to similar conclusions: In another study in the Mediterranean, conservation agriculture, especially no/reduced tillage, lessens trade-offs the most (Lee et al. 2019). In a long-term multiservice experiment in Europe, the ES multifunctionality superiority of conservation and organic farming compared to conventional cropping was proven. Different regulating and supporting ESs were enhanced here, but conventional cropping was still higher yielding (Wittwer et al. 2021). Globally, Garbach et al. (2017) synthesize that most studies provide evidence that organic and conservation agriculture are synergistic or neutral for the ES combinations of yield and soil quality. Nevertheless, for the concrete case of alternative practices in pulse systems in the Mediterranean, our research shows that empirical evidence and multiservice studies, especially with a focus on biodiversity, are still scarce and yet too few to deduce clear trade-offs or even label a practice as multibeneficial.

5 | Conclusion

Our study provides the first meta-analysis on effects of alternative management decisions on biodiversity and ES in alternative pulse systems. Organic and conservation agriculture elements seem promising starting points for ES-enhancing pulse management: We found significant positive impacts of organic farming on biodiversity, no tillage on soil quality and diversified rotations on yield. In multiservice trials, no tillage tended to be synergistic for yield and soil quality. However, the impact of management factors in pulse systems should not be evaluated in isolation from local site conditions. In general, empirical and quantifiable evidence about alternative pulse practices and multiservice studies, especially focusing on nonmarket pulse services and biodiversity, are still scarce. Therefore, currently, it is not possible to make broad, data-driven management recommendations. Nevertheless, our findings are well founded hypotheses that warrant further investigations and/or can be tested in practical settings and highlight current research and knowledge gaps. We recommend targeting the following research needs: (i) synthesizing evidence from grey literature, (ii) establishing long-term cropping trials to account for slow variables in ecosystem processes, (iii) installing standardized pulse field trials testing a wide range of different alternative management practices (other than tillage) and their combinations in a diverse set of environments and (iv) examining particularly associated biodiversity and multiple-service outputs.

Author Contributions

Anna-Lena Vollheyde: conceptualization, formal analysis, investigation, methodology, visualization, writing–original draft, writing–review and editing. **Miguel A. Cebrián-Piqueras:** conceptualization, funding acquisition, supervision, writing–review and editing. **Christina von Haaren:** conceptualization, funding acquisition, supervision, writing–original draft, writing–review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are openly available at Open Research Knowledge Graph (for biodiversity at https://doi.org/10.48366/R677195, for yield at https://doi.org/10.48366/R641482 and for soil quality at https://doi.org/10.48366/R641487).

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