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REVIEW ARTICLE

# The reflection of principles and values in worldwide organic agricultural research viewed through a crop diversification lens. A bibliometric review

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## Abstract

Organic agriculture and organic food have expanded in recent decades but have undergone conventionalisation. Some claim that this contradicts some or all of the principles of 'health', 'ecology', 'fairness' and 'care' established by the International Federation of Organic Agricultural Movement (IFOAM). It is currently unclear how research on organic food/agriculture is structured, whether it embraces these principles, or how key crop diversification, driving sustainability, are addressed. To fill these knowledge gaps, we conducted a bibliometric analysis of 10,030 peer-reviewed articles published from 1945 to 2021 with topic and textual analysis. Our main findings were the following: (1) research is compartmentalised into scales and disciplines, with at field-scale 'weed', 'soil', 'pest and disease' management and 'livestock farming' seldom addressed together, or with environmental assessment separated from socioeconomic studies at farm scale. (2) The proportion of publications on 'consumers' preferences' and 'product quality' research almost tripled in 20 years, from 10 to 27%, emphasizing the consumer orientation of research on organic agriculture and organic food. (3) Only 4% of articles covered all four IFOAM principles, while associated values such as 'resilience', 'integrity', 'equity', 'transparency' and 'justice' were even less frequently addressed. (4) Fewer diversification practices have been tested in organic than in conventional agriculture research, with fewer articles on 'crop mixtures' or 'bee-friendly crops' and a smaller range of legumes considered. (5) Research on genetic improvement and processing of organic legumes is lacking, which could constrain adoption of legumes in organic farming even more than in conventional agriculture. These results indicate a need for increasing interdisciplinary efforts at field level, with systematic measurement of multiple processes (weed-nutrient-pest dynamics). Future studies on organic agriculture should combine several diversification practices and legumes, with relevant indicators addressing the IFOAM values explicitly, and consider the whole value chain by linking producers with consumers.

**Keywords** Organic agriculture · Organic food · Bibliometric analysis · Crop diversification · Principles of organic agriculture · Food system analysis · Legume adoption · Consumers' preferences · Organic food supply chain (OFSC)

**Contents**



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## 1 Introduction

Consumer demand for organic products is increasing globally and organic food is no longer considered a niche market. Global organic sales were around $97 billion in 2018 (Willer et al. 2021), and more than 90 countries worldwide have now introduced systematic organic regulations (Willer 2017). As a result of the growing demand for organic food, organic farming has expanded (Rana and Paul 2017). The global area has grown from 11 million to 75 million hectares over the last two decades (Willer et al. 2022). There are rigorous regulations and restrictions on organic farming (e.g. no synthetic pesticides and fertilisers, fewer processing aids and additives compared to products from conventional agriculture, no genetically modified organisms or products produced from such organisms) that to some extent vary between countries. For market access, farmers are expected to follow these regulations via an organic certification process (Niggli 2015) and, as such, organic farming is the only legally defined form of farming. In this regard, it differ significantly from conventional agriculture, which is considered the current norm of agricultural production. Generally, in conventional agriculture, food production is the main objective, inputs and outputs are imbalanced, and the reliance on synthetic fertilisers and other agricultural chemicals and the production costs are high, despite the existence of a large gradient of intensity in this continuum (Sumberg and Giller 2022).

In the early 1970s, the International Federation of Organic Agriculture Movement (IFOAM) was established by 'Nature et Progrès', an international association of organic farmers, consumers and processors. IFOAM is an international umbrella organisation grouping many different stakeholders contributing to the development of organic farming. The current definition of organic agriculture according to IFOAM (IFOAM general assembly 2008) is 'a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. It highlights the fact that organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved'. Together with this definition, IFOAM established a range of aims that later became the principles of *health*, *ecology*, *fairness* and *care*. These principles represent the main set of values in organic farming systems, but it is unclear how they have been addressed by research to date (Freyer et al. 2019). The principles and associated values diverge significantly from organic farming as set out in regulation, for example, (EEC) 2092/91 (EC 1991) provides the rules of a control system for labelling agricultural products and foodstuffs as 'organic' in the EU based on practices rather than values, ethics or overall sustainability of the production process.

Research on organic agriculture is necessary to increase the positive economic, environmental and social externalities of organic systems for farmers, consumers and other stakeholders in society (Fig. 1). Different types of organic system have been developed in different countries, ranging from highly diverse agroecological systems to more input-oriented farming systems seeking higher nutrient use efficiency (Petit and Aubry 2016; Milestad et al. 2020). These organic systems form part of value chains that vary greatly in terms of distance to market, number of intermediaries and overall benefits for farmers and society (Gaitán-Cremaschi et al. 2018). Darnhofer et al. (2010) identified a trend for 'conventionalisation' where organic farmers rely increasingly on external inputs (the input substitution model). This has also been observed in surveys of practice, for example, in a study with Swedish farmers, Chongtham et al. (2017) found some farmers expressed a reliance on purchased nitrogen rather than system-based solutions to provide nitrogen via leys. These inputs, while complying with country-specific regulations for organic farming, are not always aligned with the four principles of organic farming defined by IFOAM. Some claim that conventionalised organic agriculture contradicts some or all of the IFOAM principles, especially *ecology* and *health* (De Wit and Verhoog 2007). Conventionalisation appears to have a significant negative effect on perceived contributions to environmental and social sustainability, but a significant positive effect on perceived contribution to short-term farm profitability (Goldberger 2011). Therefore, a review of existing literature on organic food and agriculture is needed to understand whether research reflects these conventionalisation trends or whether it takes a more holistic approach to organic values and principles. We do so by identifying the different topics and issues addressed by researchers.

Cropping system simplification has been a major trend in conventional and organic agricultural systems worldwide in recent decades. Conventional agriculture has experienced a large decrease in spatial and temporal diversity of cultivated species (Foley et al. 2011; Crossley et al. 2021). Decreased diversity has also been reported for organic systems, with most of the conventionalisation indicators at field level proposed by Darnhofer et al. (2010) reflecting low diversity of crops or low frequency of legumes in crop rotations. Diversification of cropping systems in general and inclusion of


**Fig. 1** **a** Scottish organic crop rotations trial in Aberdeen (Scotland) with a diversity of cereals, potatoes and leys to maintain the productivity of the system following IFOAM principles of ecology and health (photo by Christine Watson); **b** literature on intercropping in organic agriculture is currently low but increasing with for instance experiments such as on-station lupin and buckwheat in Skåne (Sweden) (photo by Alexander Menegat); **c** Aurélien and Jennifer have developed an economically viable organic farm producing vegetables in Normandy (France) to satisfy the growing demand of consumers' for local and healthy organic products (photo by Aurélien Thibaux); **d** a variety of organic products is already available on food shelves in various locations for instance in Amsterdam (photo by Pierre Chopin)

legumes in cropping systems and human diets in particular are major levers for improving the sustainability of agricultural systems (Prudhomme et al. 2020). Recent meta-analyses indicate that crop diversification generally increases both production and biodiversity but also has a positive effect on many supporting and regulating ecosystems services including water and soil quality, water regulation, pollination and pest and disease management (Tamburini et al. 2020; Beillouin et al. 2021). In the case of organic farming, the inclusion of legumes is particularly important for sustaining the fertility of the cropping systems in the long-term (Watson et al. 2017). Important research targets for increasing the sustainability of organic farming include cropping system diversification (e.g. crop mixtures) and increased legume cultivation (Röös et al. 2018). Crop diversification practices include more diverse crop rotations (Reckling et al. 2016), mixed cropping (Bedoussac et al. 2015), perennial leys or grassland (Haughey et al. 2018), inclusion of multi/service cover crops (Couëdel et al. 2018) and regionally adapted varieties or variety mixtures (Bhaskar et al. 2019). These practices mutually increase the soil fertility and reduce weed pressure (Watson et al. 2002a) while favouring natural enemies in the long term (Garratt et al. 2011). When appropriately implemented, they can lead to higher productivity (Ponisio et al. 2015; Zhao et al. 2022) and increased profitability in the long-term (Cavigelli et al. 2009; Dayananda et al. 2021). However, diversification practices are rarely implemented in conventional agriculture, partly because of lack of empirical evidence on their potential positive effects (Ponisio and Ehrlich 2016; Roesch-McNally et al. 2018) but also lack of technical knowledge among farmers and advisors, adapted machinery and locally available varieties of minor crops (Messean et al. 2021). Large-scale adoption of legume cultivation by farmers is hampered by many lock-ins, such as lack of knowledge on the impact of legumes on the sustainability of farming systems (Meynard et al. 2018). To our knowledge, no data are available on legume cultivation in organic systems, and thus research on organic food and organic agriculture may be experiencing the same lack of knowledge of potential socioeconomic and agronomic benefits and food processing possibilities as seen in research on conventional agriculture (Magrini et al. 2016).

Accurate knowledge about the current status and trends in research on organic food and organic agriculture is important for directing future research avenues (Tuomisto et al. 2012) as well as contributing to the sustainable development of organic food and farming. Research efforts on organic food and organic agriculture have not been reviewed previously. To our knowledge, only one bibliometric review has investigated organic food/farming research and it was limited

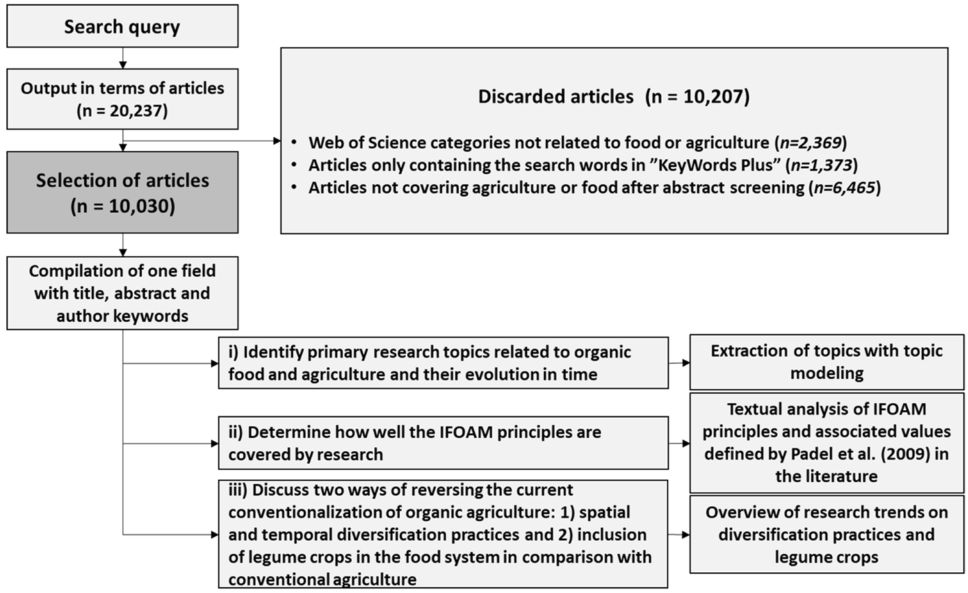


**Fig. 2** Procedure applied for article selection for the bibliometric review and analysis, and associated objectives (i)–(iii) of the review

to collaborations between countries (Aleixandre et al. 2015) while bibliometric analysis can reveal research gaps in the literature by investigating relevant topic trends (Lascialfari et al. 2022). To tackle this gap, our aims in the present study were to describe the development of research in organic food/agriculture, assess how well it connects to the principles of organic agriculture and identify scientific fields within crop diversification research to facilitate development of organic agriculture in line with the guiding principles. We specifically focus on crop diversification as an example of a concept which is core to the principles of organic farming. We applied bibliometric methods to: (i) identify primary research topics related to organic agriculture and food and changes in these over time; (ii) determine to what extent the IFOAM principles are covered by this research; and (iii) quantify the extent to which key diversification practices are addressed and whether knowledge on legume crops is produced for various users along the legume value chain.

## 2 Analysis of topics, IFOAM principles and coverage of crop diversification and legumes

We conducted a literature search of articles on organic food and organic agriculture, with filtering in several steps (see section 2.1). The final batch of papers was treated with various methods, including topic analysis (section 2.2) and textual analysis using various keywords to identify the coverage of IFOAM principles (section 2.3) and associated values, and of the two selected diversification themes namely the diversity of diversification practices (e.g., intercropping, rotations and variety mixtures) and inclusion of legume species in crop rotations (section 2.4). All data on the initial search hits, the filters applied, the final list of articles, keywords and results were entered in an Excel file within a Zenodo repository (link to paste once publication accepted). The R code is also provided in the repository.

### 2.1 Selection of articles from the organic food and organic agriculture literature

Article selection was performed systematically by formulating a search query in ISI Web of Science, the most complete and widely used database for bibliometric analyses or literature reviews (Fig. 2). ISI Web of Science has a comparable coverage to other databases such as Scopus or Dimension, but applies stricter criteria to integrated scientific journals (Stahlschmidt and Stephen 2020) which we considered important to capture scientific trends in the literature. The search was restricted to peer-reviewed articles and reviews, so conference abstracts, book chapters, editorials, letters, reprints and press releases were excluded. It was possible to include articles in all languages, since abstracts and titles are generally provided in English. The search timespan was 1945 to 24$^{th}$ January 2022.

A literature search was first conducted using the 'Topic' (TS in WebofScience) category and looking for articles that included a synonym of 'organic' linked to one synonym of 'agriculture' or 'food' or a given species of plant or animal. As with conventional agriculture, organic agriculture is not a distinct category and different organic production systems fall within the organic agriculture regulations, such as biodynamic agriculture (Steiner et al. 2005). Hence, organic synonyms included the words 'organic*', 'biodynamic*', 'regenerativ*', 'ecologic*' and 'biologic*', as used by Barbieri

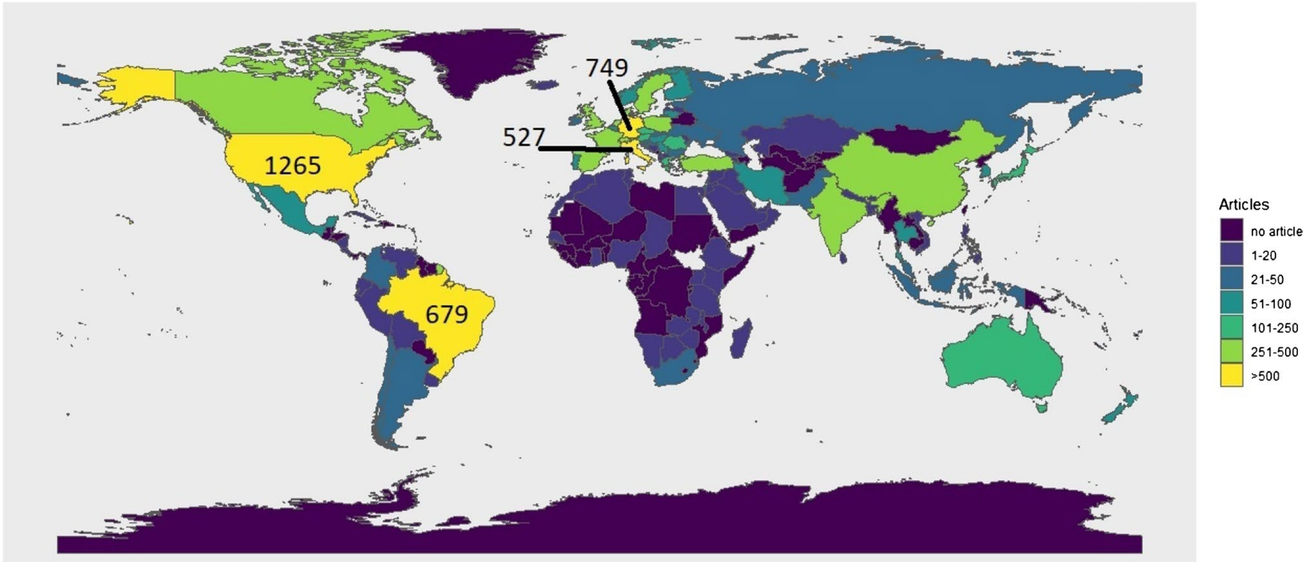


**Fig. 3** Map with the scientific production per country on organic food and agriculture as referenced by the Web of Science

et al. (2017). Each of these words was combined with a synonym of 'agriculture' or 'food', including 'agri*', 'agro*', 'horticultur*', 'farm*', 'crop*', 'produced*', 'production*', 'food*', 'manage*', 'cultivat*', 'grown'. The asterisks were included to allow detection of different variations such as plural forms (e.g. 'foods'), adjectives (e.g. 'organic') or adverbs (e.g. 'organically'). 'Produc*' was not used, as it yielded a substantial number of articles from the chemistry area containing the expression 'organic products'. 'Organic' synonyms were also combined with 258 crops (Som 2010), 67 animal species (Rege and Okeyo 2010), 23 animal or crop categories (e.g. livestock, ruminant, orchard) and 160 food products (USDA 2004), forming combinations such as 'biodynamic grapes', 'ecological livestock' and 'organic pasta' extracted from official lists.

The search equation yielded 20,237 articles with 8703 in 1945–2013 which is significantly more than the 1009 articles considered in a recent scientific literature review on organic food and agriculture (Aleixandre et al. 2015). Of these, we discarded 2369 articles within non-food or agriculture-related Web of Sciences categories (e.g. art studies), together with 1373 articles that only contained our search expressions in KeyWords Plus, based on the reference lists in the respective articles (Fig. 2). KeyWords Plus are words or phrases that frequently appear in the titles of an article's references, but since they do not directly relate to the article content we discarded papers that only had our search terms in KeyWords Plus. Screening of abstracts resulted in removal of a further 6465 articles that mentioned organic agriculture or organic food, but did not address these specifically, such as articles describing field experiments in conventional systems and indicating that the findings could be relevant to organic agriculture. In total, 10,030 articles were included in the bibliometric review (Fig. 2). For the temporal analysis, only papers up to end of 2021 were included to avoid drawing conclusions for 2022 as only a small part of the papers of that year were published when we ran the analysis. Those 10,030 articles were initiated in 108 countries and at least 300 peer-reviewed publications were produced in the USA ($n$= 1444, 15%), Germany ($n$ = 749, 8%), Brazil ($n$= 679, 7%), Italy ($n$= 664, 7%), Spain ($n$= 492, 5%), Denmark ($n$ = 412, 4%), the UK ($n$= 368, 4%), China ($n$ = 347, 3%) and France ($n$=326, 3%) (Fig. 3).

## 2.2 Identification of topics covered by the literature

We conducted topic analysis to identify the diversity of topics addressed in the literature on organic agriculture and the extent to which those were covered. We used the Latent Dirichlet Allocation (LDA) method, in which a probabilistic model assigns words a probabilistic score for the topic to which they most likely belong, to identify various topics covered in the articles (Blei et al. 2003; Weinshall et al. 2013). Every article proved to be a mixture of topics and every topic a mixture of words, with a total of 28,980 different words produced initially from the 10,030 articles. We examined all words that appeared more than 20 times in the articles ($n$=4442 words, representing >94% of word frequency) and manually merged similar words, such as 'growers', 'producers' and 'farmers', resulting in a matrix with all the keywords used in each article. This merging was limited to strictly similar words and not undertaken for words related to stakeholders or paradigms that are different in attributes or characteristics. For instance, citizen and consumer were not merged as consumer represent a more precise description of function of stakeholder in research. This threshold of 20 repetitions per word ensures the feasibility of the classification process and a good representativity of the frequency in the sample. Beyond this threshold, words were either too highly specific or not related to agriculture or food anymore. We fitted the LDA model using the 'lda.collapsed.gibbs.sampler' function in the 'lda' R package to estimate the probability of each article belonging to a topic (Chang 2015). We did not pre-set the number of topics, but explored the coherence of topics using a coherence score, which represented the ratio of inter-topic variability to intra-topic variability. Nine topics with the highest coherence scores (with a value of 516,784) were finally selected. For each topic, we looked at the 15 most frequent words and, for each article, calculated the probability of it belonging to one topic. Each document was attributed the highest probability of belonging to one topic, following the method in Hossard and Chopin (2019). By using the most frequent words associated to each topic and articles allocated to those topics, we could summarize the content of topic. Particularly, the most common words found in the title, abstract and keywords allowed us to distinguish spatial scales of interest (i.e., field, farm, landscape), scientific fields (soil sciences, ecology) or stakeholder type. Trends in the literature were assessed by determining the number of articles on each topic published throughout the study period (1945-2021).

## 2.3 Coverage of IFOAM principles

We performed textual analysis of the content of articles to determine the coverage of the four IFOAM principles *health*, *ecology*, *fairness* and *care*. Textual analysis is a method of data analysis that closely examines either the content and meaning of texts or their structure and discourse (Given 2008; Tamburino et al. 2020). We looked at the associated values for each IFOAM principle listed and discussed by Padel et al. (2009), where: *health* encompasses 'food quality', 'plant health', 'soil health', 'animal health', 'non-polluting', 'system health', 'resilience' and 'integrity'; *ecology* includes 'closing cycles', 'environmental protection', 'self-regulation', 'ecological systems', 'site-specific' and 'reduced inputs'; *care* includes 'precaution/prevention', 'tacit knowledge', 'responsibility', 'exclude GMOs' and 'future generations'; and *fairness* encompasses 'respect', 'fairness', 'food sovereignty', 'animal welfare', 'equity', 'stewardship', 'justice' and 'transparency'. These ethical values of organic agriculture are taken from the literature and operationalize the principles, which are very broad (Padel et al. 2007). They have a normative objective indicating what is 'right' or 'good' organic system. Hence, we can distinguish how the current research on organic systems is encouraging organic system in some direction within this space of values. Searching for values in publications via search words linked to them allows understanding of how organic research addresses these values explicitly. A small number of papers embracing the different principles of IFOAM would ultimately lead to concerns on the ability of agricultural research to produce holistic research and knowledge in disruption with the 'conventionalised' organic systems.

We analysed the title, abstract and keywords of all selected articles that addressed one or several of the four principles by searching for the body of words for each value. We added synonyms of values we were able to identify from various IFOAM documents (e.g. Weidmann et al. 2007) and scientific articles discussing the IFOAM principles (e.g. De Wit and Verhoog 2007). We double-checked manually words with a potential double meaning, e.g. 'stress' in the 'system health' value can be understood as 'emphasise'. Of the articles reviewed, 1339 could not be attributed to any of the IFOAM principles.

## 2.4 Research on temporal and spatial crop diversification and legume production

In order to provide a more specific overview of research on organic agriculture, we selected two research areas related to diversification practices aimed at increasing the sustainability of food and agriculture: (i) spatial and temporal crop diversification practices ('crop diversification practices') and (ii) inclusion of legumes in the organic food system ('legume crop production'). For each research area, we established a list of relevant search words. For 'crop diversification practices', we used the classification and associated keywords from Hufnagel et al. (2020) referring to four temporal mechanisms of crop diversification ('crop rotation', 'double to multiple cropping', 'catch crops', 'relay cropping'), combined with seven spatial crop diversification keywords ('alley cropping', 'inter*cropping', 'mixed crop*', 'companion crop*', 'variety mixture*', 'bee-friendly plant*' and 'trap crop*'). For each crop diversification practice, we established a list of synonyms, such as 'cover crop*' for 'catch crops'. We compared the frequency of articles mentioning crop diversification practices in organic agriculture with frequencies reported previously for all types of agriculture (Hufnagel et al. 2020), to identify differences between research on conventional and organic production. As noted by Hufnagel et al. (2020), 'the search terms were not exhaustive and overlaps between categories were unavoidable'. We performed a comparative analysis between organic and conventional by comparing the content of the papers in the organic literature with published reviews which target conventional food and agriculture.

For legume production, we used the list of legume species provided by Magrini et al. (2019), based on both common names and Latin names, to identify the crops studied. Using the same framework, we compared the coverage of 10 scientific fields identified by Magrini et al. (2019) as being of interest in agri-food system research, i.e. genetics (breeding of legumes), agronomy, ecophysiology, biotic stress, animal feeding, processing, nutrition, allergy, acceptability and socioeconomics aspects. Knowledge of all of these scientific fields is needed to address the sustainability of agri-food systems. We then compared the proportions of papers published on each scientific field for organic (our analysis) and conventional agriculture (based on Magrini et al. 2019), in order to assess the extent to which organic agriculture addresses downstream interests, an aspect that is lacking in research on conventional agriculture.

### 2.5 Limits of the study

Bibliometric and textual approaches rely on the analysis of words in the title, abstract and keywords with various tools. Using title, abstract and keywords, as done in the topic analysis, make the analysis sensitive to the choice of words used by the authors. We assumed that the words had been carefully chosen and adequately depicted the orientation of the paper and its content. For the textual analysis used to capture the IFOAM principles and values in each published paper, we based our analysis on a large list of synonyms, which allowed the different variants of IFOAM principles to be captured. However, the large number of papers meant that we could not check all papers manually for each principle, which possibly resulted in reference to the principles being wrongly identified in some papers. We tried to minimise this potential error by examining a random sample of 100 papers for each value, to identify expressions containing our search words. This led to us reducing or broadening our list of synonyms iteratively to ensure a valid ensemble of papers for each principle and value. We also accept that the global scope of the review may hide local nuances, for example, in comparing between crop types studied. Regarding the IFOAM principles, it was difficult to distinguish the scale of analysis hence our consideration about IFOAM principles and their assessment applies across scales from field to landscape in general. In relation to the study of diversification practices, our analysis suffers from similar limitations to the studies it builds on such as Hufnagel et al. (2020). The lack of consensus on crop diversification practices both in terms of definition and classification prevent the compilation of an adequate list of search term for each category. Finally, we extracted data from ISI Web of Science which is the most rigorous in terms of journals selected and indexed (Stahlschmidt and Stephen 2020). The use of SCOPUS would have generally resulted in a similar number of papers. We focused on the category 'agriculture and food' but screened carefully papers not in this category which did not fall into the topic of organic agriculture.

## 3 Domination of mono-disciplinarity and single spatial scale focus of topics

Analysis of topics covered by the articles revealed research on organic agriculture and organic food to be primarily mono-disciplinary. At field scale, topics were divided among soil sciences, weed sciences, pest sciences and livestock sciences, while at farm level, they were split between environmental impact assessments and socioeconomic assessments, with consumers clearly separated (Table 1). For the topics at field level, the articles assessed the consequences of crop or livestock management practices, such as soil tillage or animal nutrition and feed ration on soil physical, chemical and biological quality, weed population and dynamics, diseases, yield and crop product or milk and meat quality. Keywords relating to 'Soil management' indicated research about effects of organic fertilisers and amendments (e.g., compost and manure) management of soil fertility, nutrient dynamic, microbial activity, carbon sequestration and energy efficiency. In 'Weed control', the impact of weeds on yield was researched in relation to tillage, seed (density), mulch and rotations. In the topic 'product quality', articles focused on the impact of organic farming on the composition and quality parameters related to the quality of different cultivars or genotypes, with indicators such as the level of antioxidants in type of crops including cereals (wheat) and vegetables (tomato). The topic 'pest and disease management' included words related to disease and pest control in organic farming, such as oil, extracts or copper, and particularly focusing on organic wine production. The topic 'livestock farming' included all research on organic livestock production, focusing particularly on feed quality and quantity impacts on livestock production. This mono-disciplinary emphasis of previous research has already been highlighted for organic agriculture, where 'researchers remain inexperienced in multidisciplinary, multifunctional and participatory research' (Barbercheck et al. 2012, p. 93). More recently, Freyer et al. (2019) claimed that organic agriculture and organic food research is not significantly multidisciplinary, due to institutional and educational barriers.

Despite the mono-disciplinarity of topics, some proximity of topics was observed (Fig. 4A). The proximity between 'livestock farming' and 'product quality' (topics 4 and 2) reflected major research on the relative impacts of organic and conventional farming on product quality, including nitrate, nitrite or metals such as cadmium in meat, bacteria (e.g. listeria; Failla et al. 2021) and other indicators such as fatty acids (Wanniatie et al. 2019; Gálvez et al. 2020). Research on the health benefits of organic products was reflected in these topics, with many reviews and meta-analyses highlighting various benefits in terms of composition of meat or other livestock products in organic compared with conventional production (Palupi et al. 2012; Średnicka-Tober et al. 2016b, Średnicka-Tober

**Table 1** The 15 most frequent keywords for each of the nine topics identified using the Latent Dirichlet Allocation (LDA) approach. Keywords represent the words most closely associated with each topic. The star (*) represents different variations of the root word (e.g., efficien* for efficient and efficiency)

| Topic 1: farm socio-economic impacts | Topic 2: product quality | Topic 3: weed control | Topic 4: livestock farming | Topic 5: soil management | Topic 6: pest and disease management | Topic 7: landscape ecology | Topic 8: consumers' preferences | Topic 9: farm environmental assessment |
|---|---|---|---|---|---|---|---|---|
| farmer | fruit | weed | milk | soil | extract | speci* | Food | farm |
| agriculture* | cultivar | crop | dair* | fertil* | resist* | landscap* | consum* | system |
| farm | content | yield | cow | compost | disease | divers | purchas* | rice |
| sustain | yield | cover | feed | microbio* | grape | pest | market | energy |
| develop | antioxid | tillage | meat | manur* | oil | abund | consumpt | emiss |
| economy* | variet* | seed | anim* | nutrient | sampl* | manag | attitude* | crop |
| ecology* | acid | wheat | herd | carbon | wine | field | behaviour | input |
| market | phenol | mulch | pig | plant* | isol | orchard | organ* | product |
| social | tomato | grain | acid | manag* | pathogen | community | price | convent |
| polic* | wheat | rotat* | diet | amend* | contamin* | habitat | health | yield |
| food | genotyp | clover | egg | nitrogen | fungi | biodivers* | intent | econ |
| certify | cultiv* | soil | fatti | biomass | pesticide | farm | label | effici |
| participatori | grown | winter | graz | system | copper | predat* | survey | cost |
| sector | quality | legume | grassland | matter | control | insect | payment | model |
| adopt | compound | manure | farn | crop | treatment | nematode* | prefer | environment |

et al. 2016a). Some papers explored the impacts of livestock management strategies on livestock product quality (e.g. Liu et al. 2020), but none of the articles in our dataset contained any review or meta-analysis of these impacts.

'Soil management' and 'Weed control' (topics 5 and 3) were also jointly addressed in some articles, for instance on the design of organic cropping systems with conservation tillage or no-tillage, in which synergies between reduced weed infestation and maintenance of long-term fertility of the system for productivity are sought (Peigné et al. 2007; Halde et al. 2015; Hashimi et al. 2019; Littrell et al. 2021). The proximity between these two topics was also reflected in the large number of alternative products tested to control weeds while acting assoil amendments, such as tea compost (Vail et al. 2020), green manure (Carlesi et al. 2020) and dead mulches (Sihi et al. 2017; Ginakes et al. 2020), and additional and novel crops in the rotations (e.g. quinoa) (Wieme et al. 2020). However, the potential effects on pests were not assessed in those studies, but treated separately in the distantly related topic 'pest management'. Potential interactions with livestock were also not assessed, with a lack of articles specifically targeting crop-livestock integration in organic systems in comparison with conventional agriculture according to previous reviews at farm and regional level (Peyraud et al. 2014; Martin et al. 2016). This is a major gap in the literature, as current organic systems are in some cases highly dependent on conventional agriculture in terms of provision of manure to maintain fertility and productivity over time (Nowak et al. 2013). These results indicate a need for increasing interdisciplinary efforts at field level, with systematic measurement of multiple processes (for instance, weed-nutrient-pest dynamics) influencing quality and yield (Bilsborrow et al. 2013; van Bruggen et al. 2016).

Topics such as nutrient management clearly cross scales (field to farm to landscape) and can be understood and managed at a variety of different scales. They also cut across the boundaries between the crop and livestock sciences. In terms of our review structure these would accordingly sit in topics 4, 5 and 9. In reality, studies are often bounded by scale and focus across scales less often. Taking nutrient budgets as an example, Gadermeier et al. (2011) calculated field scale nutrient budgets for organic farms, Watson et al. (2002a, b) and Nesme et al. (2012) compiled farmgate nutrient budgets for organic farms. Some published studies also study dependence of arable systems on livestock farms for nutrient supplies (e.g. Foissy et al. 2013; Nowak et al. 2015). There are modelling studies where farm scale nutrient budgets have been used to show the possible impact of organic farming on nutrient management at catchment level (e.g. Garnier et al. 2016) but the distribution of organic farms within landscapes at current conversion levels means there are unlikely to be any studies of entirely organically farmed catchments.

The four remaining topics focused on different parts of the organic agri-food system, at farm level with 'farm socioeconomic impacts' and 'farm environmental assessment' (topics 1 and 9) and at landscape level and consumer level with 'landscape ecology' (topic 7) and 'consumers' preferences' (topic 8), respectively. In contrast to all other topics, 'landscape ecology' covered ecological interactions among fields, farms and landscapes in relation to biodiversity or

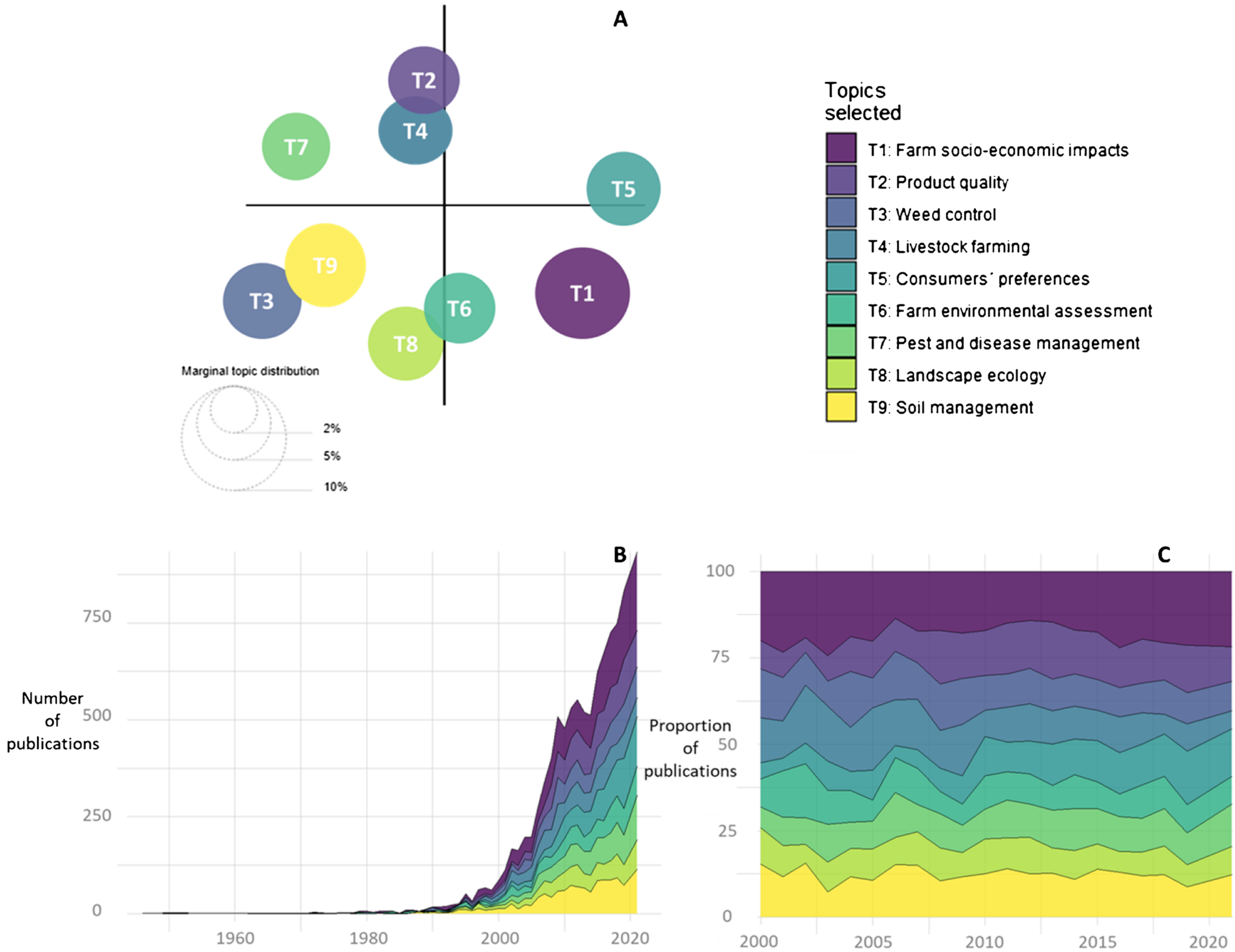


**Fig. 4** **A** Inter-topic distance map via multidimensional scaling showing the overlap of topics 1–9. **B** Evolution of the number of published articles per topic from 1945 to 2021, indicating significant emergence of research on organic agri-food in the late 1990s. **C** Changes in the proportions of articles on each topic 2000–2021, showing the increase in research on consumers' preferences and product quality

natural pest control studies. These studies examined in particular the influence of organic or conventional crop fields in a landscape composed of a certain proportion of organic agriculture, and hence the effect on populations of natural enemies or abundance of species of interest, such as pollinators.

The topic 'farm environmental assessment' also covered issues relating to energy use and emissions from farming systems, and particularly efficiency of production. It was disconnected from 'farm socioeconomic impacts', which addressed the impact of policies on farm economic performance in relation to market and certification. This reinforced the monodisciplinary perspective of research to date on organic food and organic agriculture. It is a concern that research targeting farming systems has not accounted for factors at other scales that drive the viability of organic systems. Moreover, considering the current higher prices of organic products, closer links are needed with 'consumers' preferences', here disconnected from other research (Fig. 4A). For instance, links to consumer willingness to pay for organic products based on information on pesticide use on these products could help identify market opportunities at regional level (Barlagne et al. 2015).

## 4 Increased consumer-oriented research in the literature

A plot of the number of published articles mentioning the nine topics over time revealed a marked increase in frequency since the year 2000 (Fig. 4B). The proportions of organic food research papers on the topics 'consumers' preferences' and 'product quality' showed particular increases, from 4 to 14% and 6 to 13%, respectively, in the period 2000–2021 (Fig. 4C). These increases indicate that recent research on organic food and agriculture has been dominated by a consumer-oriented perspective, rather than an environmental protection perspective. Some previous studies have reported an increase in research on consumer interest (e.g. Hemmerling et al. 2015), while we were able to quantify this increase for the first time. It appears to relate to health consciousness and perceived higher quality of organic products, which are reported to be among the top factors explaining consumption of organic products, ahead of concern for the environment (Rana and Paul 2017; Li et al. 2019). The nutritional value of products from organic agriculture has often been compared with that of products from conventional agriculture (Vigar et al. 2020), especially components of interest such as the level of desirable antioxidants (e.g. Bragueto Escher et al., 2019). Interestingly, the debate about the quality of organic food is still largely open, as lack of robust comparison of raw and processed products undermines the conclusions drawn in some parts of the literature (Suciu et al., 2019). Consumers' preferences for higher quality products, for instance lower levels of pesticide residues (Gomiero 2018), rather than lower environmental impacts of organic agriculture, could explain why organic production systems have undergone conventionalisation (Darnhofer et al. 2010). As a result, current organic systems may meet the expectations of consumers to some extent, but do not significantly reduce the negative impacts of agriculture on the environment. In fact, a meta-analysis by Tuomisto et al. (2012) found that, while organic systems had lower energy requirements, they had higher land use consumption and higher eutrophication and acidification potential per unit of product unit (Seufert and Ramankutty 2017). The choice between 'per land' or 'per product' calculation of impacts strongly modifies the performance of organic agriculture (Seufert and Ramankutty 2017). In contrast to 'product quality' and 'consumers' preferences', there has been a declining trend in research on 'livestock farming', from 12 to 5% publications (Fig. 4C). This could also be linked to the more health-focused perspective of consumers in developed countries, among whom consumption of animal products is decreasing.

## 5 Poor coverage of IFOAM principles and associated values

Many of the articles on organic agriculture and organic food in our dataset addressed either one (4020 articles, 40%) or two (3654 articles, 36%) of the IFOAM principles of organic farming, while 877 articles (9%) addressed three and only 140 articles (1%) addressed all four IFOAM principles (Fig. 5). The principles *health* and *ecology* were often addressed together (in 2432 articles, 20%), probably because

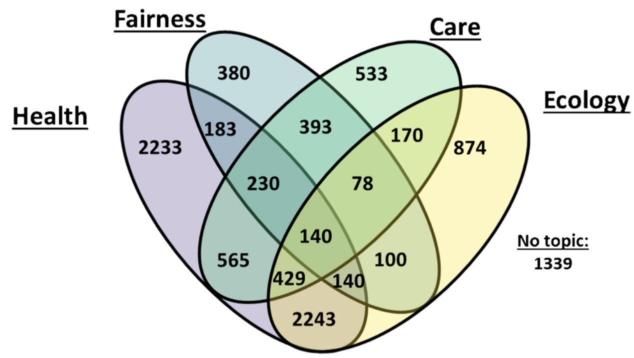


**Fig. 5** Venn diagram showing overlaps between publications to date on the four IFOAM principles. Numbers indicate the amount of articles covering the IFOAM principles represented by each ellipse, e.g. 533 articles cover only the 'care' principle and140 cover all four principles

they both target biophysical processes such as 'soil health' for *health* and 'closing cycles' for *ecology* (Fig. 6). Moreover, many values from the *health* and *ecology* principles were linked. For instance, research on replacing pesticides with higher crop diversity contributed to increased 'environmental protection' in the *ecology* principle, hence contributing to the 'non-polluting' value of the *health* principle. 'Future generations' in the *care* principle was addressed in 95 articles. Research at the intersection between principles was not abundant, as only 140 articles (1%) addressed all four principles.

The low number of papers targeting all four IFOAM principles shows a disconnection between biophysical research, encompassing the principles of *health* and *ecology*, and more socioeconomic research, addressing *care* and *fairness*. This dichotomy between agriculture-oriented research and socioeconomic research is a problem, as research at 'the crossroad of agricultural and social sciences' is required to understand drivers for conversion to organic farming (Lamine and Bellon 2009). The low number of studies addressing simultaneously the different principles of organic farming poses a barrier to fully realise the potential of organic agriculture compared with other types of agricultural systems. As mentioned by Sajadian et al. (2017, p. 103), when assessing the impact of organic agriculture, 'all indicators should be considered an inseparable set and all should be used in the development of organic farming'. Evaluation of the effects of organic systems is currently imbalanced, since the majority of published articles have assessed environmental effects of organic food and organic agriculture targeting the *ecology* and *health* of the systems, rather than the *fairness* and *care*. For environmental externalities, meta-analysis and comparisons of systems have shown that organic cropping systems appear to have a positive impact per unit area

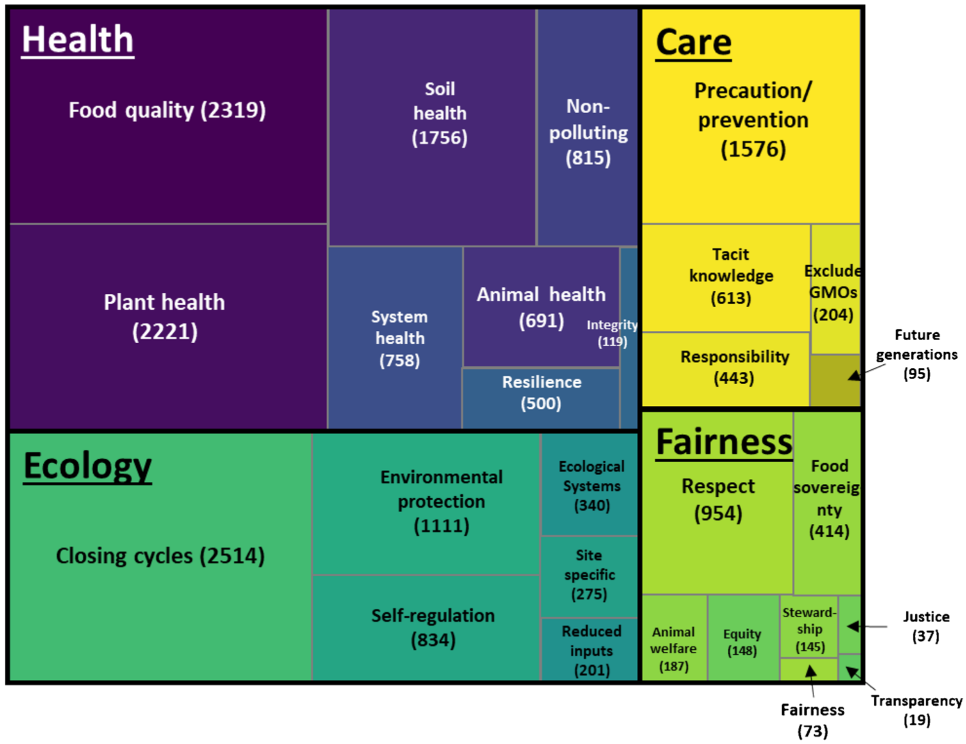


**Fig. 6** Tree map showing coverage of the ethical values behind the four IFOAM principles (Padel et al. 2007). Each principle is represented by a colour (purple for *health*, dark green for *ecology*, yellow for *care* and green for *fairness*). Each sub-division represents a value of the different principles, as presented by Padel et al. (2009). The size of each rectangle is proportional to the number of articles covering the value (shown in brackets). Note that an article can cover several values

(Tuomisto et al. 2012). However, more research is required to capture the full environmental impact of organic systems, as some effects are poorly considered, e.g. effects on biodiversity (van der Werf et al. 2020). The research needs are even greater regarding socioeconomic effects of organic systems, and the outcomes of organic systems for farmers and society. For instance, MacRae et al. (2007) showed that organic systems require more labour, increase demand for local goods and services, and require a greater commitment to participation in civic institutions. However, due to the low number of studies performed for these indicators (Seufert and Ramankutty 2017) (e.g., only 2 for labour requirements), uncertainty about these effects remains high

In the following section, we first describe the coverage of values associated with the IFOAM principles and how they were covered by the literature in our dataset and then identify potential research avenues to produce sustainable organic systems based on gaps in values addressed.

## 5.1 Health

*Health* was particularly addressed in the literature, through the values ‘food quality’ (*n*=2319), ‘plant health’ (*n*=2221) and ‘soil health’ (*n*=1756), but ‘resilience’ (*n*=500) was poorly addressed and ‘integrity’ (*n*=119) was almost completely absent (Fig. 5). Scrutiny of a random sample of 100 abstracts showed that ‘food quality’ addressed the nutritional value of products from organic agriculture, often in comparison with conventional agriculture. ‘Plant health’ focused primarily on weed control with tillage or catch crops and direct or indirect biological pest control with e.g. biopesticides, semi-natural habitats or in-field diversity of crops. ‘Soil health’ related mostly to nitrogen dynamics in the soil and ‘non-polluting’ use of inputs (*n*=815) and to the ability of organic systems to reduce pesticide and nitrogen run-off to the environment. ‘Animal health’ (*n*=691) focused on the impact of livestock management and feeds on diseases and ‘system health’ (*n*=758) primarily referred to the ability of organic systems to reduce disturbances to the ecosystem.

## 5.2 Ecology

*Ecology* was the second most frequently addressed principle, particularly the value ‘closing the cycle’ (*n*=2504), which referred primarily to nitrogen, carbon and phosphorus flows within the system. ‘Environmental protection’ (*n*=1111) covered mostly environmental assessments of agricultural production under organic systems, using life cycle assessment (LCA) (Fig. 6). This was connected to ‘reduced inputs’ (*n*=201), capturing studies addressing decreases in external inputs and maintenance of quality, productivity and soil fertility. ‘Self-regulation’ (*n*=834) in the literature referred to pest regulation by natural enemies promoted by organic systems. An ‘ecological systems’ (*n*=340) perspective was rarely applied. ‘Site-specific’ (*n*=275) related to the link between agricultural management and the biophysical conditions of a region.

### 5.3 Fairness

*Fairness* was the least frequently addressed IFOAM principle in organic agriculture and food research, despite having the largest number of values (*n*=8 as for the *health* principle) (Fig. 6). 'Respect' (*n*=954) addressed to a large extent moral norms and ethics of organic production, respect for the environment, animal welfare or consumers. 'Food sovereignty' (*n*=414) referred to the ability of organic systems to feed the world and the productivity of systems. 'Equity' (*n*=148) mostly referred to gender equity studies on differences between conventional and organic agriculture. 'Stewardship' (*n*=145) mostly related to consumers' and farmers values regarding organic production and consumption, respectively. The 'fairness' value (*n*=73) addressed fair prices of organic products for consumers and producers, and relationships among stakeholders in the entire food chain. 'Justice' (*n*=37) referred to socioeconomic aspects such as labour. 'Transparency' (*n*=19) addressed as the accessibility of information regarding the management of farms and product and price information for consumers.

### 5.4 Care

The *care* principle was addressed particularly via the 'precaution/prevention' value (*n*=1576), which covered much of the food safety research (e.g. mycotoxin contamination), but also potential benefits, such as disease prevention (Fig. 6). 'Tacit knowledge' (*n*=613) covered the use of various types of knowledge in design and assessment of organic systems, mostly at field level. 'Responsibility' (*n*=443) referred to consumer trust in organic production. The value 'exclude GMO' (*n*=204) was addressed in articles questioning the use of GM seeds for organic production. 'Future generations' (*n*=95) covered approaches to responsible use of resources (e.g. preservation of environment capital such as the soil fertility).

A significant number of values related to organic farming were not sufficiently addressed for all principles. For *health*, the low number of articles addressing 'resilience' and 'integrity' shows that analysis of organic food systems to date has overlooked some properties of agricultural systems. Resilience of agricultural systems has been examined in recent years (e.g. Tittonell 2014; Urruty et al. 2016), but in studies focusing almost entirely on conventional systems and the potential of diversification for increasing the sustainability and resilience of these systems (e.g. Hossard et al. 2021). One study in our dataset looked at the stability of productivity of organic compared with conventional systems at field level, but stability is only one of component of resilience (Darnhofer 2021). Larger-scale studies at farm level (as done by Bouttes et al. (2019) for organic livestock farms) and at regional level could provide knowledge on the ability of organic systems to stabilise food production or rebound from shocks, for instance in diverse cropping systems (Egli et al. 2021).

The low attention to 'integrity', the quality of a system that performs its intended function unimpaired, with no unauthorized manipulation of the system, could be explained by its unclear definition for agricultural systems and the lack of indicators for its quantification. Integrity has only recently been addressed in articles about agroecosystems (Blumetto et al. 2019) despite its early definition (Verhoog et al. 2007). In a review of sustainability assessment tools at farm level, Chopin et al. (2021) found no indicators relating to integrity of farming systems. For the *ecology* principle, the value 'reduced inputs' was least often addressed, suggesting that most articles did not consider reductions in inputs to be an objective of organic systems. There is also a need to consider how proposed interventions for managing crop protection fit with the ecological values and principles of organic farming. For example, hot water has been identified as a possible control measure for the perennial weed *Rumex obtusifolius* (Latsch et al. 2016). The study addressed the possible impact of the treatment on soil structure but not on the soil microbiome. In the *fairness* principle, the values 'equity', 'justice' and 'transparent' were not addressed and there was no research on how the added value of organic products or power is split among producers, consumers and other stakeholders in the value chain. For the *care* principle, the discussion about 'future generations' was guided by papers related to food security aspects. More work should be done on the ability of organic food and organic agriculture to sustain the food system in the long run, while still meeting the primary objective of feeding the world's population. We see a particular need for proper indicators and frameworks targeting all IFOAM principles and values, to assess the extent to which organic systems at different scales and different locations meet these principles. It has been suggested that such indicators could also be used for organic labelling (Sajadian et al. 2017).

## 6 Potential for development of diversification practices to increase the sustainability of organic systems

In total, 1076 articles out of the 10,030 mentioned at least one crop diversification practice (Fig. 7). Of these 1076 articles, 235 mentioned two diversification practices, such as the combined effect of different crop rotations including green manure (e.g. Alam et al. 2018) and 50 mentioned

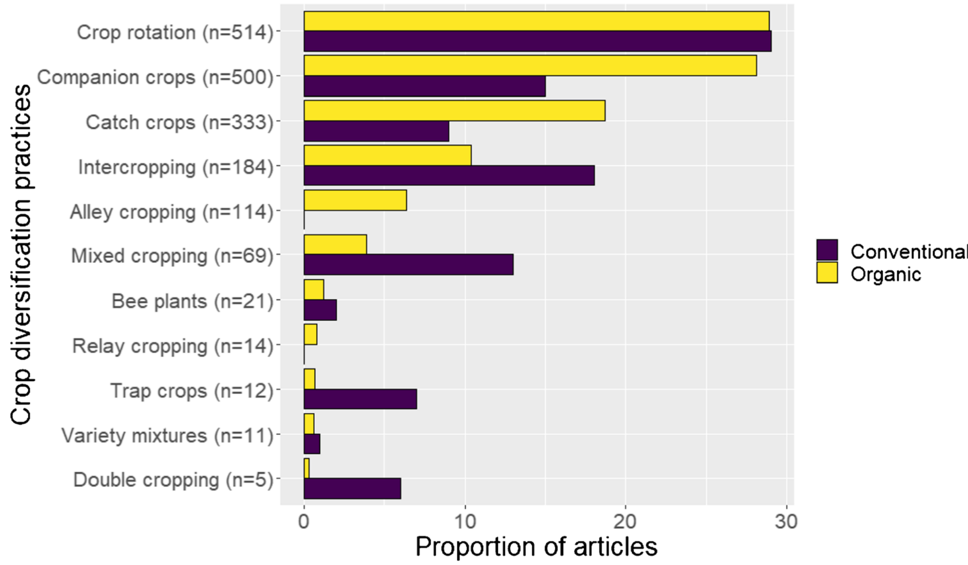


**Fig. 7** Proportion of articles covering diversification practices in organic agriculture ($n$=1076) and conventional agriculture ($n$=42,131). Values in brackets indicate number of studies in the organic category

more than two (in average 3.6 practices are mentioned in each of these 50 articles—not shown). Articles reporting more than three practices generally dealt with drivers of development of these practices within organic agriculture. Publications about conservation agriculture also fell within this category, but most of these articles described theoretical rather than actual systems.

There were significant differences between organic and conventional agriculture in the diversification practices that received most attention in the literature. Published articles addressing diversification practices in organic agriculture focused primarily on crop rotations (29%), companion crops (28%) and, to a lesser extent, catch crops (18%) and intercropping (11%) (Fig. 7). Compared with conventional agriculture, the proportion of papers was much higher for companion crops and catch crops and lower for crop rotation in organic agriculture. In contrast, the proportion of articles on intercropping and mixed cropping was much lower for organic agriculture (11% and 4%, respectively) than conventional agriculture (18% and 13%, respectively). Research on the effects of bee-friendly plants, variety mixtures, trap crops, alley cropping, double cropping to multiple cropping, and relay cropping was almost non-existent (Fig. 7).

Analysis of the organic food/agriculture literature showed that research on diversification practices was mostly unifactorial, with 80% of papers targeting just one diversification practice. Organic food and agriculture research seemed to rely more on substitution of inputs from the conventional agriculture paradigm, rather than re-design of systems around e.g. increased diversity (Duru et al. 2015). For diversification practices, the focus was on comparing a given organic system with another organic system in which a cover crop was introduced or a crop in the existing rotation was replaced. For instance, the sole focus of published articles that covered catch crops was about nitrogen control after cereal growing, with no consideration of other dimensions such as final product quality, soil fertility or pest control. Studies investigating several processes jointly were lacking, with the nitrogen and weed dynamics in cover crops mostly addressed in separate studies, despite their links. System approaches combining multiple innovative practices such as diversification practices were lacking, despite their often stated importance in solving complex issues. Future research needs to address larger complex systems mixing a large number of innovations in system experiments, as done by Jacobsen and Jordan (2009) for example with a combination of alley cropping with perennial legumes, cover crops and agroforestry. Those experiments could help bridge the gaps between the different disciplines highlighted previously with more systematic monitoring of nutrient, weed and pest dynamics simultaneously. Another future research pathway could be to expand the tracking of practices and innovations by organic farmer, as done for farmers cultivating organic vegetables (Morel et al. 2017) or operating conventional diversified systems (e.g. Salembier et al. 2015).

The analysis also revealed a weak focus in the organic food/agriculture literature on some practices such as bee-friendly plants and trap crops that can benefit biodiversity and possibly raise yield via increased pollination and natural pest control (Pfiffner et al. 2019). Research to date on these techniques has not covered all types of production and zones, and is generally limited to fruit trees or vegetables such as tomatoes (Balzan and Moonen 2014). Some studies in our dataset examined increases in biodiversity, but not the effect on crop yields. For instance, Henriksen and Langer (2013) studied the effect of organic agriculture on flowering of bee-friendly plants in road verges and

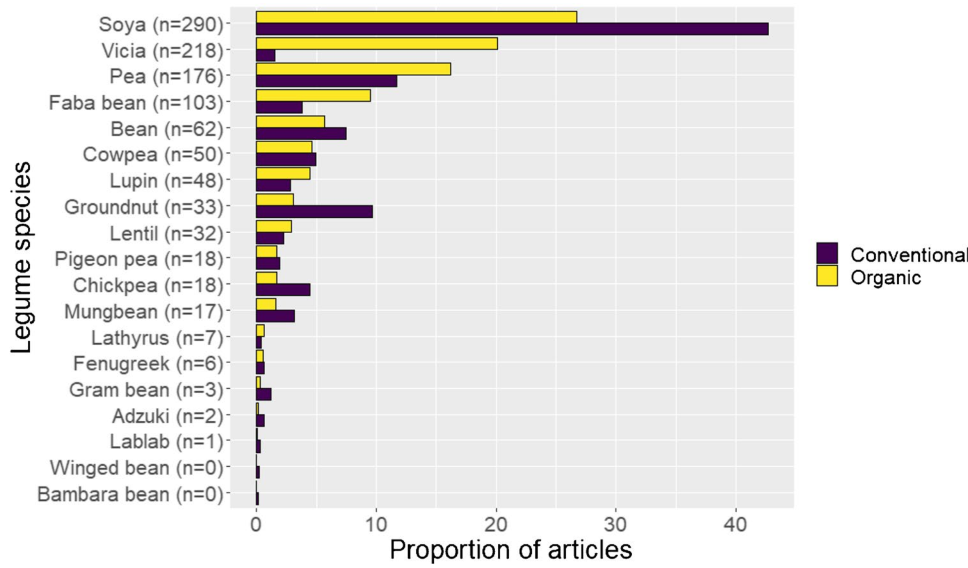


**Fig. 8** Proportion of studies in organic and conventional research covering different legume species. Values in brackets indicate the number of studies for the organic category. In total, 708 papers mentioned at least one legume species

wheat fields, but did not quantify wheat yields. Variety mixtures were poorly addressed in organic food publications and need to be covered in future research, as the literature on conventional agriculture shows that variety mixtures are high- performing in the presence of specific limiting factors, such as diseases or pests (Costanzo and Bàrberi 2014). The lack of research in the organic sector may be due to lack of modern varieties that produce high yields under organic conditions (Murphy et al. 2007; Bueren et al. 2011). Alley, double and relay organic cropping have scarcely been studied, possibly because they can be confounded with intercropping. Intercropping has been studied more frequently in conventional than organic systems, with studies on cereal with legumes (e.g. pea-barley, sown and harvested together) show higher and more stable yields and revenues and improved use of abiotic resources than sole crops (Bedoussac et al. 2015), combined with reduced weed competition and disease burden (Hauggaard-Nielsen et al. 2008). Intercrops have also been shown to provide greater yield benefits under low input conditions (Hauggaard-Nielsen et al. 2006) which perhaps explains why they have been studied more in organic farming.

## 7 Legume-based system knowledge needed to reverse conventionalisation of organic systems

There were significant differences between organic and conventional farming also as regards the legume species targeted in research (Fig. 8). Organic farming research addressed vetch, pea and faba bean (20%, 16% and 9% of published articles, respectively) relatively more than conventional farming (2%, 12% and 4%, respectively). Research on conventional farming was targeted more towards soybean and groundnut. Of the articles addressing legume production, those on organic agriculture covered more than one species (16%) more frequently than those on conventional agriculture (6%) (Fig. 8).

A larger number of legume species were tested in organic food/agriculture research than in research on conventional agriculture. In a meta-analysis of diversity of crop rotation species, Barbieri et al. (2017) found that legumes were more frequently introduced in organic crop rotations in Europe than in conventional rotations. This can be explained by the fact that organic systems are more dependent on legumes for nitrogen supply and that different legume species to prevent the build-up of diseases. For example in Europe, it is recommended that peas and faba bean are not grown more than once every 5 years, while cereals such as winter wheat and maize can generally be re-cropped after two years without major detrimental effects of pests and diseases. Research on novel legume crops could address opportunities for increasing the frequency of legumes in rotations and hence sustain the fertility of organic systems without relying on external inputs, such as manure from conventional agriculture or costly organic fertilisers.

Analysis of the number of papers covering each scientific field in agri-food system research on organic legumes revealed that the proportion of articles published about genetic improvement of legumes was low (<5% of papers) compared to that in research on conventional systems (20%) (Fig. 9). However, organic farming was better represented in agronomy, often with the aim of demonstrating the delivery of ecosystem services by legume-supported organic rotations. Typical keywords related to efficiency of inputs, provision of ecosystem services and socioeconomics. No study addressed more than seven of the 10 scientific fields identified by Magrini et al. (2019) for the food system and only 21

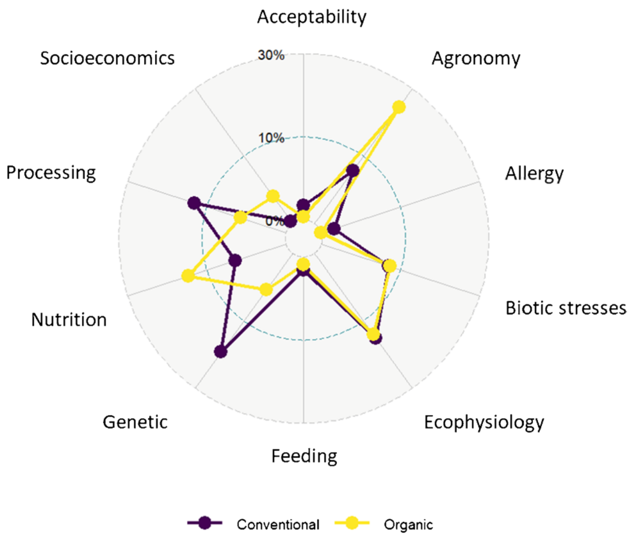


**Fig. 9** Proportion of articles on organic and conventional agriculture in our dataset covering the different scientific fields identified by Magrini et al. (2019)

out of 956 papers addressed more than five scientific fields. Most studies adopted either a field perspective overlapping with agronomy, ecophysiology and biotic stresses, or a feeding, processing and nutrition perspective (Fig. 9).

There was a lack of research on diversification of organic food/agriculture with legumes beyond the field level. This lack of research included studies addressing socioeconomic aspects of legumes, especially at farm scale, and all steps of the value chain such as nutrition, socioeconomics aspects in the value chain or processing. Research on processing of organic legumes was also scarce (5%, compared with 13% for conventional agriculture), indicating fewer market opportunities for organic farmers. Lack of such research has been identified previously as a lock-in in development of legumes for conventional agriculture (Magrini et al. 2016; Meynard et al. 2018), while we are first to report it for organic agriculture and organic food. Within the entire literature on food and agriculture, there was a particular lack of studies on processing for organic food systems, including a lack of research on organic legume products for human consumption. The number of studies on genetics was particularly low, which is well aligned with the reported lack of availability of cultivars adapted to organic agriculture. Bueren et al. (2011) estimated that around 95% or organic crop production was built on varieties bred for the conventional sector. Even where producers are using organically certified seed, varieties have not necessarily been bred organically with traits suited to organic production (Shelton and Tracy 2016). More studies at farm level and on the whole supply chain are needed to facilitate transition of conventional to organic cropping systems with a larger diversity of legumes (Magrini et al. 2018).

## 8 Conclusions and future outlook

Our bibliometric analysis showed that research to date on organic food and organic agriculture has mainly been concerned with consumer perceptions about organic food and quality, particularly in comparison with conventional foods. This emphasis on consumer health-consciousness could explain why organic systems mimic conventional systems and focus on meeting consumer demand for perceived higher quality products, rather than improving environmental protection. Research on organic food and organic agriculture is currently mainly mono-disciplinary, hampering assessment of the overall effects of organic systems on the environment and the socioeconomic benefits. Experiments combining different disciplines and testing multiple diversification practices could provide the necessary insights, in the same way as research on integrated crop-livestock organic production. The focus of research on crop diversification in organic farming was different from that in conventional farming research with more emphasis on the use of service crops and less on rotation and cash crop mixtures. The four IFOAM principles of organic agriculture (*health*, *ecology*, *fairness* and *care*) are seldom addressed together in the literature on organic agriculture, due to a general lack of emphasis on some associated values such as integrity or equity within organic systems. Future research assessing organic systems using a list of indicators specifically targeting each principle, and most linked values, is one option to remedy this to ensure that the organic system whatever their scales (cropping systems, farming systems, landscapes) meet the ethical values of IFOAM. Similarly, a whole-system perspective would increase understanding of how key practices, such as legume inclusion or improved soil nutrient management, can increase the sustainability of organic cropping systems. Moreover, some research is needed to develop some currently minor topics such as the impact of organic agriculture on biodiversity which is mostly addressed in a utilitarian perspective in terms of natural pest control. As in conventional agriculture, lock-ins currently exist due to most research targeting agronomic improvement of organic systems rather than the whole supply chain.

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**Author contribution** Conceptualization: PC, AM and CW; data collection: PC, AM and CW; methodology: PC, AM and CW; formal analysis: PC; writing—original draft: PC; writing—review and editing: PC, AM, GB, SD, OJ, IK, ML, TO, RR, IO and CW; funding acquisition: AM, IO and GB.

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**Data availability** All data used are available online.

**Code availability** The entire R code is provided along with inputs files.

## Declarations

**Ethics approval** Not applicable.

**Consent to participate** Not applicable.

**Consent for publication** Not applicable.

**Conflict of interests** The authors declare no competing interests.



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