agronomy

MDPI

Review

The Effects of Cover Crops on Multiple Environmental Sustainability Indicators—A Review

Clément Rivière [1], Audrey Béthinger [1] and Jacques-Eric Bergez [2,*]

[1] DEPE, INRAE, CEDEX 07, F-75338 Paris, France
[2] AGIR, INRAE, Université de Toulouse, F-31320 Castanet-Tolosan, France
* Correspondence: jacques-eric.bergez@inrae.fr

Abstract: Cover crops have been introduced in European agricultural systems due to their multiple agro-ecological services and environmental benefits, which do not necessarily affect profitability. Our paper follows a systematic literature review approach to highlight the results of 51 studies on the effects of adopting cover crops. We used a list of 41 agri-environmental sustainability indicators to present the different impacts of cover crops in European pedoclimatic situations. Herein, we review the positive effects of cover crops on agri-environmental sustainability (e.g., reduced soil erosion and nitrate leaching, higher carbon sequestration and soil quality, biodiversity enhancement, and reduced mineral fertilizer requirement), but also the more variable effects associated with the use of cover crops (e.g., management and interest for farm economics, nutrient and water competition with cash crops, and improved GHG balance, even if N20 emissions are slightly increased). Our review highlights these synergies among the sustainability indicators. More research data are needed on the multiple effects of cover crops in the context of diverse site-specific conditions and farm-management practices, especially between the traditional positive effects of cover crops (i.e., soil C sequestration and fertilizer savings) and their effects on climate change (i.e., GHG net balance and potential effects on global warming).

Keywords: cover crops; European countries; sustainability indicators; multicriteria assessment

Citation: Rivière, C.; Béthinger, A.; Bergez, J.-E. The Effects of Cover Crops on Multiple Environmental Sustainability Indicators—A Review. *Agronomy* **2022**, *12*, 2011. https://doi.org/10.3390/agronomy12092011

Academic Editors: Tiziano Gomiero, Lisa Lobry de Bruyn and Ji Li

Received: 20 July 2022
Accepted: 22 August 2022
Published: 25 August 2022

1. Introduction

Over recent decades, EU member states have shown a willingness to improve the environmental and socio-economic sustainability of their agricultural systems. As part of the European Nitrate Directive, the generalization of permanent soil cover using cover crops (CC) during the fall and winter periods is one of the main European public policies introduced to promote more sustainable agriculture [1]. This soil coverage using CC concerns all fallow periods (i.e., bare soil between the harvest of a main crop and the sowing of the next main crop) that precede a spring-summer crop. There are four main classes of CC [2]: legumes (e.g., alfalfa, vetches, and clovers), non-legumes (e.g., spinach, canola, and flax), grasses (e.g., ryegrass and cereals such as barley), and brassicas (e.g., rapeseed, mustard, radish, and turnip). The use of CC still represents a small percentage of cropland in Europe compared to bare soil. However, it grew from 6.5 to 8.9% of the EU-28 arable land between 2010 and 2016 [3]. Their adoption by farmers is progressing due to an encouragement by agronomists for their multi-ecosystem and agro-ecological services [4,5] and due to policies in some areas of the EU's agricultural land through the Common Agricultural Policy.

The scientific literature on CC's effects on European farming systems mainly deals with environmental sustainability criteria (e.g., the soil erosion rate, soil structure, nitrate leaching, nutrient and organic matter supply, weeds, pest and disease control, soil quality, and greenhouse gas balance) but also with socio-economic criteria (e.g., crop yield and economic returns). Several reviews and meta-analyses have already shown that the adoption of CC in temperate regions can provide multiple benefits to both famers and society [2,4,6–12]. Two reports from the French National Research Institute for Agriculture, Food, and Environment (INRAE, France) have provided a comprehensive bibliographic analysis on the agronomic and environmental effects of introducing CC in cropping systems [1,13]. A recent meta-analysis has shown that CC generate an increase in organic matter, carbon and nitrogen in the soil, better soil erosion control, a decrease in nitrate leaching, and an increase in biodiversity [14]. Besides these positive effects, the literature also highlights the fact that the use of CC can have variable effects. For example, CC increased N_2O emissions but the GHG balance was generally improved when carbon sequestration was considered (e.g., [1,15]). A possible resource (nutrient and water) competition with cash crops may occur, as well as an uncertain economic benefit with lower yields of cash crops in the short-term [6,14]. Despite the numerous papers and reviews on CC's effects on agri-environmental criteria, few have attempted to consider a wide range of sustainability indicators to assess their multiple effects. A study with such an attempt is the recent paper [4]. In this regard, a review of the existing literature about potential CC benefits and disadvantages is needed to better understand the effects of CC on agri-environmental sustainability criteria.

In this paper, we aimed to answer two questions: (i) What are the environmental and socio-economic effects of cover crops' introduction on sustainability indicators across regions in Europe? (ii) How have the effects been assessed and what analytical frameworks have been used? We used the word 'effect' rather than 'impact', as the latter could have a negative connotation while 'effect' is more neutral. The main purpose of this work is to review the effects of introducing CC on the environmental sustainability of agroecosystems by reviewing the literature while considering a wide range of sustainability indicators. This paper describes the empirical material of the conceptual companion paper written by [16].

2. Constitution of a Corpus and Data Analysis

Our study is based on a systematic literature review protocol. According to the Cochrane definition [17], a systematic literature review uses systematic and explicit methods to identify, select, critically appraise, extract, and analyze data from relevant research studies. It is a methodological, rigorous, and reproducible synthesis of the results from scientific papers, undertaken in response to a research question [17]. We used the *rapid review* type that is a form of knowledge synthesis in which components of the systematic literature review process are simplified or omitted to produce information in a timely manner [18]. Such a review follows the following protocol: (i) the literature is searched on more than one database (limited to published sources); (ii) the search is limited by both date and language; (iii) the source screening is performed by a single reviewer; (iv) the data abstraction is performed by one person while another person verifies it; (v) lastly, one person assesses the risk of bias while another person verifies it [18]. Based on this protocol, our systematic literature review is qualitative and provides a synthesis from previous study results, which is different from the quantitative analysis known as meta-analysis.

2.1. From a Research Question to Query Building

We used the PICO (Population, Intervention, Comparator, and Outcome) method for defining the general scope of our review and formulating our questions of interest [17]. The PICO framework helps to outline the keywords for query construction and to set the limits of inclusion and exclusion in the selection process (Table 1).

Population: Refers to the terms related to European countries/regions, i.e., the EU 27 countries plus the United Kingdom and Switzerland, and Common Agricultural Policy.

Intervention: Refers to the presence of CC. We defined a CC as sown plants growing between cash crops and during a fallow period between the harvest and planting of regular crops. From this broad definition, we included cover crops as well as catch crops (known as nitrogen-fixing crops), green manures, and crop residues such as mulch. All these words were entered in our query plus the terms intermediate crop, intercropping, and undersown crop.

Table 1. PICO method and process for query building.

Questions	1. What are the environmental and socio-economic effects of cover crops' introduction on sustainability indicators across regions in Europe? 2. How have the effects been assessed and what analytical frameworks have been used?		
Key concept	Countries of the European Union	Introduction of cover crops (CC)	Assessment of CC's effects and environmental sustainability approaches
Population	- The 27 countries of the European Union (EU) - Plus, the United Kingdom and Switzerland		
Intervention	Presence of CC in the targeted countries		
Comparator	- Farm-management practices with and without CC - Farm systems before and after the use of CC		
Outcome	- CC's effects on multiple sustainability indicators: environmental criteria (e.g., nitrate leaching, erosion, and biodiversity) and socioeconomic criteria (e.g., productivity, crop yields, and climate change) - Sustainability assessment methods: agri-environmental indicators (AEI), ecosystem services assessment (ESA), life cycle assessment (LCA), and yield gap analysis (YGA). - Spatio-temporal monitoring: scientific models and tools used for CC monitoring (e.g., model approaches, remote sensing, and hybrid methods)		
Example of keywords	Europe*, EU*, names of the countries	Catch crop*, cover crop*, crop residue, mulch, intermediate crop	Environment* indicator,sustainability indicator, ecosystem service*, life cycle*, yield gap*, multi-scale

Comparator: Indicates which comparative factors should be considered. We focused this work on studies that reported their results by comparing with/without or before/after the introduction of cover crops.

Outcome: Terms related to the main methods used for assessing environmental sustainability; synonymous terms of sustainability indicators, environmental-effect assessment, or multi-criteria analysis; and generic terms associated with spatial scales for monitoring (cf. Appendix A).

2.2. Literature Research Strategy

We used the Web of Science Core Collection (WoS) and Scopus databases in July 2020. We searched for all types of documents (articles, books, book chapters, reviews, and proceeding papers) with no search limits placed on the citation indexes; a timespan limitation of 2000–2020 of was set, and only English documents were curated. We searched the topic terms related to our PICO key concepts in the title, the abstract, the keywords, and the authors' keywords.

2.3. Study Selection Process and Eligibility Criteria

The detailed study-selection process (Figure 1) was based on the PRISMA diagram [19].

The following criteria were applied to assess the eligibility of the studies and to decide on their inclusion or exclusion in this systematic literature review:

- Studies assessing CC's effects in European countries. We excluded sources from other countries and regions of the world, except for two studies in the USA.
- Studies with a minimum aggregation analysis at the farm and field levels, if available at regional and national scales.
- Studies with a temporal frame of at least three years.
- Studies comparing situations with and without CC, but also studies that deal with other farm-management practices (e.g., reduced fertilization, reduced tillage, or no-till farming) whether in organic, conventional, or both systems.
- Studies reporting at least one of the three outcome types of the PICO framework.

- Document types—articles only (no books, book chapters, reviews, nor proceeding papers). Only primary studies are included in the results of this paper, and other reviews on the subject are only mentioned or discussed.
- Timespan limited to 2000–2020, but we included four studies from 2021.
- Language—English.

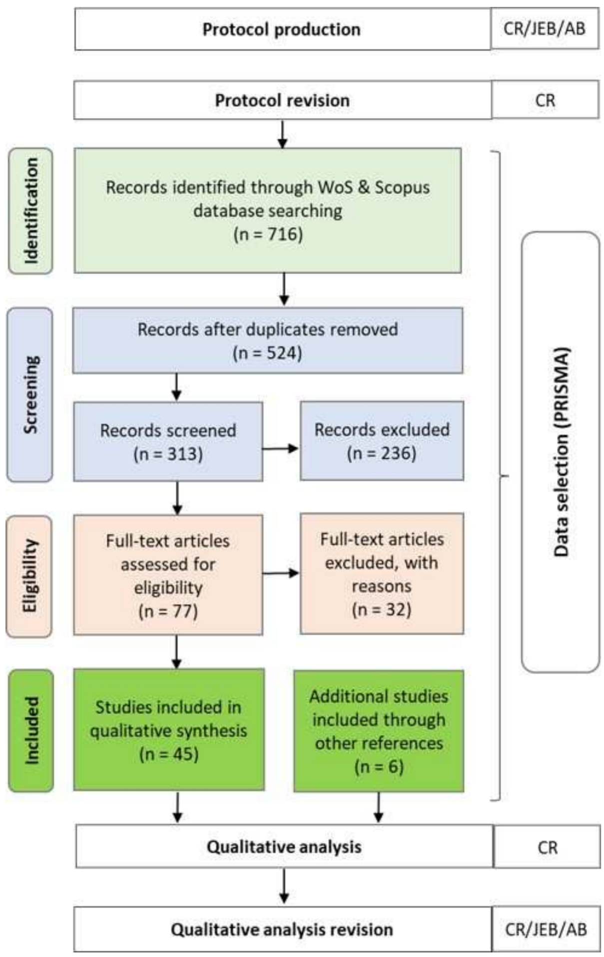

Figure 1. Data selection process—protocol based on PRISMA figure. Initials in the right column indicate the person(s) who performed the given step.

2.4. Data Collection and Qualitative Analysis

In order to help represent the effects of CC, we used the 'Driver-Pressure-State-Impact-Response' (DPSIR) general framework. The DPSIR framework is a conceptual tool for analyzing all the cause-effect relationships of a system between human activity and the environment. According to the DPSIR definition [20], social demographic and economic developments in societies act as a *Driver* (e.g., changes in lifestyles, consumption and production patterns, or land use strategies). These drivers exert some *Pressure* on the environment by releasing pollutant substances (e.g., emissions), physical and biological agents, and use resources for human activities. These pressures alter the *State* of the environment, which refers to the quantifiable and qualitative physical, biological, and chemical conditions in a defined area. These chain reaction flows *Impact* the environment and the provision of ecosystem benefits and those of the socioeconomic system, which leads to a societal and political *Response* that refers to the actions carried out by society and governments in order to minimize the negative effects on the environment due to anthropogenic developments. To represent this cause-effect chain for the use of CC on the environment, we used the analytical framework developed by [16], who developed a set of 41 environmental issues sorted in a DPSIR manner:

(i) *Driver*, three indicators: nutrition of human population, agri-environmental public policy, and farmers' income-economy.
(ii) *Pressure*, eight indicators: landscape structure, land use, traffic intensity (labor input, soil compaction, number of machineries in use, etc.), fertilizer inputs, pesticide inputs, water inputs (irrigation), energy inputs, and GHG emissions.
(iii) *State*, eight indicators: albedo, soil structure, soil organic matter content, soil-storage capacity, nutrient levels in soil (availability of N, P, and K), water-use efficiency, N-use efficiency, and sensitivity to nutrient losses (i.e., nitrate leaching).
(iv) *Impact*, 21 indicators for assessing CC's effects on provisional, regulatory, and cultural ecosystem services (i.e., harvested biomass or yield, yield gap, carbon storage or sequestration, erosion control rate, infiltration rate, drinking water, water purification, nutrient regulation, local climate regulation, pest and disease control, pollination, and aesthetic value), but also on society and the environment (i.e., human health, changes in soil quality, water use and scarcity, eutrophication, aquatic or terrestrial ecotoxicity, fine particulate matter formation, global climate change, biodiversity loss, energy depletion, and natural resource availability).

3. Results

We gathered the conclusions of the 51 papers obtained by the PRISMA approach that assessed either the positive, negative, or variable effects of CC on the environmental sustainability of different agroecosystems (cf. Table A1). As the rapid SLR is mainly a qualitative approach, we present the results by summing the different papers per environmental indicator depending on the observed impact: positive (in green), negative (in red), and variable (in grey) (Figure 2).

Some indicators, as presented in Section 2.4, have been studied to various degrees. For some indicators, there are many papers (e.g., 'GHG emissions' and 'Harvested biomass/Yield') while for some others no papers have been established (e.g., 'Nutrition of population', 'Water purification', 'Local climate regulation', 'Aesthetic value', and 'Fine particulate matter formation').

For quite a large number of indicators, the different papers report only positive effects of the cover crop (15/41—36.6%), and occasionally along with a variable effect (6/41—14.6%), as it may depend on the experimental context. This is mainly the case for the "state indicators". For five indicators, positive and negative effects are reported. This is mainly the case for the agronomical inputs ('Water input', 'Fertilization input', and 'Pesticides input'). However, for some indicators, more controversial effects have been reported (5/41—12.2%). Let us focus on the two indicators that have the highest number of studies in more detail:

- 'GHG emission' as part of the 'Pressure indicators'. Since the year 2000, the effects of cover crops on GHG emissions have been largely studied (see Appendix B). On the one hand, different authors have measured a positive effect of CC on GHG emission, often with a focus on N_2O emissions and sometimes CO_2:
    - Ref. [21] used an LCA approach in a Mediterranean organic-fruit-orchard system, which showed the potential of CC to reduce GHG emissions. Their results also suggested that the increase in N_2O emissions due to the extra N inputs from the legume CC was much lower than the effect on soil carbon in terms of climate change mitigation.
    - Over a 10-year experiment in Spain, Ref. [22] simulated the effects of the establishment of CC (vetch and barley), compared to the traditional fall-winter fallow, on the environmental pressures in terms of Global Warming Potential (GWP) and the total CO_2-eq emissions balance. They showed that higher GHG emission mitigation was obtained with legume CC, but both legume and cereal CC reduced N_2O emissions. Their study also highlighted that the management of synthetic N fertilization is crucial for GWP mitigation, particularly through the adjustment of N inputs to crop needs, which allows for N-synthetic inputs to be reduced with CC treatments.

- ○ Compared to bare soil, Ref. [15] showed—via simulating scenarios—that CC could improve the mean direct GHG balance by 315 kg CO_2-eq·ha^{-1}·year^{-1} from 2007 to 2052 in rainfed and irrigated cropping systems of southern France. This decrease in CO_2-eq (CO_2 + N_2O) emitted in cropping systems represented a decrease from 4.5% to 9% of annual GHG emissions from French agriculture.
- ○ Ref. [23] have assessed the effects of management practices on GHG emissions for 15 European cropland sites and showed that when maize was combined with CC, compared to sites where no CC was grown, organic carbon fertilization inputs increased, while GHG emissions from fertilizer operations were mitigated.
- ○ Using a model approach combined with remote sensing, Ref. [24] assessed the mitigatory potential of CC on GHG fluxes (CO_2 and N_2O) and albedo. The authors found that CC could reduce CO_2 emissions without affecting N_2O emissions by the year 2050.
- ○ Ref. [25] showed that CC increased CO_2 emissions by 44% from 2007 to 2013 in the soils of Veneto (Italy) with the highest soil organic carbon content, but overall, CC management reduced GHG emissions by mitigating N_2O (by more than 50%) and CH_4 emissions, mainly due to their positive effect of an increased fertilization efficiency.
- ○ Ref. [26], across all arable land in France, highlighted that the CC scenario slightly increased N_2O emissions but decreased indirect emissions and had the highest mitigation potential (9.1 Mt CO_2-eq·yr^{-1}) compared to the baseline scenario.

On the other hand, the negative effects of CC on the GHG emissions indicator were reported:

- ○ Ref. [27] showed that the introduction of a legume CC increased N levels in the soil through additional biological fixation in almost all the simulated locations across the EU. Despite the strong reduction of mineral N fertilizers, using leguminous CC continuously led to a soil N surplus in the mid-term that increased gaseous N emissions and induced an increase in the cumulative soil GHG flux of 31 Mg CO_2-eq·ha^{-1} for EU countries by 2100.
- ○ Ref. [28] studied a 19-year experiment in Northern France and reported that legume CC and green manures provided the highest organic N inputs from symbiotic fixation but also high rates of N_2O emissions due to the absence of tillage and the presence of living mulch compared to its incorporation in soil. These high N_2O emissions resulted in a slightly positive GHG balance.
- ○ Ref. [29] showed through long-term field experiments in Europe that CC could lead to substantial N_2O emissions after their incorporation in soil and decomposition, particularly for legume CC with high N content.
- ○ Ref. [30], using an LCA approach, reported that CC led to a higher global warming potential in Switzerland (especially the legume CC treatment, followed by a non-legume and a mixed treatment) when compared to the use of bare soil during the fallow period by increasing GHG emissions in the field (i.e., additional N_2O emissions from crop residues) and the additional energy demand for seeding/mulching (i.e., the additional CO_2 emissions from the increased number of machines necessary for the cultivation of CC).
- ○ The French experiment of [31] highlighted that conventional intensive tillage systems with the introduction of CC presented greater onsite GHG emissions compared to the use of fallow between cash crops, again due to the energy demand of the machinery use necessary for the CC's establishment (i.e., pre-sowing-soil tillage, sowing, and CC incorporation to the soil) and termination. On the other hand, legume CC significantly decreased external GHG emissions due to lower requirements for N fertilizers.
- ○ In the Veneto region, Ref. [32] simulated different treatments from 2010 to 2014 and their results indicated that the no-tillage requirements associated with CC practices

reduced CO_2 emissions due to the reduced use of mechanization and yield-drying requirements. However, this reduction in CO_2 emissions was largely offset by higher emissions from pesticides and planting operations.

◦ Ref. [33] simulated the long-term (1991–2013) effect of manure and composting practices on all the cropland soils of Switzerland with reduced tillage and winter CC compared to conventionally managed soils. The maximum reduction in net GHG emissions was predicted for each crop under the organic compost practice when combined with reduced tillage and winter CC (e.g., -4.17 Mg CO_2-eq·ha^{-1}·yr^{-1} for maize). However, the additional organic matter together with the manure practice alone or combined with winter CC tended to increase soil N_2O emissions.

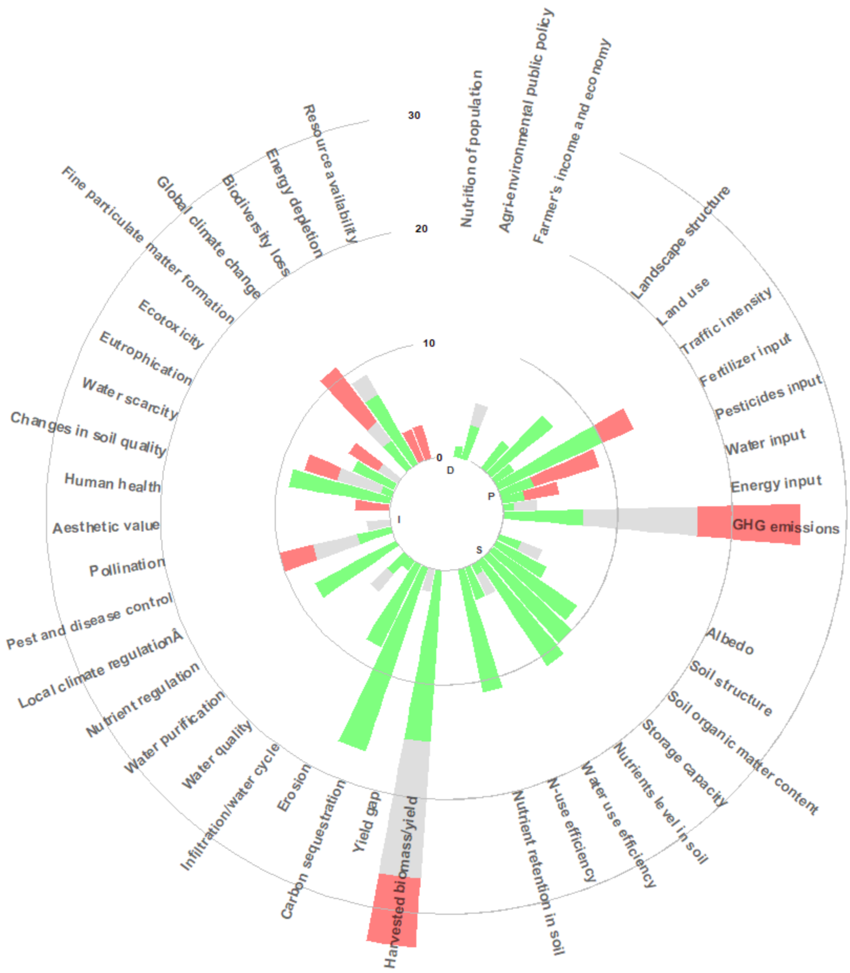

Figure 2. For each environmental sustainability indicator, the bar represents the number of papers showing a positive (green), a negative (red), or a variable effect (grey) on the environment. Indicators are sorted depending on the DPSIR framework (see [16]).

It is quite clear that for such a complex process (GHG emission), the results greatly differ depending on how it is calculated and on the system at hand.

- 'Harvested biomass/yield' as part of the 'Impact indicators'. Studies reported variable and potential negative effects of CC on "Harvested biomass/yield'.
    ◦ Ref. [34], in a Mediterranean vineyard experiment, showed that yields decreased as the CC's soil coverage increased, especially in shallow soils. From this study, a CC soil coverage of 30% was recommended for balancing the trade-offs between Mediterranean winegrowers' yield objectives and soil-protection goals.

- ◦ In northern French conservation agriculture systems with CC, Ref. [28] showed that yields were lower compared to other systems.
- ◦ Ref. [35] showed that repeated catch crops can lead to positive effects on harvested biomass even if those effects do not always appear in the first few years, due to the effect of cover crops on the soil's N mineralization that takes several years to have an impact on yields.
- ◦ Ref. [36] showed that CC cultivation led to a variable effect on main crop yields, but compared to the business-as-usual practices, CC slightly improved crop yields, particularly when CC were introduced between two winter cereals.
- ◦ Ref. [26] observed that the use of CC had little effect on most crop yields in France, except for rapeseed (+8%) and silage maize (−7%).

4. Discussion and Conclusions

Compared to the study by [1] or even [4], in this review, we used a different approach by scanning a set of indicators involving flows and synergies between the results among the sustainability indicators. If one wants a more quantitative analysis on the impact of introducing CC on some specific indicators, another methodology such as a meta-analysis should be used. Following the presentation of these results, as expected, CC had positive effects on the selected sustainability indicators in most of the studies assessed. Cover crops increased the field-scale benefits and sustainability of agricultural production systems without seeking an economic return *a priori*, and their area increased in temperate countries such as the US [37] and those in Europe [3]. The economic interest in the introduction of cover crops compared to a bare soil is known and predictable but not always similar and therefore provides contrasts. For example, Ref. [5] performed a comprehensive economical analysis of the impacts of CC on the economic returns of the cropping system. In general, due to the implementation of a CC, the farmers could generally obtain good yields. More recently, a two-year maize-soybean rotation with an oat CC provided a 5% increase in the direct margin in a field experiment in southwest France. This experiment was conducted as part of the DiverIMPACTS project running from 2017 to 2022 and supported by the EU's HORIZON 2020 research program. However, the effect of CC towards a potential economic return for farmers involves a greater workload, which may hinder the CC's acceptance. For example, under 2% of US cash-crop-production farmland currently incorporates a cover crop [37]. In addition to this barrier, there is a new crucial problem directly related to climate change and the trend of more frequent dry summers, which is an increasing issue in successfully establishing a cover crop [38].

In general, the controversial and variable effects of CC [12] in the selected studies have shown the differences in the systems evaluated, the differences in the calculation methods used, and the synergies between the sustainability indicators (e.g., CC's effects on pesticide inputs or water inputs and pest and disease control or water scarcity). Indeed, the negative or variable effects of CC are mainly due to the variability within the key management factors, such as the sowing and destruction dates of the CC, the choice of species and their degree of mixing, and the adapted practices with respect to the specific conditions of the different agricultural sites (soils, climate, and cropping systems), where each context causes different problems [38]. For example, we know that non-leguminous species tend to increase a possible N-preemptive competition that is unfavorable for the succeeding cash crops, especially when they are destroyed late, whereas leguminous species that are destroyed earlier produce green manures that could be favorable to yields [1,6]. Taking another example, we know that one of the most important cover crop benefits is decreasing nitrate leaching by increasing the N retention in soils over winter [39]. In a DiverIMPACTS study case in the Netherlands—a field experiment that introduced CC (such as Italian rye-grass) sown under maize during the growing season or after the harvest—it was recommended that to prevent hydric stress for maize, CC should be removed under a month before sowing the cash crop, as already demonstrated (e.g., [12]). In terms of GHG emissions, CC have positive effects that can mitigate the global warming potential of agricultural fields [11], but the results of the studies are highly variable as this factor depends on explanatory elements such as the depth of the soil or the choice of species [15,28]. So, it is important to understand the different conditions and calculation methods in the selected studies, which may or may not include some trade-offs, to clarify the conclusions on GHG emissions and global climate change analyses. Another important point to consider is that the variability of the results, in general, is also due to differences between the short- and long-terms, and this review considers more short-term studies (3–5 years duration). For example, the uncertain economic benefit of CC through variable effects on the yields of subsequent cash crops is assessed in the short-term, whereas in the long-term (10–15 years at least) the effects of CC are generally positive, except on legumes [1,6].

From this systematic literature review, we can also conclude that there is quite a lot of variability between the selected studies; therefore, there is a need for more data on the effects of CC on environmental issues. The introduction of catch and cover crops must be based on site-specific agricultural management across EU countries and on their different environmental conditions, especially under climate change conditions. This would help to clarify the synergies among the indicators caused by the effects of cover crops, for example, on the indicator of global climate change that is mainly related to the GHG net balance (i.e., soil carbon sequestration and GHG emissions-exchange indicators), inputs savings (i.e., mostly fertilizer input indicator), and albedo indicators.

Author Contributions: Conceptualization and methodology, C.R., A.B., J.-E.B. Writing and original draft preparation, C.R. Reviewing and editing, C.R., A.B., J.-E.B. All authors have read and agreed to the published version of the manuscript.

Funding: This study was financed by INRAE's DEPE department and the TEMPAG organization (OECD).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors wish to thank the INRAE librarians (S. Le-Perchec and V. Lelièvre) who helped building the general literature query and J Constantin and L Alletto for their careful reading and comments.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study, in the collection, analyses, or interpretation of data, and no role in the writing of the manuscript or in the decision to publish the results.

Appendix A. Details of the Query for the WoS Database (Same Query for Scopus)—July 2020

Set 1: TS = (europe* OR "EU" OR "european union*" OR "european community" OR "EU countr*" OR "EU state*" OR "EU member state*" OR "EU region*" OR "southern europe" OR "northern europe" OR "western europe" OR "eastern europe" OR austria* OR belgi* OR bulgaria* OR croatia* OR cyprus OR cypriot OR "czech republic" OR czechia OR denmark OR danmark OR danish OR estonia* OR finland OR finnish OR france OR french OR german* OR greece OR greek OR hungary OR hungarian OR ireland OR irish OR italy OR italian OR latvia* OR lithuania* OR luxembourg OR malta OR maltese OR netherlands OR dutch OR holland OR poland OR polish OR portugal OR portuguese OR romania* OR slovakia* OR slovenia* OR spain* OR sweden OR swedish OR switzerland OR swiss OR "united kingdom" OR "UK" OR "great britain" OR britain OR england OR "common agricultur* polic*" OR "CAP")

Set 2: TS = ("catch crop*" OR "cover crop*" OR "crop residue*" OR "intermediate crop*" OR "living mulch*" OR "dead mulch*" OR "mulch of residue*" OR "green manur*" OR "intermediate plant*" OR "inter crop*" OR "undersown crop*")

Set 3: #1 AND #2

Set 4: TS = ("ecosystem* service*" OR "ecosystem* approach*" OR "ecosystem* analysis" OR "ecosystem* service* assessment$" OR "ecosystem* service* analysis" OR "ecosystem* service* approach*" OR "LCA" OR "life cycle assessment*" OR "life cycle analysis" OR "life cycle approach*" OR "yield* gap*" OR "yield* gap* analysis" OR "yield* gap* assessment$" OR "yield* gap* approach*" OR "AEI*" OR "agri* environment* indicator$" OR "agro environment* indicator$" OR "environment* indicator$" OR "sustainability indicator$" OR "pressure indicator$" OR "impact* indicator$" OR "agri* environment* assessment*" OR "agri* environment* monitor*" OR "agri* environment* analysis" OR "agri* environment* evaluat*" OR "environment* assessment*" OR "environment* evaluat*" OR "environment* impact$" OR "environment* effect$" OR "impact* assessment*" OR "impact* evaluation*" OR "effect* assessment*" OR "effect* evaluation*" OR "benefit* analysis" OR "multicriteria*" OR "multi criteria*" OR "model* approach*" OR "model* scale$" OR "large scale$" OR "cross scale$" OR "multi scale*" OR "multilevel" OR "multi level" OR "regional level" OR "regional scale" OR "national level" OR "national scale" OR "national monitor*")

Query used: (#3 AND #4)

Language: English

Document types: All types of documents

Custom year range: 2000 to 2020

Web of Science Core Collection: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC

Appendix B

Table A1. Selected studies from the systematic literature review of the cover crops case study.

N°	Selected Author and Study Names by Chronological Order	Agri-Environmental Indicators Assessed	Location and Cash Crop Production	Sustainability Assessment Methods Used
1	[40]	Erosion	Spain (South) Olive orchard	Field trial; Agri-environmental indicators (AEI)
2	[23]	Land use; GHG emissions; Carbon sequestration; Erosion; Global climate change	Europe (climate gradient) Rapeseed, Winter wheat, Sunflower, Durum wheat, Peas, Sorghum, Rye, grass/maize, Fennel/maize, Spring barley, Maize, Winter barley, Sugar beet, Mustard/maize, Triticale, Potato seeds, Potato, Rice	Modelling; AEI, Ecosystem Services Assessment (ESA), Life Cycle Assessment (LCA)
3	[41]	Water use efficiency; Water cycle; Water scarcity	France (South) Vineyard	Modelling; AEI, ESA
4	[42]	Nutrient levels in soil; Eutrophication	Belgium (Walloon region) Typical Belgium crop rotations	Modelling; AEI
5	[35]	Fertilizer input; Nutrient retention in soil; Harvested biomass/yield; Nutrient regulation	France (North) Winter wheat, Spring barley, Spring pea, Silage maize, Sugar beet	Modelling; AEI
6	[36]	Nutrient retention in soil; Harvested biomass/yield; Nutrient regulation	Western Europe Fodder crop rotations: grass leys, legume leys, winter wheat, barley, maize	Modelling; AEI

Table A1. *Cont.*

N°	Selected Author and Study Names by Chronological Order	Agri-Environmental Indicators Assessed	Location and Cash Crop Production	Sustainability Assessment Methods Used
7	[43]	Storage capacity; Carbon sequestration	European Union arable soils Main European cash crops	Modelling; AEI
8	[44]	Farmers' economy; GHG emissions; Nutrient retention in soil; Harvested biomass/yield; Carbon sequestration; Erosion; Nutrient regulation; Water cycle; Pest control; Changes in soil quality	USA (Mid-Atlantic climate) Soybean, Maize, Wheat	Modelling; AEI, ESA
9	[21]	Traffic intensity; Fertilizer input; Pesticide input; Water input; Energy input; GHG emissions; Nutrient levels in soil; Harvested biomass/yield; Carbon sequestration; Global climate change	Spain Orchards	Modelling; LCA
10	[22]	Soil structure; Soil organic matter (SOM) content; Carbon sequestration	Spain (Southeast) Organic rainfed orchard	Experiment; AEI
11	[45]	Fertilizer input; Storage capacity; Nutrient retention in soil; Harvested biomass/yield; Carbon sequestration; Nutrient regulation	France (Brittany) Winter wheat, forage maize	Long-term experiment; AEI
12	[46]	Pesticide input; Harvested biomass/yield; Pest control; Biodiversity loss	France (Burgundy and Poitou-charente) 26 cropping systems	Modelling and simulation; AEI, AEI-Yield Gap Analysis (YGA)
13	[47]	Human health; Changes in soil quality; Eutrophication; Ecotoxicity; Global climate change; Biodiversity loss; Energy depletion	France (Burgundy, Moselle, Beauce) Oilseed rape, Rape seed, Winter wheat, Winter barley, Spring barley, Winter pea, Spring pea	Modelling; Life cycle assessment (LCA)
14	[48]	Landscape structure; Land use; Erosion	pan European sites Common wheat, Durum wheat, Rye, Barley, Grain maize, Rice, Dried pulses, Protein crop, Potatoes, Sugar beet, Oilseeds, Rape, Sunflower seed, Linseed, Soya, Cotton seed, Tobacco	Modelling; AEI
15	[49]	Farmers' economy; Pesticide input; GHG emissions; Harvested biomass/yield; Erosion; Pest control; Water scarcity;	France (Haute-Normandie, Champagne-Ardenne, Rhône-Alpes, Centre, Aquitaine, Franche-Comté) Alfalfa, Faba bean, Fescue, Hemp, Fiber flax, Grain maize, Silage maize, Oilseed rape, Sugar beet, Soybean, Spring pea, Sunflower, Triticale, Winter barley, Winter pea, Winter wheat	Modelling; AEI

Table A1. *Cont.*

N°	Selected Author and Study Names by Chronological Order	Agri-Environmental Indicators Assessed	Location and Cash Crop Production	Sustainability Assessment Methods Used
16	[25]	GHG emissions; Storage capacity; Nutrient retention in soil; Erosion; Water quality; Nutrient regulation;	Italy (Veneto region) Maize, Wheat, Barley, Soybean, Sunflower, Rapeseed, Potato, Sugar beet, Pastures, and meadows	Modelling and simulation; AEI
17	[50]	Soil structure	Germany (Lower Bavaria) Silage maize and sugar beet	Field trial; AEI
18	[51]	Storage capacity; Nutrient levels in soil; Harvested biomass/yield; Carbon sequestration	France (Southwest) Sorghum, Sunflower, Durum wheat, Winter pea, Soybean, Spring pea	Experiment; AEI
19	[52]	Nutrient levels in soil; Nutrient retention in soil	Belgium (Flanders) Cut grassland, Silage maize, Potatoes, Sugar beets, Winter wheat	Simulated scenarios; AEI
20	[32]	Fertilizer input; Pesticide input; GHG emissions; SOM content; Storage capacity; Carbon sequestration	Italy (Veneto region) Wheat, Maize, Soybean, Rapeseed	Farm scale measurements and modelling; AEI
21	[30]	Eutrophication; Ecotoxicity; Global climate change; Biodiversity loss	Switzerland (Zurich-Reckenholz) Winter wheat, Maize, Faba bean, Grass–clover ley	Field experiment; LCA
22	[53]	N-use efficiency; Harvested biomass/yield	Denmark (Southern Jutland, Central Jutland, Western Zealand) Spring barley, Winter wheat, Spring wheat, Winter rye, Winter triticale, Lupin, Faba bean, Pea, Spring barley, Potato, Grass-clover	Long-term field experiment; AEI, AEI-YGA
23	[54]	Farmers' economy; SOM content; Nutrient levels in soil; Harvested biomass/yield; Water quality	UK (Norfolk) Winter wheat, Winter barley, Spring barley, Spring beans	Field experiment; AEI
24	[34]	Harvested biomass/yield; Water scarcity	France (South) Vineyard	Modelling and simulation; AEI, ESA
25	[55]	Fertilizer input; Harvested biomass/yield; Nutrient regulation	Denmark (Foulum, Jyndevad) Maize, Sugar beet, Hemp, Winter triticale	Field experiment; AEI, ESA
26	[31]	GHG emissions; Carbon sequestration	France (Southwest) Sorghum, Sunflower, Durum wheat, Winter pea	Field experiment and model-simulation; AEI
27	[15]	GHG emissions; Storage capacity; Water use efficiency; Nutrient retention; Carbon sequestration; Water scarcity	France (Southwest) Maize, Wheat, Soybean, Sunflower, Pea, Sorghum	Field experiment and long-term simulating scenarios; AEI, AEI-ESA

Table A1. *Cont.*

N°	Selected Author and Study Names by Chronological Order	Agri-Environmental Indicators Assessed	Location and Cash Crop Production	Sustainability Assessment Methods Used
28	[56]	Soil structure; SOM content; Nutrient levels in soil; Nutrient retention in soil; Changes in soil quality; Biodiversity loss	France (Brittany) Maize, Winter wheat, Winter barley, Silage maize	Farm surveys and modelling; AEI
29	[57]	SOM content; Changes in soil quality	France (North) Spring wheat, Green pea, Maize	Experiment; AEI
30	[58]	Albedo	Europe (pedoclimatic zones) No specific crops.	Satellite, meteorological and land cover data; AEI
31	[59]	SOM content; Storage capacity; Nutrient levels in soil; Carbon sequestration; Water quality; Nutrient regulation; Changes in soil quality	Italy (Veneto region) Winter wheat, Oilseed rape, Soybean, Maize	Field experiment and modelling; AEI, ESA
32	[60]	Land use; Biodiversity loss	Spain (Andalusia) Olive orchards	Field study and modelling; AEI
33	[61]	Farmers' economy; Soil structure; Nutrient levels in soil; Nutrient retention in soil; Harvested biomass/yield; Pest control; Changes in soil quality; Biodiversity loss	UK (Leicestershire) Wheat, Rapeseed	Field experiment; ESA, AEI-ESA
34	[29]	GHG emissions; Nutrient levels in soil; Harvested biomass/yield	Europe (Norway, Denmark, Poland, Switzerland, Italy, Spain) Crop depends on the site (mainly wheat and maize)	Field experiment and model simulation; AEI
35	[22]	Traffic intensity; Fertilizer input; Water input; Energy input; GHG emissions; Albedo; SOM content; Harvested biomass/yield; Global climate change	Spain (Madrid) Maize, Sunflower	Long term field experiment and modelling; AEI
36	[62]	Agri-environmental public policy; Nutrient levels in soil; Erosion, Nutrient regulation; Changes in soil quality	Baltic Sea region Variety of cash crops depending on the region	Analysis and synthesis; AEI
37	[28]	Fertilizer input; GHG emissions; SOM content; Storage capacity; Nutrient levels in soil; N-use efficiency; Nutrient retention; Harvested biomass/yield; Carbon sequestration; Global climate change	Switzerland (Therwil) and Denmark (Aarhus) Alfalfa, Beetroot, White cabbage, Clover-grass ley, Hemp, Lupin, Oat, Potato, Spring barley, Silage maize, Soybean, Spring pea, Spring wheat, Triticale, Winter barley, Winter wheat	Long-term experiment and modelling; AEI
38	[3]	Erosion	Europe Crop depends on the site	Modelling; AEI
39	[63]	Harvested biomass/yield; Pest and disease control	Switzerland (Changins) Maize	Field experiment; AEI

Table A1. *Cont.*

N°	Selected Author and Study Names by Chronological Order	Agri-Environmental Indicators Assessed	Location and Cash Crop Production	Sustainability Assessment Methods Used
40	[24]	GHG emissions; Albedo; Carbon sequestration	Europe Crop depends on the site	Modelling and remote sensing; AEI
41	[64]	Landscape structure; Land use; Pollination; Biodiversity loss	Europe Crop depends on the site	Modelling; AEI, ESA
42	[65]	Fertilizer input; Harvested biomass/yield	Europe (Belgium, France Germany, The Netherlands, Finland, Latvia, Norway, Sweden, Italy, Spain). Crop depends on countries	Data analysis; AEI
43	[66]	Landscape structure; Land use; Biodiversity loss	Europe (west-east European transect) Vineyards	Modelling; ESA, AEI, AEI-ESA
44	[33]	GHG emissions; Storage capacity; Harvested biomass/yield; Carbon sequestration	Switzerland Wheat, Maize, Barley, Rape, Beets, Potatoes, Spelt, Sunflower, Peas, Beans, Oats	Modelling; AEI, AEI-YGA
45	[27]	Fertilizer input; GHG emissions; Nutrient retention; Harvested biomass/yield; Carbon sequestration	Europe Crop depends on the site	Field scale and modelling; AEI
46	[67]	Land use; Carbon sequestration	Kazakhstan (Almaty), Finland (South), Italy (North) Spring barley, Maize	Experiment and modelling; AEI
47	[68]	Land use; Fertilizer input; Pesticide inputs; N-use efficiency; Harvested biomass/yield; Pest control	Switzerland (Tänikon) Winter wheat, Maize	Experiment and modelling; AEI
48	[69]	Harvested biomass/yield	Italy (central Italy) Maize, Durum wheat, Sunflower	Long term experiment and modelling; AEI
49	[26]	Fertilizer input; Water input; GHG emissions; Storage capacity; Harvested biomass/yield; Carbon sequestration	France (arable land) Grain and silage maize, Winter wheat, Rapeseed, Sugar beet, Sunflower, Winter and spring pea, Temporary grasslands	High-resolution modelling; AEI
50	[70]	Harvested biomass/yield; Changes in soil quality	North-south European gradient Crop depends on the site	Experimental sites and Modelling; AEI
51	[71]	Soil structure; SOM content; Changes in soil quality	USA (transect) Crop depends on the site	Farm scale experiment and modelling; AEI

References

1. Justes, E.; Beaudoin, N.; Bertuzzi, P.; Charles, R.; Constantin, J.; Durr, C.; Hermon, C.; Joannon, A.; Le Bas, C.; Mary, B.; et al. Réduire Les Fuites de Nitrate au Moyen de Cultures Intermédiaires. In *Colloq. Restit. l'étude '"Cultures Intermédiaires"'*; Maison de l'horticulture: Paris, France, 2012; p. 8.
2. Abdalla, M.; Hastings, A.; Cheng, K.; Yue, Q.; Chadwick, D.; Espenberg, M.; Truu, J.; Rees, R.M.; Smith, P. A critical review of the impacts of cover crops on nitrogen leaching, net greenhouse gas balance and crop productivity. *Glob. Chang. Biol.* **2019**, *25*, 2530–2543. [CrossRef] [PubMed]

3. Borrelli, P.; Panagos, P. An indicator to reflect the mitigating effect of Common Agricultural Policy on soil erosion. *Land Use Policy* **2020**, *92*, 104467. [CrossRef]
4. Gardarin, A.; Celette, F.; Naudin, C.; Piva, G.; Valantin-Morison, M.; Vrignon-Brenas, S.; Verret, V.; Médiène, S. Intercropping with service crops provides multiple services in temperate arable systems: A review. *Agron. Sustain. Dev.* **2022**, *42*, 39. [CrossRef]
5. Bonnet, C.; Gaudio, N.; Alletto, L.; Raffaillac, D.; Bergez, J.-E.; Debaeke, P.; Gavaland, A.; Willaume, M.; Bedoussac, L.; Justes, E. Design and multicriteria assessment of low-input cropping systems based on plant diversification in southwestern France. *Agron. Sustain. Dev.* **2021**, *41*, 65. [CrossRef]
6. Tonitto, C.; David, M.B.; Drinkwater, L.E. Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics. *Agric. Ecosyst. Environ.* **2006**, *112*, 58–72. [CrossRef]
7. Basche, A.D.; Miguez, F.E.; Kaspar, T.C.; Castellano, M.J. Do cover crops increase or decrease nitrous oxide emissions? A meta-analysis. *J. Soil Water Conserv.* **2014**, *69*, 471–482. [CrossRef]
8. Blanco-Canqui, H.; Shaver, T.M.; Lindquist, J.L.; Shapiro, C.A.; Elmore, R.W.; Francis, C.A.; Hergert, G.W. Cover crops and ecosystem services: Insights from studies in temperate soils. *Agron. J.* **2015**, *107*, 2449–2474. [CrossRef]
9. Poeplau, C.; Don, A. Carbon sequestration in agricultural soils via cultivation of cover crops—A meta-analysis. *Agric. Ecosyst. Environ.* **2015**, *200*, 33–41. [CrossRef]
10. Bedoussac, L.; Journet, E.-P.; Hauggaard-Nielsen, H.; Naudin, C.; Corre-Hellou, G.; Jensen, E.S.; Prieur, L.; Justes, E. Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. A review. *Agron. Sustain. Dev.* **2015**, *35*, 911–935. [CrossRef]
11. Kaye, J.P.; Quemada, M. Using cover crops to mitigate and adapt to climate change. A review. *Agron. Sustain. Dev.* **2017**, *37*, 4. [CrossRef]
12. Meyer, N.; Bergez, J.E.; Constantin, J.; Justes, E. Cover crops reduce water drainage in temperate climates: A meta-analysis. *Agron. Sustain. Dev.* **2019**, *39*, 3. [CrossRef]
13. Pellerin, S.; Bamière, L.; Réchauchère, O. *Stocker Du Carbone Dans Les Sols Français, Quel Potentiel Au Regard De L'objectif 4 Pour 1000 Et A Quel Coût ? Synthèse du rapport d'étude, INRA (France)*; INRAE: Paris, France, 2019.
14. Shackelford, G.E.; Kelsey, R.; Dicks, L.V. Effects of cover crops on multiple ecosystem services: Ten meta-analyses of data from arable farmland in California and the Mediterranean. *Land Use Policy* **2019**, *88*, 104204. [CrossRef]
15. Tribouillois, H.; Constantin, J.; Justes, E. Cover crops mitigate direct greenhouse gases balance but reduce drainage under climate change scenarios in temperate climate with dry summers. *Glob. Chang. Biol.* **2018**, *24*, 2513–2529. [CrossRef] [PubMed]
16. Bergez, J.-E.; Béthinger, A.; Bockstaller, C.; Cederberg, C.; Ceschia, E.; Guilpart, N.; Lange, S.; Müller, F.; Reidsma, P.; Riviere, C.; et al. Integrating agri-environmental indicators, ecosystem services assessment, life cycle assessment and yield gap analysis to assess the environmental sustainability of agriculture. *Ecol. Indic.* **2022**, *141*, 109107. [CrossRef]
17. Higgins, J.; Thomas, J.; Chandler, J.; Cumpston, M.; Li, T.; Page, M.; Welch, V. *Cochrane Handbook for Systematic Reviews of Interventions*; John Wiley & Sons, Ltd.: Chichester, UK, 2019.
18. Khangura, S.; Konnyu, K.; Cushman, R.; Grimshaw, J.; Moher, D. Evidence summaries: A rapid review method. *Syst. Rev.* **2012**, *1*, 2–8. [CrossRef]
19. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *BMJ* **2009**, *339*, 332–336. [CrossRef]
20. Gabrielsen, P.; Bosch, P. *Environmental Indicators: Typology and Use in Reporting*; European Environment Agency: Copenhagen, Denmark, 2003; pp. 1–20.
21. Aguilera, E.; Guzmán, G.; Alonso, A. Greenhouse gas emissions from conventional and organic cropping systems in Spain. II. Fruit tree orchards. *Agron. Sustain. Dev.* **2015**, *35*, 725–737. [CrossRef]
22. Ceschia, E.; Béziat, P.; Dejoux, J.F.; Aubinet, M.; Bernhofer, C.; Bodson, B.; Buchmann, N.; Carrara, A.; Cellier, P.; Di Tommasi, P.; et al. Management effects on net ecosystem carbon and GHG budgets at European crop sites. *Agric. Ecosyst. Environ.* **2010**, *139*, 363–383. [CrossRef]
23. Lugato, E.; Cescatti, A.; Jones, A.; Ceccherini, G.; Duveiller, G. Maximising climate mitigation potential by carbon and radiative agricultural land management with cover crops. *Environ. Res. Lett.* **2020**, *15*, 094075. [CrossRef]
24. Dal Ferro, N.; Cocco, E.; Lazzaro, B.; Berti, A.; Morari, F. Assessing the role of agri-environmental measures to enhance the environment in the Veneto Region, Italy, with a model-based approach. *Agric. Ecosyst. Environ.* **2016**, *232*, 312–325. [CrossRef]
25. Quemada, M.; Lassaletta, L.; Leip, A.; Jones, A.; Lugato, E. Integrated management for sustainable cropping systems: Looking beyond the greenhouse balance at the field scale. *Glob. Chang. Biol.* **2020**, *26*, 2584–2598. [CrossRef] [PubMed]
26. Autret, B.; Beaudoin, N.; Rakotovololona, L.; Bertrand, M.; Grandeau, G.; Gréhan, E.; Ferchaud, F.; Mary, B. Can alternative cropping systems mitigate nitrogen losses and improve GHG balance? Results from a 19-yr experiment in Northern France. *Geoderma* **2019**, *342*, 20–33. [CrossRef]
27. Doltra, J.; Gallejones, P.; Olesen, J.E.; Hansen, S.; Frøseth, R.B.; Krauss, M.; Stalenga, J.; Jończyk, K.; Martínez-Fernández, A.; Pacini, G.C. Simulating soil fertility management effects on crop yield and soil nitrogen dynamics in field trials under organic farming in Europe. *Field Crops Res.* **2019**, *233*, 1–11. [CrossRef]
28. Prechsl, U.E.; Wittwer, R.; van der Heijden, M.G.A.; Lüscher, G.; Jeanneret, P.; Nemecek, T. Assessing the environmental impacts of cropping systems and cover crops: Life cycle assessment of FAST, a long-term arable farming field experiment. *Agric. Syst.* **2017**, *157*, 39–50. [CrossRef]

29. Plaza-Bonilla, D.; Nogué-Serra, I.; Raffaillac, D.; Cantero-Martínez, C.; Justes, É. Carbon footprint of cropping systems with grain legumes and cover crops: A case-study in SW France. *Agric. Syst.* **2018**, *167*, 92–102. [CrossRef]
30. Launay, C.; Constantin, J.; Chlebowski, F.; Houot, S.; Graux, A.; Klumpp, K.; Martin, R.; Mary, B.; Pellerin, S.; Therond, O. Estimating the carbon storage potential and greenhouse gas emissions of French arable cropland using high-resolution modeling. *Glob. Chang. Biol.* **2021**, *27*, 1645–1661. [CrossRef]
31. Pezzuolo, A.; Dumont, B.; Sartori, L.; Marinello, F.; De Antoni Migliorati, M.; Basso, B. Evaluating the impact of soil conservation measures on soil organic carbon at the farm scale. *Comput. Electron. Agric.* **2017**, *135*, 175–182. [CrossRef]
32. Lee, J.; Necpálová, M.; Six, J. Biophysical potential of organic cropping practices as a sustainable alternative in Switzerland. *Agric. Syst.* **2020**, *181*, 102822. [CrossRef]
33. Schipanski, M.E.; Barbercheck, M.; Douglas, M.R.; Finney, D.M.; Haider, K.; Kaye, J.P.; Kemanian, A.R.; Mortensen, D.A.; Ryan, M.R.; Tooker, J.; et al. A framework for evaluating ecosystem services provided by cover crops in agroecosystems. *Agric. Syst.* **2014**, *125*, 12–22. [CrossRef]
34. Delpuech, X.; Metay, A. Adapting cover crop soil coverage to soil depth to limit competition for water in a Mediterranean vineyard. *Eur. J. Agron.* **2018**, *97*, 60–69. [CrossRef]
35. Constantin, J.; Beaudoin, N.; Launay, M.; Duval, J.; Mary, B. Long-term nitrogen dynamics in various catch crop scenarios: Test and simulations with STICS model in a temperate climate. *Agric. Ecosyst. Environ.* **2012**, *147*, 36–46. [CrossRef]
36. Moreau, P.; Ruiz, L.; Raimbault, T.; Vertès, F.; Cordier, M.O.; Gascuel-Odoux, C.; Masson, V.; Salmon-Monviola, J.; Durand, P. Modeling the potential benefits of catch-crop introduction in fodder crop rotations in a Western Europe landscape. *Sci. Total Environ.* **2012**, *437*, 276–284. [CrossRef] [PubMed]
37. Runck, B.C.; Khoury, C.K.; Ewing, P.M.; Kantar, M. The hidden land use cost of upscaling cover crops. *Commun. Biol.* **2020**, *3*, s42003–s42020. [CrossRef]
38. Alonso-Ayuso, M.; Quemada, M.; Vanclooster, M.; Ruiz-Ramos, M.; Rodriguez, A.; Gabriel, J.L. Assessing cover crop management under actual and climate change conditions. *Sci. Total Environ.* **2018**, *621*, 1330–1341. [CrossRef] [PubMed]
39. Constantin, J.; Mary, B.; Laurent, F.; Aubrion, G.; Fontaine, A.; Kerveillant, P.; Beaudoin, N. Effects of catch crops, no till and reduced nitrogen fertilization on nitrogen leaching and balance in three long-term experiments. *Agric. Ecosyst. Environ.* **2010**, *135*, 268–278. [CrossRef]
40. Gómez, J.A.; Guzmán, M.G.; Giráldez, J.V.; Fereres, E. The influence of cover crops and tillage on water and sediment yield, and on nutrient, and organic matter losses in an olive orchard on a sandy loam soil. *Soil Tillage Res.* **2009**, *106*, 137–144. [CrossRef]
41. Celette, F.; Ripoche, A.; Gary, C. WaLIS-A simple model to simulate water partitioning in a crop association: The example of an intercropped vineyard. *Agric. Water Manag.* **2010**, *97*, 1749–1759. [CrossRef]
42. Sohier, C.; Degré, A. Modelling the effects of the current policy measures in agriculture: An unique model from field to regional scale in Walloon region of Belgium. *Environ. Sci. Policy* **2010**, *13*, 754–765. [CrossRef]
43. Lugato, E.; Bampa, F.; Panagos, P.; Montanarella, L.; Jones, A. Potential carbon sequestration of European arable soils estimated by modelling a comprehensive set of management practices. *Glob. Chang. Biol.* **2014**, *20*, 3557–3567. [CrossRef]
44. Guardia, G.; Aguilera, E.; Vallejo, A.; Sanz-Cobena, A.; Alonso-Ayuso, M.; Quemada, M. Effective climate change mitigation through cover cropping and integrated fertilization: A global warming potential assessment from a 10-year field experiment. *J. Clean. Prod.* **2019**, *241*, 118307. [CrossRef]
45. Cohan, J.; Besnard, A.; Hanocq, D.; Moquet, M.; Constantin, J. Evolution des fournitures d azote et du stockage de l azote et du carbone du sol dans les rotations fourragères maïs—Blé de deux essais de longue durée Les dispositifs Analyses des rendements et des doses d engrais azotés optimaux Evaluation des fournit. *Fourrages* **2015**, *223*, 33–38.
46. Mézière, D.; Colbach, N.; Dessaint, F.; Granger, S. Which cropping systems to reconcile weed-related biodiversity and crop production in arable crops? An approach with simulation-based indicators. *Eur. J. Agron.* **2015**, *68*, 22–37. [CrossRef]
47. Nemecek, T.; Hayer, F.; Bonnin, E.; Carrouée, B.; Schneider, A.; Vivier, C. Designing eco-efficient crop rotations using life cycle assessment of crop combinations. *Eur. J. Agron.* **2015**, *65*, 40–51. [CrossRef]
48. Panagos, P.; Borrelli, P.; Meusburger, K.; Alewell, C.; Lugato, E.; Montanarella, L. Estimating the soil erosion cover-management factor at the European scale. *Land Use Policy* **2015**, *48*, 38–50. [CrossRef]
49. Craheix, D.; Angevin, F.; Doré, T.; de Tourdonnet, S. Using a multicriteria assessment model to evaluate the sustainability of conservation agriculture at the cropping system level in France. *Eur. J. Agron.* **2016**, *76*, 75–86. [CrossRef]
50. Götze, P.; Rücknagel, J.; Jacobs, A.; Märländer, B.; Koch, H.J.; Christen, O. Environmental impacts of different crop rotations in terms of soil compaction. *J. Environ. Manage.* **2016**, *181*, 54–63. [CrossRef]
51. Plaza-Bonilla, D.; Nolot, J.M.; Passot, S.; Raffaillac, D.; Justes, E. Grain legume-based rotations managed under conventional tillage need cover crops to mitigate soil organic matter losses. *Soil Tillage Res.* **2016**, *156*, 33–43. [CrossRef]
52. De Waele, J.; D'Haene, K.; Salomez, J.; Hofman, G.; de Neve, S. Simulating the environmental performance of post-harvest management measures to comply with the EU Nitrates Directive. *J. Environ. Manage.* **2017**, *187*, 513–526. [CrossRef]
53. Shah, A.; Askegaard, M.; Rasmussen, I.A.; Jimenez, E.M.C.; Olesen, J.E. Productivity of organic and conventional arable cropping systems in long-term experiments in Denmark. *Eur. J. Agron.* **2017**, *90*, 12–22. [CrossRef]
54. Cooper, R.J.; Hama-Aziz, Z.; Hiscock, K.M.; Lovett, A.A.; Dugdale, S.J.; Sünnenberg, G.; Noble, L.; Beamish, J.; Hovesen, P. Assessing the farm-scale impacts of cover crops and non-inversion tillage regimes on nutrient losses from an arable catchment. *Agric. Ecosyst. Environ.* **2017**, *237*, 181–193. [CrossRef]

55. Manevski, K.; Lærke, P.E.; Olesen, J.E.; Jørgensen, U. Nitrogen balances of innovative cropping systems for feedstock production to future biorefineries. *Sci. Total Environ.* **2018**, *633*, 372–390. [CrossRef] [PubMed]
56. Viaud, V.; Santillàn-Carvantes, P.; Akkal-Corfini, N.; Le Guillou, C.; Prévost-Bouré, N.C.; Ranjard, L.; Menasseri-Aubry, S. Landscape-scale analysis of cropping system effects on soil quality in a context of crop-livestock farming. *Agric. Ecosyst. Environ.* **2018**, *265*, 166–177. [CrossRef]
57. Alahmad, A.; Decocq, G.; Spicher, F.; Kheirbeik, L.; Kobaissi, A.; Tetu, T.; Dubois, F.; Duclercq, J. Cover crops in arable lands increase functional complementarity and redundancy of bacterial communities. *J. Appl. Ecol.* **2019**, *56*, 651–664. [CrossRef]
58. Carrer, D.; Pique, G.; Ferlicoq, M.; Ceamanos, X.; Ceschia, E. What is the potential of cropland albedo management in the fight against global warming? A case study based on the use of cover crops. *Environ. Res. Lett.* **2018**, *13*, 044030. [CrossRef]
59. Camarotto, C.; Dal Ferro, N.; Piccoli, I.; Polese, R.; Furlan, L.; Chiarini, F.; Morari, F. Conservation agriculture and cover crop practices to regulate water, carbon and nitrogen cycles in the low-lying Venetian plain. *Catena* **2018**, *167*, 236–249. [CrossRef]
60. Carpio, A.J.; Castro, J.; Tortosa, F.S. Arthropod biodiversity in olive groves under two soil management systems: Presence versus absence of herbaceous cover crop. *Agric. For. Entomol.* **2019**, *21*, 58–68. [CrossRef]
61. Crotty, F.V.; Stoate, C. The legacy of cover crops on the soil habitat and ecosystem services in a heavy clay, minimum tillage rotation. *Food Energy Secur.* **2019**, *8*, e00169. [CrossRef]
62. Krievina, A.; Leimane, I. Comparison of the support for catch crops in the baltic sea region countries. *Res. Rural Dev.* **2019**, *2*, 95–102. [CrossRef]
63. Büchi, L.; Wendling, M.; Amossé, C.; Jeangros, B.; Charles, R. Cover crops to secure weed control strategies in a maize crop with reduced tillage. *Field Crops Res.* **2020**, *247*, 107583. [CrossRef]
64. Cole, L.J.; Kleijn, D.; Dicks, L.V.; Stout, J.C.; Potts, S.G.; Albrecht, M.; Balzan, M.V.; Bartomeus, I.; Bebeli, P.J.; Bevk, D.; et al. A critical analysis of the potential for EU Common Agricultural Policy measures to support wild pollinators on farmland. *J. Appl. Ecol.* **2020**, *57*, 681–694. [CrossRef]
65. Francaviglia, R.; Álvaro-Fuentes, J.; Di Bene, C.; Gai, L.; Regina, K.; Turtola, E. Diversification and management practices in selected European regions. A data analysis of arable crops production. *Agronomy* **2020**, *10*, 297. [CrossRef]
66. Hall, R.M.; Penke, N.; Kriechbaum, M.; Kratschmer, S.; Jung, V.; Chollet, S.; Guernion, M.; Nicolai, A.; Burel, F.; Fertil, A.; et al. Vegetation management intensity and landscape diversity alter plant species richness, functional traits and community composition across European vineyards. *Agric. Syst.* **2020**, *177*, 102706. [CrossRef]
67. Valkama, E.; Kunypiyaeva, G.; Zhapayev, R.; Karabayev, M.; Zhusupbekov, E.; Perego, A.; Schillaci, C.; Sacco, D.; Moretti, B.; Grignani, C.; et al. Can conservation agriculture increase soil carbon sequestration? A modelling approach. *Geoderma* **2020**, *369*, 114298. [CrossRef]
68. Wittwer, R.A.; van der Heijden, M.G.A. Cover crops as a tool to reduce reliance on intensive tillage and nitrogen fertilization in conventional arable cropping systems. *Field Crops Res.* **2020**, *249*, 107736. [CrossRef]
69. Adeux, G.; Cordeau, S.; Antichi, D.; Carlesi, S.; Mazzoncini, M.; Munier-Jolain, N.; Bàrberi, P. Cover crops promote crop productivity but do not enhance weed management in tillage-based cropping systems. *Eur. J. Agron.* **2021**, *123*, 126221. [CrossRef]
70. Garland, G.; Edlinger, A.; Banerjee, S.; Degrune, F.; García-Palacios, P.; Pescador, D.S.; Herzog, C.; Romdhane, S.; Saghai, A.; Spor, A.; et al. Crop cover is more important than rotational diversity for soil multifunctionality and cereal yields in European cropping systems. *Nat. Food* **2021**, *2*, 28–37. [CrossRef]
71. Wood, S.A.; Bowman, M. Large-scale farmer-led experiment demonstrates positive impact of cover crops on multiple soil health indicators. *Nat. Food* **2021**, *2*, 97–103. [CrossRef]