Changing perspectives on chicken-pastured orchards for action: A review based on a heuristic model

Sara Bosshardt, Rodolphe Sabatier, Arnaud Dufils, Mireille Navarrete

Changing perspectives on chicken-pastured orchards for action: a review based on a heuristic model

Authors

Sara Bosshardt*, Rodolphe Sabatier, Arnaud Dufils, Mireille Navarrete

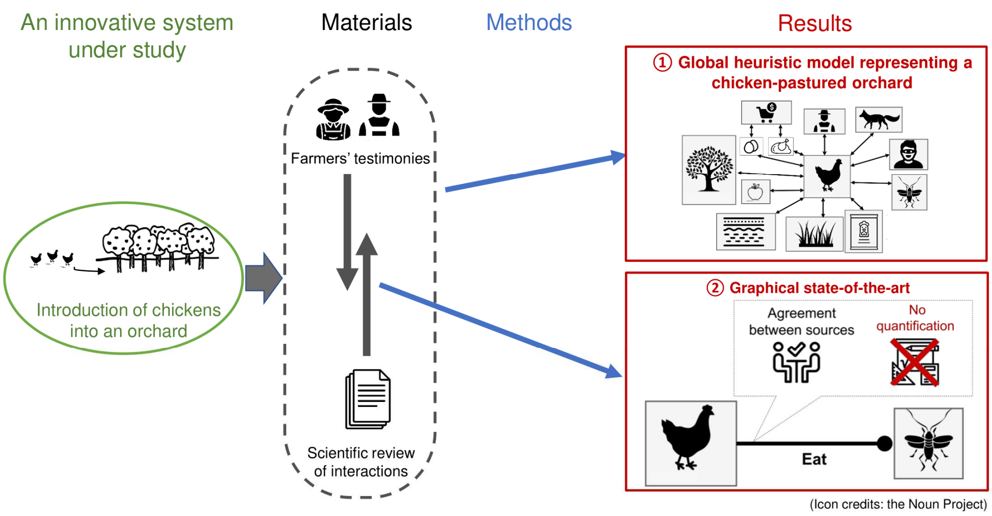
INRAE, UR 767 Ecodéveloppement, 84000 Avignon, France

*Corresponding author: sara.bosshardt@inrae.fr

Highlights

- Chicken-pastured orchards are increasing in popularity among fruit growers involved in the agroecological transition
- These agroforestry systems are complex and a global consideration of interactions and components is needed
- We built a global heuristic model of chicken-pastured orchards and compared the scientific state-of-the art to farmers' testimonies on some interactions
- We showed that the scientific literature is lacking and rarely fits farmers' expectations for numerous interactions
- More agroecological approaches are needed to study these systems and to help fruit growers design and manage chicken-pastured orchards

Graphical Abstract



Abstract

Context

Agroforestry and, more precisely, the integration of animals into orchards, represent an interesting source of income diversification for fruit growers who are confronted with rising climatic and economic risks. Besides farm resilience and optimisation of land use, this association seems to provide reciprocal benefits for both trees and animals, such as: nutrient cycling, weed management, natural protection and pest control. In particular, poultry and, more specifically, chickens, have caught the attention of numerous fruit growers in search of simple and time-saving agroecological solutions to regulate pests and weeds in their orchards. Yet, whereas traditional silvopastoral systems involving livestock have been extensively studied, the advantages and disadvantages of introducing chickens into orchards have been overlooked.

Objective

In this review, we aimed to build a heuristic representation of a chicken-pastured orchard in order to better understand this complex agroecosystem. We also compared the scientific state-of-the-art concerning some characteristics of this system to situations in the field.

Methods

We first carried out a synthesis using an initial set of information (scientific articles, grey literature, testimonies, etc.) to build a simple heuristic representation based on compartments in interaction. We then examined the nature of information on interesting interactions by comparing 86 scientific articles to 26 farmers' testimonies.

Results and conclusion

We show that the scientific and empirical knowledge concerning chicken-pastured orchards is uneven. More precisely, we identified four types of divergence on some characteristics of the information from different sources concerning the system. One general finding is that the absence of consensus about crucial aspects of the complex dynamic of chicken-pastured orchards and a lack of quantification approaches on several interactions are not consistent with farmers' needs. We suggest that including farmers in the scientific process as well as fostering interdisciplinary systemic approaches, notably between agronomy, animal science and ecology, could greatly benefit the study and design of agroecological integrated systems such as chicken-pastured orchards.

Significance

To our knowledge, this review is the first one to present a global view of chicken-pastured orchards. The review built around the heuristic model aims at helping scientists identify knowledge gaps and new research questions. In addition, the heuristic model can also be a useful tool for designing and managing innovative systems together with the farmers concerned.

Keywords

poultry; agroforestry; fruit grower; diversification; agroecology; ecosystem services

1. Introduction

Fruit growers in Europe are confronted with rising agronomic, economic and social challenges at this time. Moreover, these challenges are somewhat contradictory like, for example, the fact that consumers expect fruit growers to produce fruits using environmentally-friendly practices and, at the same time, demand higher quality fruits (Alaphilippe et al., 2021). Fruit production is also becoming more vulnerable to the consequences of climate change, such as the potential emergence of tree pests (Gomez-Zavaglia et al., 2020) and the shifts in plant phenological traits (Leolini et al., 2018; Vanalli et al., 2021) that lead to huge production losses (Agreste, 2021; Hostalnou, 2021). Recent late frosts in spring 2021 wiped out future fruit harvests in France and forced the French government to declare the event as an “agricultural disaster” in order to compensate fruit growers (France Relance, 2021).

To address these major challenges, fruit growers need to reinvent their activity. Agroforestry is one of the available and promising options (Pantera et al., 2018). This term is defined as the “collective name for land-use systems and technologies where woody perennials are deliberately used on the same land-management units as agricultural crops and/or animals in some form of spatial arrangement or temporal sequence” (Nair, 1993). More precisely, the integration of understorey crops or animals in orchards is an emerging practice for an ever-increasing number of fruit growers who hope to diversify their income sources and provide partial responses to a number of agronomical challenges (García de Jalón et al., 2018; Smith et al., 2013). These approaches that put tree products at the centre belong to what Pantera (2018) calls “high value tree agroforestry”.

Two different ways of orchard diversification are thus possible: intercropping and the introduction of animals. Regarding animals, different species are likely to be introduced: cattle, horse, sheep, chicken, geese, etc. (Brodt et al., 2020; López-Sánchez et al., 2020; Massaccesi et al., 2019; Orefice et al., 2017; Pantera et al., 2018). In contrast with understorey crops, the presence of animals in orchards seems less spatially constrained. Animals provide additional services in response to the diverse challenges of fruit production (Brodt et al., 2020; Corroyer, 2017; Coulon et al., 2000), such as fertilisation (Röhrig et al., 2020a; Soudet et al., 2021), weed control (Lavigne and Lavigne, 2013) and pest control (Clark and Gage, 1996; Pedersen et al., 2004). In parallel, orchards also offer partial responses to vital current issues in animal husbandry, such as animal welfare (García de Jalón et al., 2018), the management of farm effluents (Billen et al., 2021; Brodt et al., 2020) and the feed costs for animals (Meng et al., 2016; Röhrig et al., 2020a).

The advantages and drawbacks of this association strongly depend on the animal species. Compared to livestock, poultry husbandry seems to offer more flexibility to farmers, notably through an easy valorisation of the products (eggs and meat) and limited supervision, notably to avoid damage to trees (Cazaux, 2015; López-Sánchez et al., 2020). Hence, poultry represents an interesting choice for fruit growers who are usually not experienced in animal husbandry because investments in terms of money, time and knowledge are limited compared to livestock. The rising number of fruit growers currently attracted to this practice obviously reflects the interest of fruit growers in these poultry/orchard associations. More precisely, chicken (*Gallus gallus domesticus*), which designates both laying hens and broilers, is the most common poultry subspecies raised by a large number of fruit growers and that we have chosen to focus on in this article. It should be noted that chicken-pastured orchards must be distinguished from silvopastoralism with poultry, also referred to as silvopoultry, in which the types of trees (timber, fruit production, etc.) and poultry (chicken, geese, ducks, etc.) are not specified. They must also be distinguished from what we refer to as free-range chickens in wooded ranges, in which animal husbandry is the main activity on the farm. As defined, chicken-pastured orchards correspond to one type of silvopoultry system, and despite a husbandry component, the main activity is fruit production. In addition, concerning the use of semantics, the term “pastured” seems more adapted to chicken behaviour than “grazed”, which refers more to systems that include sheep or other livestock.

Consequently, whereas traditional silvopastoralism with sheep or cattle has been extensively investigated, far less is known about these chicken-pastured orchard systems, even though they are promising agroecological systems for an increasing number of fruit growers. What is more, these systems raise new scientific issues on agroecological dynamics (Soudet et al., 2021). Indeed, the functioning and management of such agroecosystems are complex because they result in the integration of several interactions, feedbacks and compartments, at various temporal and spatial scales. There is thus a need to construct a global view of all those components in order to represent how this system functions. For this purpose, heuristic representations make it possible to combine and reveal diverse knowledge from a systemic point of view, and, as such, they are useful research tools to help design and manage agroecosystems (Le Page et al., 2014).

In addition, several authors have highlighted the fact that farmers are part of these agroecosystems and build agroecological knowledge through their action on these systems. The integration of farmers’ knowledge into research approaches is therefore considered as essential to build an exhaustive overview of the functioning of agroecological systems, as well as to become involved in an effective agroecological transition (Altieri, 2002). Action-oriented research thus makes it necessary to find a balance between scientific research and farmers’ needs in the field, and to take empirical knowledge into consideration.

For these reasons, the objectives of this article are: (1) to obtain a simple heuristic representation of the components and interactions resulting from the introduction of chickens into an orchard; and (2) to draw up a scientific state-of-the-art of some of these interactions, and to compare current scientific knowledge to farmers’ expectations. This analysis was based on two sets of data: an extensive review of the literature and a collection of fruit growers’ testimonies about chicken-pastured orchards.

In this article, we first describe our methods (Section 1). Then, in Section 2, we present a simplified heuristic model of a chicken-pastured orchard based on a mental synthesis of information, and describe the dynamics involved. This representation is then refined and observed with a focus on the relative interest of research and farmers in each dimension of the system. Our results notably reveal several scientific gaps and a disconnection between scientific and fruit growers' concerns. This observation is finally discussed in Section 3 with a more global approach in order to identify the reasons for this situation, to draw a parallel with other domains and to develop research and operational perspectives about chicken-pastured orchards.

2. Materials and methods

Since most of the chicken-pastured orchards currently in operation belong to fruit growers who have introduced chickens into an existing orchard, chickens are at the centre of our representation. We therefore focused on the interactions between chickens and the other compartments (trees, pests, herbaceous stratum, etc.) and not between these other compartments.

2.1. Construction of a global heuristic model of the agroecosystem

To build an initial heuristic model of the "chicken-pastured orchard" agroecosystem, we used an initial set of various materials: peer-reviewed articles, grey literature (including technical literature and grey scientific literature) and farmers' testimonies taken during a field visit (FV) with fruit growers who own chicken-pastured orchards, and that were personally collected by the authors during two collective field visits.

Grey scientific literature notably includes conference proceedings, non-peer-reviewed articles, Master's or PhD theses, generally from within the French scientific community (Appendix B). The interest of such literature is to provide an image of scientific research in the making since theses and conference proceedings often precede peer-reviewed articles. Similarly, we also used French technical literature, mainly corresponding to technical guides and technical articles written for future and current farmers (generally chicken farmers). These documents were collected using different means: (i) exchanges with experts in the domain; (ii) searches on technical institution websites (e.g., the French Technical Institute for the Poultry, Rabbit and Fish Sectors/ITAVI and the French National Federation for Organic Agriculture/FNAB); and (iii) specific databases (HAL, google scholar, HAL INRAE, etc.). Due to their heterogeneity and the difficulty of carrying out systematic research to find them, these articles were not included in the exhaustive review (Section 2.2.) but were used to construct an initial version of our heuristic model. It was then improved through a systematic review process of the scientific literature in order to include interactions that were missed in the first rough analysis and to obtain a final validated version of the model.

2.2. Representing the state-of-the-art of some of the interactions

2.2.1. Selection of interesting interactions

Among all the interactions represented in the global model (*Figure 1*), we chose to focus more deeply on a restricted number of interactions that concern the sustainability of the association between chickens and orchards. More precisely, we selected all of the interactions emanating from the chicken compartment as being prone to impact fruit tree production (directly or indirectly). We also included other interactions that are liable to impact chicken sustainability in a way specific to orchards and that appeared to be significant according to farmers' testimonies, namely:

-the risks of chicken intoxication in a context of high pesticide use in orchards;

-the question of welfare and protection offered by trees to chickens;

-the question of work organisation for fruit growers who associate chickens with orchards.

Interactions concerning meteorological conditions and wild fauna were indirectly included through the question of welfare and protection provided by trees to chickens.

2.2.2. Search of the scientific literature

Based on this selection, we combined two search queries to find scientific literature related to each of these interactions on Scopus (whose results were more exhaustive than WoS). Our results focus on chickens because we could not find enough material about other poultry subspecies (geese, etc.) whose behavioural characteristics differ too much to be mixed with chickens in the model.

To compensate for the small number of research articles available, we established the working hypothesis that the type of tree did not significantly modify the nature of interactions. We therefore combined articles related to fruit trees in chicken-pastured orchards and any type of tree in silvopoultry systems with chickens.

(i) Final search query on silvopoultry systems on Scopus (last access: June 2021)

((TITLE(hen$ OR chicken$ OR broiler$ OR *poultry) OR KEY (hen$ OR chicken$ OR broiler$ OR *poultry)) AND TITLE-ABS-KEY(agroforestr* OR *silvopoultry OR silvopast* OR "crop animal" OR "integrated agriculture" OR orchard OR (integration PRE/2 animal*)) AND NOT TITLE-ABS-KEY(litter OR manure)) AND (EXCLUDE(DOCTYPE, "er")) AND (LIMIT-TO(SUBJAREA, "AGRI") OR LIMIT-TO(SUBJAREA, "ENVI"))

Since we only collected 46 articles, most of which were not entirely relevant to our question, we decided to extend our search to free-range chicken systems on the basis of the hypothesis that some extrapolations could be made concerning some interactions. We thus wrote a second search query referring to the different compartments and interactions previously selected.

(ii) Final search string on free-range chicken systems, focusing on interactions and compartments of interest (last access: June 2021)

((TITLE(hen$ OR chicken$ OR broiler$ OR poultry) OR (TITLE(egg$) AND TITLE-ABS-KEY(hen$))) AND KEY(pasture* OR (free AND rang*) OR grazing OR foraging) AND TITLE-ABS-KEY(orchard* OR tree* OR soil OR (grass* OR weed* OR herb* OR vegetation OR pasture) OR (biodiversit* OR insect* OR earthworm* OR (pest* AND fruit*) OR spider$) OR vole OR (gasteropod* OR snail* OR slug*) OR predation) AND NOT ALL(ducked OR prairie OR harrier$) AND NOT TITLE(*manure* OR *litter*)) AND (EXCLUDE(DOCTYPE , "er")) AND (LIMIT-TO(SUBJAREA, "AGRI") OR LIMIT-TO(SUBJAREA, "ENVI"))

A total of 155 documents were obtained with (ii) on Scopus.

We examined 195 articles from searches (i) and (ii), among which we identified 68 articles of interest for our heuristic model (*Figure 2* and *Table 1*). We also included 18 other articles in our model that we obtained through careful searches (other articles from known authors, references in a pertinent article, etc.).

Among the 86 articles listed, 51% concern laying hens, 30% broilers and 19% concern both. Similarly, 14% of the articles concern chicken-pastured orchards, 7% other silvopoultry systems, 71% free-range systems and 6% both chicken-pastured orchards and free-range systems.

2.2.3. Obtaining farmers' testimonies

Twenty-six testimonies from French fruit growers who raised chickens under orchards were obtained, directly or indirectly (see Appendix B). Exhaustivity is not an option in such a process and our priority was to collect testimonies from a diversity of sources and formats in order to address the entire range of possible situations. Four types of data were gathered (*Table 1*): field visits (FV, see 1.a), farmers' interviews (FI), videos (V) and grey literature (GL). Farmers' interviews (FI) were taken from a field survey carried out between August 2018 and June 2019 within the EIP-Agri DEPASSe (https://www.grab.fr/wp-content/uploads/2018/09/plaquette-depasse-V8.pdf). Testimonies (V) were taken from four relevant videos on the integration of chickens under orchards. We also retrieved testimonies from different French grey literature media (GL), namely, one technical guide, one technical book and three technical articles.

2.2.4. Identification of related information sources

Precise examination of the literature and testimonies allowed us to improve our heuristic model and to link each article/testimony to the appropriate interactions in *Table 1*. Only primary articles in which some data were specifically acquired on this interaction (through experiments, field observations, surveys, etc.) were included. Reviews and articles citing one interaction as a hypothesis were thus excluded.

2.2.5. Representation of interactions and the nature of information

Interactions were related to one of three categories: (1) chicken health and welfare; (2) chicken nutrition; and (3) the physical, biological and chemical impact of chickens. For each heuristic interaction between two compartments, we characterised and represented the nature of information according to three dimensions:

(i) the sense of the information (e.g., chickens play a role on trees or the opposite);
(ii) the existence of quantifications: depending on the type of source, the information may be qualitative (e.g., chickens eat weeds) or quantified (e.g., chickens ingest 70 g of forage/day);
(iii) the consistency of information from several sources.

2.2.6. Comparison between interactions

We then compared interactions based on some characteristics of the information to identify four categories of interactions corresponding to divergences between and within scientists and farmers. To do so, we assumed that the number of scientific articles for one interaction reflected the level of scientific interest toward a question. The interaction was considered as "quantified" as long as we could find one quantification in the scientific literature. Similarly, situations of disagreement correspond to discrepancies between quantifications (between scientific articles), or even oppositions concerning the existence or not of an interaction (within and between scientific articles and farmers' testimonies).

3. Results

First, we will describe the global model of a chicken-pastured orchard and the nature and organisation of interactions. We will then focus on some interactions that we propose to categorise, depending on some characteristics of the information, by examining the results and attention given by researchers and practitioners to each different dimension.

3.1. Nature and organisation of interactions in a chicken-pastured orchard

In pastured orchards, three types of interactions were identified from the literature (*Figure 1)*: (i) chickens interact directly with trees; but (ii) also interact with other biophysical components that may have an indirect impact on trees (the soil, the herbaceous ground cover, the fauna); (iii) on a broader spatial scale, there is an interaction between chickens and the socio-technical environment (farmers, farm equipment, marketing channels). Moreover, the presence of chickens involves the inclusion of compartments (predators, rodents, thieves), considered as external disturbers of the original “simple” orchard and which farmers have to deal with.

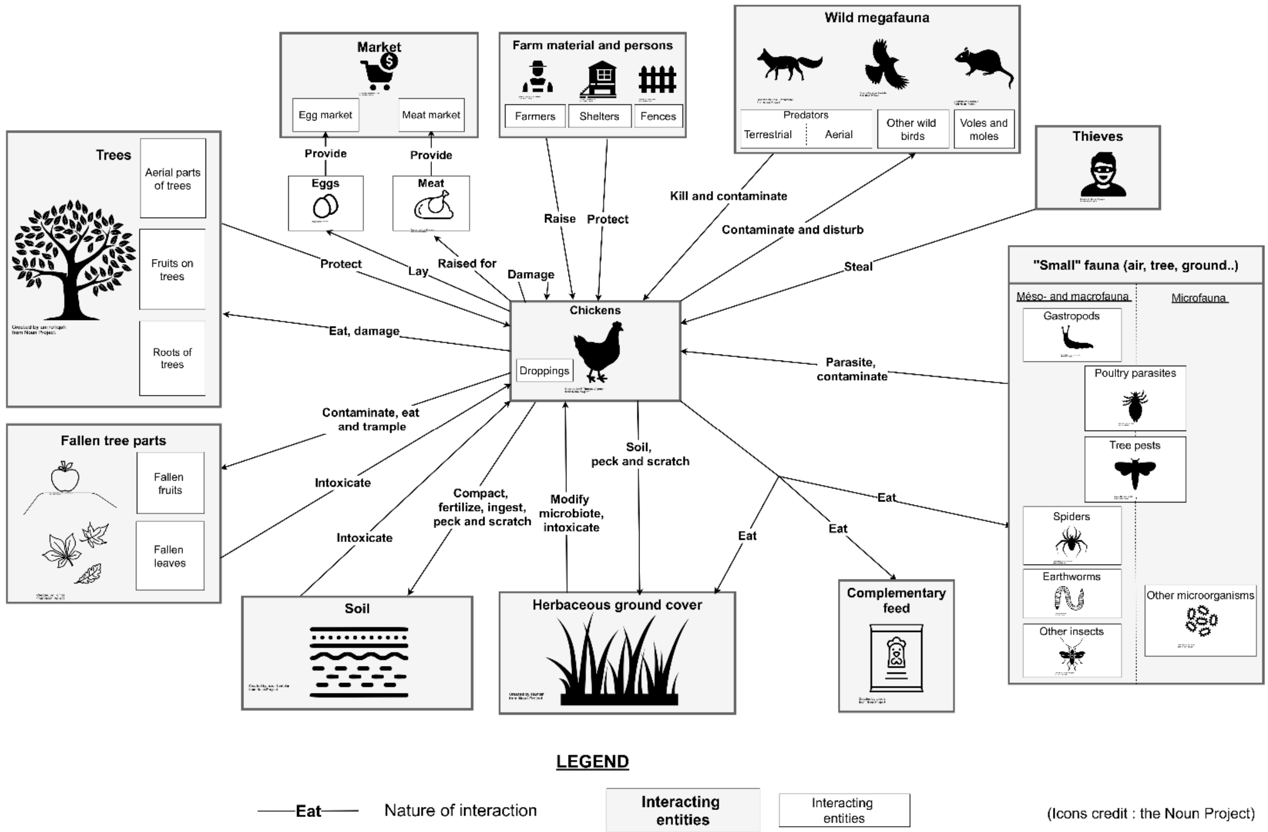


Figure 1: Heuristic model of a chicken-pastured orchard. Only direct interactions linked to the chicken compartment are represented. The chicken compartment is connected to other compartments (represented by rectangles), with directed arrows. The nature of the interaction is given by verbs of action.

3.1.1. Interactions with trees

The association of chickens and trees results in some beneficial direct interactions. Trees buffer meteorological conditions by creating a suitable microclimate that protects chickens against wind, extreme temperature and sun (Jones et al., 2007). In return, chickens create a healthier telluric environment for trees by cleaning tree residues (fallen leaves and fruits) (Timmermans and Bestman, 2016). However, this association is not always a win-win partnership. Chickens can also damage trees and fruits (Hilaire et al., 2001), particularly by eating them, and contaminate fallen fruits as well (Coisne, 2020). Correspondingly, feeding on fallen tree elements can result in a higher risk of intoxication, particularly in the case of a chemically-treated orchard (ADABio, 2020).

3.1.2. Interactions with the biophysical components of an orchard

However, besides these direct effects, most interactions occur indirectly through other compartments of the system.

First of all, some elements from the agroecosystem represent complementary nutritional resources for chickens. Chickens naturally consume grass from the herbaceous stratum (Antell and Ciszuk, 2006) and feed on different types of arthropods that live in the trees, the air and the herbaceous stratum (Clark and Gage, 1996). Depending on the intensity of ingestion and the nature of the arthropods impacted (tree pests, auxiliary fauna, etc.), chickens can improve or impair tree health (ADABio, 2020). Spontaneous intake of elements from the agroecosystem can also impact chicken health. Ground ingestion (Jurjanz et al., 2015), for example, is not considered as a source of nutriments and potentially limits the ingestion of other elements. Contaminated soil and herbaceous ground cover (resulting from orchard treatment, for example) can also result in some intoxication of chickens (Vries et al., 2006). To maintain chickens in a good health and at a sufficient production level, farmers complement this spontaneous intake with feed available in various forms (pellets, whole grains, etc.) (Bryden et al., 2021).

Chickens can also alter the physical structure of the soil and herbaceous stratum by compacting (Su et al., 2018), pecking and scratching them (Breitsameter et al., 2014). They also induce changes in the chemical composition of the soil (Hilimire et al., 2013) through fertilising effects with droppings that can benefit trees, but that can also result in soil pollution and the soiling of the herbaceous ground cover.

3.1.3. Other global interactions

Introducing chickens into orchards often implies a modification of agricultural practices involving poultry-dedicated infrastructures, equipment and work organisation to supply specific marketing channels (García de Jalón et al., 2018).

Finally, the presence of chickens attracts other animals that farmers have to learn how to deal with. Aerial (such as buzzards) and terrestrial predators (particularly foxes) (Bestman and Bikker-Ouwejan, 2020) and chicken thieves act as external disturbers of the agroecosystem by killing and stealing chickens, respectively. Moles and voles do not directly impact chickens but potentially damage trees, plots and poultry infrastructures (Coisne, 2020). These interactions have to be considered because they may deeply impact the sustainability of the introduction of chickens into orchards.

3.2. Characteristics of the information from different sources

In the previous model (*Figure 1*), all interactions were represented in the same way, regardless of the nature of the information. To deepen our understanding of the state-of-the-art of this system, we will now examine the different natures of knowledge that supports these interactions. *Figure 2*, using the same model representation as in *Figure 1*, thus represents some interesting characteristics of the information (quantifications, consistency between sources, etc.) by focusing on a limited number of interactions of interest. To study the level of exhaustivity of the information, we also summarized scientific references and testimonies associated with selected interactions in *Table 1*.

Through a global analysis of these characteristics of the information found in the literature and in testimonies, we identified four different situations of divergence within and between scientists and farmers to which we could link the interactions in *Figure 2*. These situations are presented successively. First, we show that some quantifications of interactions strongly differ between scientific studies. Second, we show divergences between scientists' and farmers' interests in terms of information, that we describe in terms of knowledge gaps on two dimensions: on specific mechanisms and, more generally, on chicken-pastured orchards. Third, we identify strong divergences that occur between farmers for some interactions.

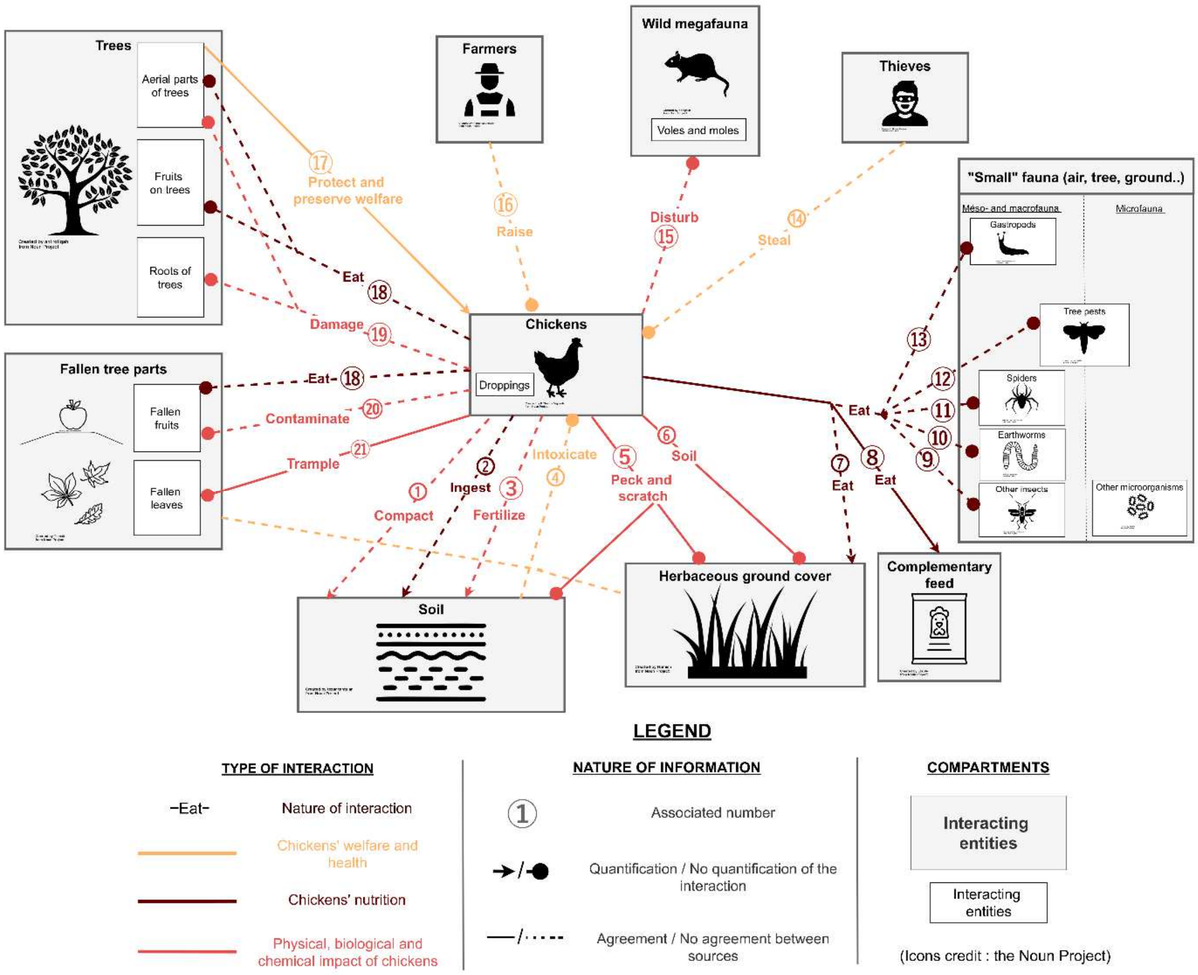


Figure 2: Graphical state-of-the-art concerning interesting interactions in a chicken-pastured orchard. Interactions are categorised into three groups with arrows coloured accordingly: chicken welfare and

health (orange); chicken nutrition (dark red); and the impacts of chickens on the rest of the system (light red). The existence of quantitative data in the literature is represented by the way the line ends: pointed if quantitative data exist; rounded otherwise. The consistency between sources is represented with the type of line for the arrow: solid in the case of relative agreement; dotted otherwise.

Table 1: Scientific references and testimonies associated with the interactions represented in Figure 2.

Compartment [a]	Interaction [a]	Precisions on interaction	Scientific references	Farmers' testimonies [b]
Soil	**① Physical impact of chickens on soil structure**	Bulk density evaluation	Glatz et al., 2005a; Hilimire et al., 2013; Liu et al., 2013; Miao et al., 2005; Su et al., 2018; Xu et al., 2014	FI1, FV2b, FI4, FI5
	② Evaluation of soil intake	No quantification	Almeida et al., 2012; Antell and Ciszuk, 2006	No data
		Partial intake quantification (through crop content)	Amaka Lomu et al., 2004; Horsted et al., 2007b; Horsted and Hermansen, 2007	No data
		Daily intake quantification	Jurjanz et al., 2015	No data
	③ Chemical enrichment of the range by chickens, notably by droppings	Integration of chickens with trees	Clark and Gage, 1997; Gai et al., 2021; Stadig et al., 2018	FI1, FV1, FV2a, FV2b, FI3, FI6, FI7, GL1, GL2, GL7, GL8, V1, V3, SA2
		Integration of chickens with crops or valued pastures	Glatz et al., 2005b, 2005a; Hilimire et al., 2013; Liu et al., 2013; Miao et al., 2005; Skřivan et al., 2015; Su et al., 2018; Xu et al., 2014; Yu et al., 2020; Zhang et al., 2020	No data
		"Classical" chicken range	Dekker et al., 2012; Maurer et al., 2013; Wiedemann et al., 2018	No data
Soil, herbaceous ground cover, fallen leaves	**④ Intoxication of chickens**	By general chemicals (dioxins, furans, DDT, etc.)	Bouwman et al., 2015; Covaci et al., 2009; Hsu et al., 2010; Kudryavtseva et al., 2020; Lin et al., 2012; Piskorska-Pliszczynska et al., 2014; Polder et al., 2016; Stephens et al., 1995; Strankowski and Stanley, 1981; Van Overmeire et al., 2009; Waegeneers et al., 2009; Zafeiraki et al., 2016	No data
		Questions about orchard treatments on	No data	FV2a, FV2b, FI4

		chickens		
Herbaceous ground cover	ⓦ Damage (without specifying the mechanisms)	Impact on vegetation biomass or species diversity of chickens	Almeida et al., 2012; Clark et al., 1995; Cosentino, 2020; Cosentino et al., 2020; Glatz et al., 2005a, 2005b; Horsted et al., 2006; Jones et al., 2007; Miao et al., 2005; Skřivan et al., 2015; Westaway et al., 2018; Xu et al., 2014; Yu et al., 2020	FV1, FV2a, FV2b, FI1, FI2, FI4, FI5, FI6, FI7, FI8, GL3, GL4, GL8, GL9, GL10, V1, V2, V3, SA1, SA2
	⑥ **Damage due to soiling**	Estimation of amount of droppings in different zones of the range	Lolli et al., 2019	No data
	⑦ **Damage due to chicken intake**	No quantification	Clark and Gage, 1996; Mayton et al., 1945	FV1, FV2a, FI1, FI2, FI5, V1, V2, GL10
		Quantification using the sward cutting technique	Dal Bosco et al., 2014; Mugnai et al., 2014; Rivera-Ferre et al., 2007	
		Quantification using dissection (crop, gizzard)	Abouelezz et al., 2013; Almeida et al., 2012; Amaka Lomu et al., 2004; Antell and Ciszuk, 2006; Horsted et al., 2007b; Lorenz et al., 2013; Ponte et al., 2008b	
		Quantification using physico-chemical analysis	Horsted et al., 2007a; Jurjanz et al., 2015; Singh et al., 2016; Skřivan and Englmaierová, 2014	
Soil and herbaceous ground cover	⑤ **Damage caused by pecking and scratching**	Scales of sward degradation	Breitsameter et al., 2014	FV1, FV2a, FV2c, FI2, FI4, GL6, GL7, V2, SA2
		Ethology studies (behavioural time budget)	Abouelezz et al., 2014; Amaka Lomu et al., 2004; Breitsameter et al., 2014; Chielo et al., 2016; Kruschwitz et al., 2008; Larsen et al., 2017; Mayton et al., 1945; Phillips et al., 2020; Phillips and Heins, 2021; Zeltner and Hirt, 2008	
Complementary feed	⑧ **Evaluation of chicken intake**	Quantification of spontaneous intake in free-range contexts	Abouelezz et al., 2013; Almeida et al., 2012; Antell and Ciszuk, 2006; Dal Bosco et al., 2014, 2010; Fanatico et al., 2013; Hammershøj and Steenfeldt, 2012; Hermansen et al., 2004; Horsted et al., 2006; Horsted and Hermansen, 2007; Ipek and Sozcu, 2017; Jurjanz et al., 2015; Lorenz et al., 2013; Meng et al., 2016; Mugnai et al., 2014; Ponte et al., 2008a, 2008b; Rivera-Ferre et al., 2007; Singh et al., 2017; Skřivan et al., 2015; Yu et al., 2020	FV1, FV2a, FV2b, FI2, FI3, FI6, FI8, GL1, GL3, GL4, GL5, GL9, SA2
Small fauna	ⓨ **General impact on populations (no**	Gastropods	Glatz et al., 2005b	No data
		Tree pests	Clark and Gage, 1996	FV1, FV2b, FI1,

	mechanisms studied)			FI2, FI3, FI4, FI5, FI8, GL1, GL2, GL9, V2, V3, SA1, SA2
		Spiders	Clark and Gage, 1997	No data
		Earthworms		
		Other pests	Phillips et al., 2020; Sun et al., 2014; Xu et al., 2014	No data
		Insects (beside pests)	Clark and Gage, 1997	GL2
	Presence of small fauna in the diet (⑨, ⑩, ⑪, ⑫, ⑬)	Gastropods	Abouelezz et al., 2013; Clark and Gage, 1996	No data
		Tree pests	Clark and Gage, 1996	FI1, FI3, FV1, FV2b, GL1, GL3, GL7, V2, V3
		Spiders	Clark and Gage, 1996)	No data
		Earthworms	Almeida et al., 2012; Amaka Lomu et al., 2004; Clark and Gage, 1996; Horsted et al., 2007b; Horsted and Hermansen, 2007	No data
		Insects (beside pests)	Abouelezz et al., 2013; Almeida et al., 2012; Amaka Lomu et al., 2004; Clark and Gage, 1996; Horsted et al., 2007b; Horsted and Hermansen, 2007; Lorenz et al., 2013; Phillips et al., 2020; Singh et al., 2017	FI1, FI2, FI3, GL1, GL7, V1, V2, V3
Thieves	**⑭ Thefts of chickens**	Farmers affected differently	No data	FV1, FI1, FI2, FI3, FI4, FI5, FI6, FI7, FI8
Moles and voles	**⑮ Impact on mole or vole populations**	Contrasted farmers' observations	No data	FV2a, FI3, GL9
Farmer	**⑯ Farmers' management of chicken husbandry**	Work organisation in chicken-pastured orchards	Elkhoraibi et al., 2017; García de Jalón et al., 2018; Rocchi et al., 2019; Röhrig et al., 2020a, 2020b	FV2b, FI1, FI2, FI4, FI5, FI6, FI7, FI8, GL1, GL3, GL8,
		Environmental or economic evaluation of chicken-pastured orchards	García de Jalón et al., 2018; Paolotti et al., 2016; Qingyan et al., 2012; Rocchi et al., 2019; Röhrig et al., 2020a, 2020b; Zhang et al., 2013	FV1, FV2a, FV2b, FI1, FI2, FI4, FI5, FI6, FI8, GL1, GL3, GL8, GL9
		Work organisation in chicken husbandry	Brannan and Anderson, 2021; Castellini et al., 2012; Hilimire, 2012; Xu et al., 2014	No data

		(besides chicken-pastured orchards)		
		Environmental or economic evaluation of chicken husbandry (besides chicken-pastured orchards)	Brannan and Anderson, 2021; Castellini et al., 2012; Hilimire, 2012; Liu et al., 2013; Martinelli et al., 2020; Xu et al., 2014; Yates et al., 2006; Zhang et al., 2020	No data
Trees	**⑰ Welfare and protection by trees for chickens**	Welfare (without specifying mechanisms)	Abouelezz et al., 2014; Larsen et al., 2017	FI1, FI5, FI6, FI7, FI8, V4, GL8, SA2
		Protection against meteorological conditions	Dal Bosco et al., 2014; Jones et al., 2007; Nagle and Glatz, 2012; Stadig et al., 2017; Zeltner and Hirt, 2008	
		Protection against predators	Bestman and Bikker-Ouwejan, 2020	
	⑱ Chickens appetence for fruits and leaves on trees and on the ground	No quantification (observations by farmers)	No data	FV1, FI1, FI2, FI3, V1, V4, GL10
	⑲ Damage to tree roots, trunk and branches	No quantification of damage	Jones et al., 2007; Larsen et al., 2017; Stadig et al., 2018; Yu et al., 2020	FV2a, FI2, FI4, GL8, GL10
Fallen tree parts	**⑳ Biological contamination of fallen fruits by chickens**	Evaluation of a potential risk	Theofel et al., 2020	GL10
	㉑ Mechanical effects on leaves by trampling	Degradation of leaves due to trampling effect	Item reported in the grey literature (Bestman, 2017; Timmermans and Bestman, 2016)	No data

Notes:

[a] *Interaction numbers and compartment names (column 2) correspond to Figure 2. ⓧ, ⓨ correspond to interesting interactions for fruit growers that cannot appear in Figure 2 because the mechanisms were not specified.*

[b] *Letters reflect the origin of the testimony: Farmers' interviews (FI), Farm visit (FV), Video (V), Grey Literature (GL), SA (Scientific Article). Each number indicates one farmer. Testimonies have been aggregated to correspond to the interaction level (column 2) and not to the precision level (column 3), except when it was relevant with respect to farmers' testimonies (③, ④, ⓨ, ⑨, ⑩, ⑪, ⑫, ⑬, ⑯).*

3.2.1. Divergence of quantifications between scientists

A first type of divergence corresponds to interactions for which scientific quantifications do not always match one another despite extensive studies (interactions ②, ⑦ in *Figure 2* and *Table 1*).

As an example, the spontaneous intake of herbaceous stratum by chickens (interaction ⑦) covers a wide range of values in the scientific literature identified: from 0.7 g of dry matter (DM) forage

/day/chicken (Jurjanz et al., 2015), to 72 g of DM forage/day/chicken (Horsted et al., 2007b). In reality, these differences mask the variability concerning experimental conditions, quantification methods and systems under study.

First, as regards experimental conditions, Horsted (2007b) obtained huge differences in forage intake depending on the nature of the complementary chicken feed and pasture. For example, wheat-fed chickens each ingested around 19.6 g DM forage on grass/clover pastures, but up to 49.5 g DM forage on chicory pastures. Genotype, broiler age, time of day, climatic conditions (summer/winter) and type of ranges (grass or tree-covered) were also identified as factors likely to make daily forage intake vary as much as ten times the minimal intake (Almeida et al., 2012; Jurjanz et al., 2015).

Second, values of forage intakes vary because quantification methods differ and do not consider the same bias (see *Table 1*-Interaction ⑦). Three collected studies (Dal Bosco et al., 2014; Mugnai et al., 2014; Rivera-Ferre et al., 2007) relied on the sward cutting method, which underestimates trampling by chickens (Jurjanz et al., 2015). Eight other studies (Abouelezz et al., 2013; Almeida et al., 2012; Amaka Lomu et al., 2004; Antell and Ciszuk, 2006; Horsted et al., 2007b; Lorenz et al., 2013; Ponte et al., 2008b) used dissection (crop and/or gizzards) combined with an equation from Antell and Ciszuk (2006) to calculate daily intake. One drawback of this method is that it is not repeatable on the same individual (Singh et al., 2016). More recently, studies focused on n-alkane analysis, which seems reliable to estimate forage intake but is harder to conduct (Jurjanz et al., 2015; Singh et al., 2016).

Third, comparison is also difficult between disparate experimental systems *(Table 2)* whose diversity reflects the heterogeneity of chicken rearing conditions in real systems.

Table 2: Diversity of experimental systems used in scientific articles about interaction ⑦.

System characteristics	Examples of modality	Examples in the literature
Outdoor stocking densities	110 chickens/ha	Amaka Lomu et al., 2004
	2,500 chickens/ha	Almeida et al., 2012; Dal Bosco et al., 2014; Lorenz et al., 2013; Rivera-Ferre et al., 2007
	≈ 40,000 chickens/ha	Ponte et al., 2008b
Access to range	Restricted in space with floorless portable metal outdoor pens	Ponte et al., 2008a
	Restricted in time	Singh et al., 2016
Type of range	Spontaneous pasture	Abouelezz et al., 2013; Lorenz

		et al., 2013; Singh et al., 2016
	Sown pastures	Horsted et al., 2007a; Rivera-Ferre et al., 2007
Shelters on range	No shelter	Almeida et al., 2012; Horsted et al., 2007b; Skřivan and Englmaierová, 2014
	Artificial shelter	Amaka Lomu et al., 2004
	Trees and bushes	Clark and Gage, 1996; Dal Bosco et al., 2014; Jurjanz et al., 2015; Mugnai et al., 2014

Except for one reference (Dal Bosco et al., 2014), all experiments were conducted on experimental farms at research centres, in a diversity of countries and climates (Denmark, Australia, Mexico, Sweden, Italy, Portugal, the Netherlands, France, Czech Republic).

As is the case with weed intake, quantifications of soil (interaction ②) vary between scientific studies.

3.2.2. Divergence of interest within and between scientists and farmers

The interactions presented in our model also differ by the level of interest they generate for scientists and farmers. More specifically, we identified two types of scientific knowledge gaps: the first concerning mechanisms and the second concerning systems in general.

Concerning mechanisms:

We first identified some knowledge gaps concerning basic mechanisms of interactions in this agroecosystem, which are mainly detrimental for scientific purposes (interactions ⑤ and ⑥ in *Figure 2* and *Table 1*). Although studies concerning the degradation of herbaceous ground cover by chickens do exist (ⓧ in *Table 1*), studies about precise mechanisms are rare and especially concern the quantification of the physical impact of chickens by pecking and scratching or soiling. Except for one study (Breitsameter et al., 2014), pecking and scratching the ground is principally studied through the prism of ethology in the other studies (see *Table 1*). However, data concerning time spent by chickens pecking and scratching are not sufficient to construct scientific mechanistic models of the impact of chickens on this agroecosystem. Evaluation of pecking and scratching in terms of weed biomass or its effect on the herbaceous stratum structure would, for example, be necessary. This lack of knowledge is not only deleterious for scientific purposes but also for the practitioners insofar as this knowledge is needed to help them design and/or manage innovative agricultural systems. Indeed, 20 farmers declared in their testimonies to be highly concerned by the effects of chickens on grass cover, and some of them reported the lack of information concerning the appropriate chicken stocking density or the appropriate dynamic management necessary to preserve the quality of the herbaceous stratum.

Similarly, we identified mechanisms observed by farmers in the field that have never or only rarely been studied by scientists. The mechanisms concerned by this lack are related to the impact of chickens on fauna (⑨, ⑩, ⑪, ⑫, ⑬ in *Figure 2* and *Table 1*). For example, the introduction of chickens into orchards is often seen by farmers as a way to control crop pests. Among the set of collected testimonies, 11 farmers reported regulation effects on apple sawfly populations *(Hoplocampa testudinea)* (GL2, GL9), apple blossom weevil *(Anthonomus pomorum)* (V3, FV2b, GL9), codling moth (*Cydia pomonella*) (FV2b, GL2, FI2), spotted wing drosophila *(Drosophila suzukii)* (FV1), olive fly *(Bactrocera oleae)* (GL1), peach fruit fly *(Bactroceraspp.zonata)* (FI1), and a diversity of other pests (V4, FI3, FI4). Two other farmers did not observe any effect on pests but mentioned that pest pressure in their orchards was originally not very high (FI5, FI8). Such observations have also been made in contexts other than French chicken-pastured orchards. A survey conducted among 18 Californian pastured-chicken producers revealed that 17% of them cited chickens as a way to control pests, and that for 6% of them, pest control was even their initial motivation to raise pastured poultry (Hilimire, 2012). In another survey concerning nine mixed farms in Italy, the three farmers who owned poultry-pastured orchards observed reduced tree pests/diseases compared to before the chickens were introduced (Röhrig et al., 2020a). The main mechanism of regulation mentioned on nine of our testimonies (FI1, FI3, FV1, FV2b, GL1, GL3, GL7, V2, V3) is ingestion of tree pests by chickens, directly or through the intake of damaged fruits.

Nevertheless, despite farmers' interest for this ecosystem service, scientific concern about it is low and the results are incomplete. We collected only one scientific article (Clark and Gage, 1996), one conference proceeding (Pedersen et al., 2004) and two grey literature articles (Hilaire et al., 2001; Lavigne and Lavigne, 2013) that studied the regulation of fruit tree pests by chickens. For all of them, the results were mitigated and the underlying mechanisms were unclear or not studied. For example, Pedersen et al. (2004) compared damage on apples and pears caused by several pests, with or without broilers under trees, but found significant effects of broilers only for capsid bug and pear midge. That may be one of the reasons for such apparent disinterest: unclear or unstable results are difficult to publish.

In addition to this direct impact, chickens also indirectly impact pest regulation by impacting the dynamics of the whole agroecosystem, including auxiliary fauna (earthworms, spiders and other insects). Even though we listed a certain number of articles dealing with the impacts on fauna (interactions ⑨, ⑩, ⑪, ⑫ in *Figure 2* and *Table 1*), very few authors carried out sufficient in-depth analyses to draw significant conclusions. For instance, among all the listed studies dealing with the impact on insects (beside pests) or ingestion of insects (besides pests), only two (Clark and Gage 1996; 1997) actually gave the names of the insect species impacted by chickens. All the other studies just used the term insects in general, neglecting the diversity of species and functions. Regardless, in all of those cases, scientific evidence would be valuable in order to (i) confirm the robustness of farmers' observations (FI1, FI2, FI3, GL1, GL7, V1, V2, V3), and (ii) identify levers to help farmers to manage the association.

Concerning systems:

Beyond knowledge gaps concerning specific mechanisms, chicken-pastured orchards are under-studied systems: only 17 articles among the whole list of articles concern chicken-pastured orchards. For some interactions (chicken/soil or chicken/herbaceous stratum), extrapolations can be made through the study of free-range chicken systems. However, for many of them, issues differ between free-range and chicken-pastured orchards. Hence, the questions of fertilisation effects ③, intoxication of chickens by chemicals ④, and the work organisation of farmers ⑯ have been studied but not often in the context of chicken-pastured orchards, despite the specific issues it raises (the benefit of this fertilisation for fruit trees, the impact of fruit tree treatments on chickens, and the management of a double activity by fruit growers, respectively).

These lacks can be illustrated through the example of work management (interaction ⑯), which represents a great challenge in chicken-pastured orchards. Indeed, several farmers' testimonies highlighted difficulties for farmers confronted with heavier workloads, more time spent on the farm due to animal presence, and conflicts in terms of space and time between the two activities (FI4, FI5, FI6, FI7, FI8, FV2b, GL3). More precisely, the long-term sustainability of farms depends on the compatibility and even complementarity of both activities. Despite this, we identified only five articles that include a social perspective and not just economic or environmental approaches to evaluate the sustainability of chicken-pastured orchards (Elkhoraibi et al., 2017; García de Jalón et al., 2018; Rocchi et al., 2019; Röhrig et al., 2020a, 2020b). Moreover, these studies focus on slightly different objects than those we identified in the testimonies. Elkhoraibi (2017) identified major challenges in poultry farming, but from US farmers who were initially chicken producers. As for Rocchi (2019), the social evaluation was limited to labour safety, animal welfare and farm integration in the landscape. However, Röhrig (2020a, 2020b) and García de Jalón et al. (2018) quickly examined trade-offs related to tree/chicken associations. Röhrig (2020a) raises the question of conflicts between both activities, the extreme complexity of management, and the need for additional external work (Röhrig et al., 2020b). García de Jalón (2018) also put forward these issues of management complexity and labour burden in the perception of agroforestry farmers. However, this approach does not specifically focus on chicken-pastured orchards and does not make it possible to draw conclusions about this specific system. Hence, there is a need for quantitative approaches to study trade-offs between both activities and the organisation of choices and adaptations made by farmers.

3.2.3. Strong divergence of observations between farmers that cannot be explained by scientific literature

The last type of divergence that we identified in the data collected concerns strong discrepancies between the farmers themselves, with farmers testifying to the existence of interactions and others negating it (interactions ①, ⑮, ⑱, ⑲ in *Figure 2* and *Table 1*). For instance, two farmers (FV2a, GL8) considered and observed that chickens potentially damage trees (trunks, roots or branches), whereas four others did not. Although the differences in farm situations (system, location, etc.) and observation bias could explain such discrepancies, no clear conclusion can be drawn.

Moreover, these interactions seem crucial for fruit growers: they are mentioned by a certain number of farmers (five testimonies for ①, four testimonies for ⑮, eight testimonies for ⑱, and eight testimonies for ⑲), and they concern major general challenges in orchards (integrity of trees and fruits, preservation of soil quality and management of rodents). For example, the issues of chickens eating fruits on trees and on the ground ⑱ or damaging the trees ⑲ can endanger the most fundamental activity of fruit growers and lead them to give up this association.

In all those interactions, referring to scientific literature does not make it possible to settle the question, either because scientific results are not conclusive ① or because literature is deeply lacking (⑮, ⑱, ⑲). Concerning damage to trees (interaction ⑲), four scientific articles mention the impact of chickens, but the trees correspond to coppice willows (Stadig et al., 2018), woodland (Jones et al., 2007), small trees on a natural meadow (Yu et al., 2020) and wooded areas in poultry ranges (Larsen et al., 2017) which deeply differ from orchard. Moreover, except for Jones (2007), the absence of damage is stated but not quantified or tested in a dedicated experiment. Precisely, in those cases, science would be necessary to help settle a debate between practitioners. There is thus a major challenge to study these interactions in order to find the eventual management levers necessary to propagate the practice of association.

4. Discussion

The results are discussed according to four perspectives. First, we present a simplified heuristic model that highlights key interactions. Second, we identify some methodological limitations of our approach. Third, we show the scientific and operational interests in building a model that compares scientific and farmers' knowledge and, last, we call for a systemic approach that reconnects animal and plant productions.

4.1. Key interactions in the heuristic model

To summarise the conclusions of the literature review based on the heuristic model, we propose here a simplified version of the model (*Figure 1*). This representation highlights the key interactions considered to be central in chicken-pastured orchards and for which information is lacking.

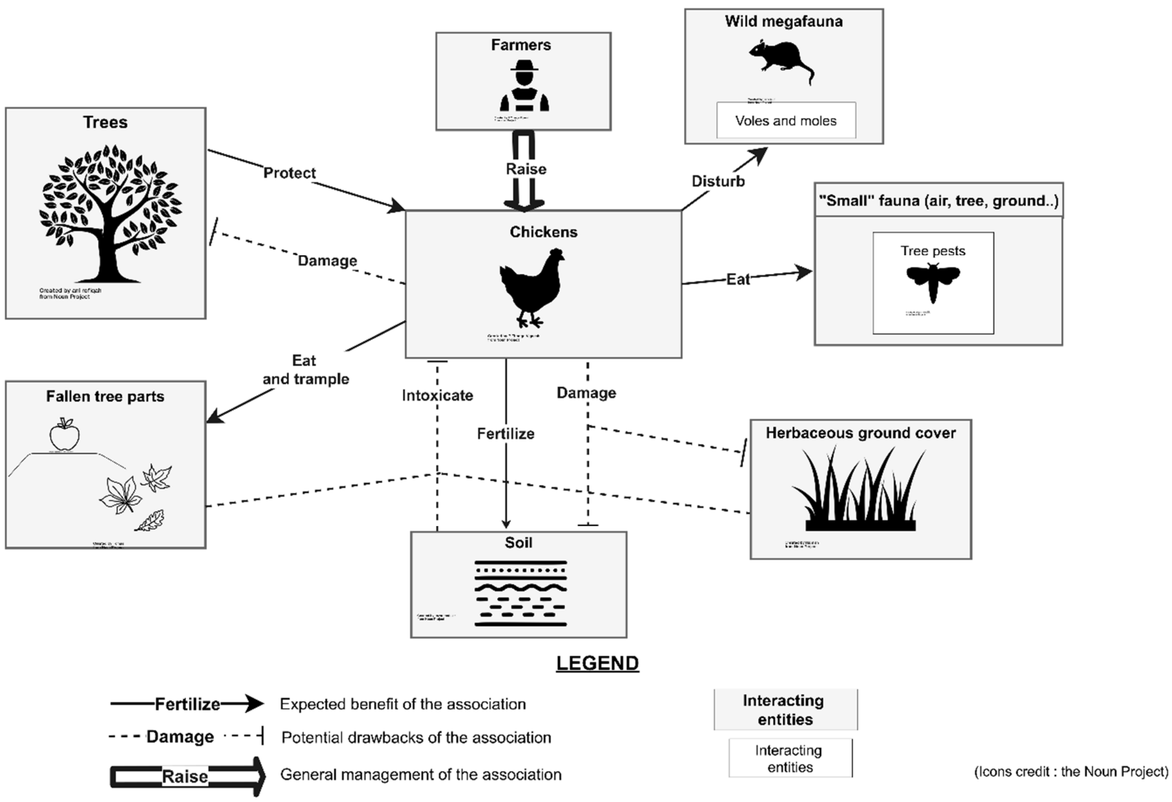


Figure 1: Simplified heuristic model based on Figure 1*, presenting key interactions on which research questions should focus.*

These interactions can be classified into three categories: interactions concerning (i) expected benefits of the chicken-tree association; (ii) potential drawbacks of the association; and (iii) general management of the association. We claim that these interactions should constitute priority research questions because their knowledge is essential to design efficient chicken-pastured orchards.

Expected benefits of the association have been reported by several farmers, but in order for these practices to be disseminated, proof should be reinforced to convince new audiences. Hence, the potential regulation and sanitation effects of chickens on the orchard (on tree pests, on moles and voles, and on fallen tree parts) need to be confirmed by scientific approaches and quantified. The other beneficial effects (protection of chickens by trees and soil fertilisation) have been partly studied but the specificities of chicken-orchard associations (for example, fertilisation with regard to fruit tree needs) should be more precisely considered. Drawbacks of the association should also be more deeply studied in order to tackle farmers' challenges and to improve already-existing chicken-pastured orchards. Hence, the general damage of chickens on orchards is known, but quantification concerning the intensity of damage is often lacking. Similarly, studying potential intoxications of chickens by orchard treatments is all the more essential when considering a dissemination of these systems towards more treatment-intensive orchards. Finally, farmers' management of the association and their ways to deal with complex trade-offs between those benefits and drawbacks need to be assessed and considered. More broadly speaking, this topic could contribute and bring new perspectives to the study of diversified agroecosystems and their specificities in terms of management complexity.

4.2. Methodological limitations of our approach

In this review, we chose to orient our approach more specifically to help the action of fruit growers introducing chickens into orchards. Hence, to study these complex systems that involve a diversity of components in interaction, we centred our heuristic model on the chicken compartment to highlight how their introduction could impact the existing tree system. Consequently, we only represented direct interactions with chickens and not interactions between other compartments, whereas, in reality, multiple interactions and retroactions do exist, for example, the structure and composition of the herbaceous stratum's impact on arthropod diversity (Demestihas et al., 2017a). Indeed, in contexts other than orchards, such as pastures, sheep and cattle grazing is known to indirectly impact this species diversity (Dennis et al., 2001). These indirect effects are multiple and should be kept in mind when designing a chicken-pastured orchard.

The previous global analysis highlighted several gaps in the scientific literature concerning chicken-pastured orchards. We counted only 17 articles out of 195 collected dealing with those systems. Hence, to obtain a sufficient number of scientific articles, we chose to broaden our search to free-range chicken husbandry. These extrapolations mainly concerned interactions between chickens and the herbaceous stratum, the soil or insects. Retrospectively, these extrapolations were interesting to obtain some range of values concerning crucial mechanisms for fruit growers, such as the ingestion of forage by chickens and the fertilisation potential of droppings. However, free-range systems deeply differ from pastured orchards. For example, the density of chickens is often much higher in free-range systems than in pastured orchards. Direct translations of the knowledge developed on free-range systems to pastured orchards are thus not always possible. Moreover, even on free-range systems, the literature collected was so disparate that even general findings about interactions were difficult to obtain and, as a consequence, interactions could only be quantified for six interactions out of 21.

We also chose not to include grey literature in the literature panorama because of its heterogeneity and of the difficulty to perform an exhaustive search using keywords. Nevertheless, recent graduate theses and conference proceedings are useful since they give a precise idea of current research themes. Even though it is not included in the review, grey literature (see Appendix A) highlights the fact that research questions on this subject evolve very quickly, which demonstrates a growing interest of the scientific community in chicken-pastured orchards.

4.3. A model that compares scientific and farmers' knowledge to reveal knowledge gaps

To study complex agroecological systems, it is often necessary to combine a plurality of knowledge and, notably, to integrate farmers' points of view (Hazard et al., 2018). Hence, scientific and farmers' knowledge can interact in different ways. In our approach, farmers' knowledge was useful to complete the list of interactions and to draw a global image of the system. Reciprocally, scientific approaches made it possible to reveal and specify underlying mechanisms when farmers only observe general impacts. In other studies, some authors noted that farmers expect scientific knowledge to answer their questions or to legitimise the practical choices they made (Hazard et al., 2018). In our case, such an expectation could not be fulfilled by this incomplete scientific literature, which is, in addition, deeply disconnected from farmers' needs. However, comparing scientific state-of-the-art to field situations allowed us to identify crucial knowledge gaps and to determine the reasons for such a situation.

Different reasons could indeed explain these huge knowledge gaps. First, chicken-pastured orchards and, more generally, grazed or pastured orchards, are minority agricultural practices: according to den Herder et al. (2017), around 5% of permanent crops in the European Union were being grazed in 2012. Second, even though grazing animals under trees is not new (Coulon et al., 2000), the reintroduction of animals into modern orchards, particularly poultry, requires to break the frontier that still persists in modernised agriculture between animal and plant production. This disconnection on farms also exists in the scientific research that is compartmentalised and reductionist. Indeed, because of their hybrid form, pastured orchards do not fit the classical conceptual frameworks of two disconnected disciplines, agronomy and animal science: for agronomy, because of the introduction of the husbandry component into the system, and for animal science, because animal products are not the principal target in these systems. This statement might explain why we observed a greater focus on classical husbandry interactions (e.g., complementary feed intake, meat and egg contamination by dioxins) by the animal sciences, which neglect to study other interactions in terms of ecosystem services provided by chickens.

4.4. Perspectives for systemic approaches

However, agroecology calls for the reconnexion between animals and crops (Altieri, 2002) to close nutrient cycles or to foster biological regulation. On the basis of these statements, we suggest that a new analytical framework needs to be considered to study interactions between animal and plant productions. This need is also reinforced by the societal and environmental issues that arise, for example, because of the disconnection between animal and plant productions, such as the deterioration of water quality (Garnier et al., 2016) and the impact on biodiversity and climate in relation to animal feed production and export (Naylor, 2005). Hence, complex and multiscale integrated systems force scientific questions and approaches to evolve towards more interdisciplinary, systemic and action-oriented approaches. Research on crop-livestock systems is an example of a research domain that successfully adopted more systemic and interdisciplinary approaches to tackle those challenges (Martin et al., 2016). To our knowledge, our study is, in a similar way, the first attempt to give a broad and systemic view on chicken-pastured orchards. Through our heuristic model, we invite agronomists, ecologists, zootechnicians and others to tackle together these knowledge gaps with new common research methodologies. Moreover, we expect that the simple global representation we built could serve as a grid to read other articles dealing with ecosystem services and interactions in traditional orchards using another point of view. Indeed, it would be interesting to cross this model with extensive studies on biodiversity dynamics in orchards to make hypotheses on the indirect impacts of chicken introduction into orchards, in order to pave the way for other research questions, for example, whether chickens impact the auxiliary fauna and if so, to what extent and with what consequences on fruit production.

In order to produce action-oriented knowledge, research questions also need to evolve through comparison with the field. Just as we did, other studies on agroecological practices pointed out some discrepancies between scientific knowledge and crucial needs for farmers, notably concerning practical management issues and ecosystem services (Brodt et al., 2020; Ditzler et al., 2021). Yet, from an operational point of view, including farmers' points of view, it is necessary to design and manage innovative agroecological systems adapted to farmers' constraints (Demestihas et al., 2017b; Fagerholm et al., 2016). Concretely, our model, which already includes empirical knowledge, could serve as a discussion tool that farmers could compare to their own local situations. This model could also be mobilised as an intermediary object for serious games in workshops with practitioners to make them work on the design of diversified systems that associate poultry and fruit trees (Duru et al., 2015).

5. Conclusion

Based on a literature review, we proposed a systemic heuristic model to represent the functioning of chicken-pastured orchards, and we compared the scientific state-of-the-art to farmers' needs. Chicken-pastured orchards are complex agroecosystems that have rarely been studied from a global perspective, and our study highlights several divergences of points of view within and between scientists and fruit growers. This review revealed important knowledge gaps, pointing out that research on these questions is not only compartmentalised, but also disconnected from farmers' needs. Interdisciplinary and systemic approaches are thus needed to promote the development of these innovative agroecological systems, which have also grown in popularity among consumers. A deep reorientation of scientific questions as well as political policies concerning integrated animal/plant systems is all the more urgent since animal husbandry and fruit production are both facing huge socio-environmental challenges that will require a rapid acceleration of the agroecological transition at a more global scale.

6. Appendix

Supplementary references of grey literature (A) and testimonies (B) on chicken-pastured orchards, and icon credits (C).

7. Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

8. Acknowledgements

This work was supported by a doctoral fellowship from the École Normale Supérieure de Paris attributed to S.B., by the Fondation de France and by INRAE (ACT Department). The authors also thank the stakeholders that gave their own testimonies or helped to identify grey literature.

9. References

Abouelezz, F., Sarmiento-Franco, L., Santos-ricalde, R., Segura-Correa, J.C., Armando, S.L., Santos-ricalde, R., Segura-Correa, J.C., 2014. Use of the outdoor range and activities of Rhode Island Red hens grazing on natural vegetation in the tropics. J. Agric. Sci. Technol. 16, 1555–1563.

Abouelezz, F.M.K., Sarmiento-Franco, L., Santos-Ricalde, R., Solorio-Sanchez, J.F., 2013. Egg production, egg quality and crop content of Rhode Island Red hens grazing on natural tropical vegetation. Trop. Anim. Health Prod. 45, 367–372. https://doi.org/10.1007/s11250-012-0225-y

ADABio, n.d. Guide Introduction de poules dans les vergers : une pratique qui porte ses fruits.

Agreste, 2021. AgresteConjoncture : Pêche, Agreste Infos rapides.

Alaphilippe, A., Bussi, C., Casagrande, M., Dardouri, T., Simon, S., Lauri, P.E., Lefèvre, A., Navarrete, M., 2021. The use of agronomic practices in IPM programmes in horticulture, in: Collier, P.R. (Ed.), In Improving Integrated Pest Management (IPM) in Horticulture. Warwick University, UK.

Almeida, G.F. d., Hinrichsen, L.K., Horsted, K., Thamsborg, S.M., Hermansen, J.E., 2012. Feed intake and activity level of two broiler genotypes foraging different types of vegetation in the finishing period. Poult. Sci. 91, 2105–2113. https://doi.org/10.3382/ps.2012-02187

Altieri, M.A., 2002. Agroecology: The science of natural resource management for poor farmers in marginal environments. Agric. Ecosyst. Environ. 93, 1–24. https://doi.org/10.1016/S0167-8809(02)00085-3

Amaka Lomu, M., Glatz, P.C., Ru, Y.J., 2004. Metabolizable energy of crop contents in free-range hens. Int. J. Poult. Sci. 3, 728–732. https://doi.org/10.3923/ijps.2004.728.732

Antell, S., Ciszuk, P., 2006. Forage consumption of laying hens - The crop content as an indicator of feed intake and AME content of ingested forage. Arch. fur Geflugelkd. 70, 154–160.

Bestman, M., 2017. Lessons learnt - Agroforestry for free-range egg production in the Netherlands.

Bestman, M., Bikker-Ouwejan, J., 2020. Predation in organic and free-range egg production. Animals 10. https://doi.org/10.3390/ani10020177

Billen, G., Aguilera, E., Einarsson, R., Garnier, J., Gingrich, S., Grizzetti, B., Lassaletta, L., Le Noë, J., Sanz-Cobena, A., 2021. Reshaping the European agro-food system and closing its nitrogen cycle: The potential of combining dietary change, agroecology, and circularity. One Earth 4, 839–850. https://doi.org/10.1016/j.oneear.2021.05.008

Bouwman, H., Bornman, R., van Dyk, C., Barnhoorn, I., 2015. First report of the concentrations and implications of DDT residues in chicken eggs from a malaria-controlled area. Chemosphere 137, 174–177. https://doi.org/10.1016/j.chemosphere.2015.06.097

Brannan, K.E., Anderson, K.E., 2021. Examination of the impact of range, cage-free, modified systems, and conventional cage environments on the labor inputs committed to bird care for three brown egg layer strains. J. Appl. Poult. Res. 30, 100118. https://doi.org/10.1016/j.japr.2020.100118

Breitsameter, L., Gauly, M., Isselstein, J., 2014. Sward botanical composition and sward quality affect the foraging behaviour of free-range laying hens. Appl. Anim. Behav. Sci. 150, 27–36. https://doi.org/10.1016/j.applanim.2013.10.009

Brodt, S.B., Fontana, N.M., Archer, L.F., 2020. Feasibility and sustainability of agroforestry in temperate industrialized agriculture: preliminary insights from California. Renew. Agric. Food Syst. 35, 513–521. https://doi.org/10.1017/S1742170519000140

Bryden, W.L., Li, X., Ruhnke, I., Zhang, D., Shini, S., 2021. Nutrition, feeding and laying hen welfare. Anim. Prod. Sci. 61, 893. https://doi.org/10.1071/AN20396

Castellini, C., Boggia, A., Cortina, C., Dal Bosco, A., Paolotti, L., Novelli, E., Mugnai, C., 2012. A multicriteria approach for measuring the sustainability of different poultry production systems. J. Clean. Prod. 37, 192–201. https://doi.org/10.1016/j.jclepro.2012.07.006

Cazaux, L., 2015. Determining Factors and Trajectories Analysis to Support System Diversification : Mixed Orchard Animals and Mixed Orchard Vegetables Systems.

Chielo, L.I., Pike, T., Cooper, J., 2016. Ranging behaviour of commercial free-range laying hens. Animals 6. https://doi.org/10.3390/ani6050028

Clark, M.S., Gage, S.H., 1997. The effects of free-range domestic birds on the abundance of epigeic predators and earthworms. Appl. Soil Ecol. 5, 255–260. https://doi.org/10.1016/S0929-1393(96)00130-8

Clark, M.S., Gage, S.H., 1996. Effects of free-range chickens and geese on insect pests and weeds in an agroecosystem. Am. J. Altern. Agric. 11, 39–47. https://doi.org/10.1017/S0889189300006718

Clark, M.S., Gage, S.H., DeLind, L.B., Lennington, M., 1995. The compatibility of domestic birds with a nonchemical agroecosystem. Am. J. Altern. Agric. 10, 114–121. https://doi.org/10.1017/S0889189300006275

Coisne, M., 2020. Des volailles pour protéger les vergers. Biofil 62–64.

Corroyer, N., 2017. Apple orchards grazed in France.

Cosentino, C., 2020. First results on the evaluation of the ground-cover biodiversity in an agroforestry poultry system. Acta Fytotech. Zootech. 23, 15–22. https://doi.org/10.15414/afz.2020.23.mi-fpap.15-22

Cosentino, C., Freschi, P., Fascetti, S., Paolino, R., Musto, M., 2020. Growth control of herbaceous ground cover and egg quality from an integrated poultry-hazelnut orchard system. Ital. J. Agron. 15, 214–221. https://doi.org/10.4081/ija.2020.1594

Coulon, F., Dupraz, C., Liagre, F., Pointereau, P., 2000. Étude des pratiques agroforestières associant des arbres fruitiers de haute tige à des cultures ou des pâtures.

Covaci, A., Roosens, L., Dirtu, A.C., Waegeneers, N., Van Overmeire, I., Neels, H., Goeyens, L., 2009. Brominated flame retardants in Belgian home-produced eggs: Levels and contamination sources. Sci. Total Environ. 407, 4387–4396. https://doi.org/10.1016/j.scitotenv.2008.09.057

Dal Bosco, A., Mugnai, C., Rosati, A., Paoletti, A., Caporali, S., Castellini, C., 2014. Effect of range enrichment on performance, behavior, and forage intake of free-range chickens. J. Appl. Poult. Res. 23, 137–145. https://doi.org/10.3382/japr.2013-00814

Dal Bosco, A., Mugnai, C., Sirri, F., Zamparini, C., Castellini, C., 2010. Assessment of a global positioning system to evaluate activities of organic chickens at pasture. J. Appl. Poult. Res. 19, 213–218. https://doi.org/10.3382/japr.2010-00153

Dekker, S.E.M.M., Aarnink, A.J.A.A., De Boer, I.J.M.M., Koerkamp, P.W.G.G., 2012. Total loss and distribution of nitrogen and phosphorus in the outdoor run of organic laying hens. Br. Poult. Sci. 53, 731–740. https://doi.org/10.1080/00071668.2012.749342

Demestihas, C., Plénet, D., Génard, M., Raynal, C., Lescourret, F., 2017a. Ecosystem services in orchards. A review. Agron. Sustain. Dev. 37. https://doi.org/10.1007/s13593-017-0422-1

Demestihas, C., Plénet, D., Génard, M., Raynal, C., Lescourret, F., 2017b. Ecosystem services in orchards. A review. Agron. Sustain. Dev. 37. https://doi.org/10.1007/s13593-017-0422-1

den Herder, M., Moreno, G., Mosquera-Losada, R.M., Palma, J.H.N., Sidiropoulou, A., Santiago Freijanes, J.J., Crous-Duran, J., Paulo, J.A., Tomé, M., Pantera, A., Papanastasis, V.P., Mantzanas, K., Pachana, P., Papadopoulos, A., Plieninger, T., Burgess, P.J., 2017. Current extent and stratification of agroforestry in the European Union. Agric. Ecosyst. Environ. 241, 121–132. https://doi.org/10.1016/j.agee.2017.03.005

Dennis, P., Young, M.R., Bentley, C., 2001. The effects of varied grazing management on epigeal spiders, harvestmen and pseudoscorpions of Nardus stricta grassland in upland Scotland. Agric.

Ecosyst. Environ. 86, 39–57. https://doi.org/10.1016/S0167-8809(00)00263-2

Ditzler, L., van Apeldoorn, D.F., Pellegrini, F., Antichi, D., Bàrberi, P., Rossing, W.A.H., 2021. Current research on the ecosystem service potential of legume inclusive cropping systems in Europe. A review. Agron. Sustain. Dev. 41. https://doi.org/10.1007/s13593-021-00678-z

Duru, M., Therond, O., Martin, G., Martin-Clouaire, R., Magne, M.A., Justes, E., Journet, E.P., Aubertot, J.N., Savary, S., Bergez, J.E., Sarthou, J.P., 2015. How to implement biodiversity-based agriculture to enhance ecosystem services: a review. Agron. Sustain. Dev. 35, 1259–1281. https://doi.org/10.1007/s13593-015-0306-1

Elkhoraibi, C., Pitesky, M., Dailey, N., Niemeier, D., 2017. Operational challenges and opportunities in pastured poultry operations in the United States. Poult. Sci. 96, 1648–1650. https://doi.org/10.3382/ps/pew448

Fagerholm, N., Torralba, M., Burgess, P.J., Plieninger, T., 2016. A systematic map of ecosystem services assessments around European agroforestry. Ecol. Indic. 62, 47–65. https://doi.org/10.1016/j.ecolind.2015.11.016

Fanatico, A.C., Brewer, V.B., Owens-Hanning, C.M., Donoghue, D.J., Donoghue, A.M., 2013. Free-choice feeding of free-range meat chickens. J. Appl. Poult. Res. 22, 750–758. https://doi.org/10.3382/japr.2012-00687

France Relance, 2021. L'assistance de l'État face aux gels destructeurs dans l'agriculture [WWW Document]. URL https://www.gouvernement.fr/l-assistance-de-l-etat-face-aux-gels-destructeurs-dans-l-agriculture (accessed 6.15.21).

Gai, X., Zhong, Z., Zhang, X., Bian, F., Yang, C., 2021. Effects of chicken farming on soil organic carbon fractions and fungal communities in a Lei bamboo (Phyllostachys praecox) forest in subtropical China. For. Ecol. Manage. 479, 118603. https://doi.org/10.1016/j.foreco.2020.118603

García de Jalón, S., Burgess, P.J., Graves, A., Moreno, G., McAdam, J., Pottier, E., Novak, S., Bondesan, V., Mosquera-Losada, R., Crous-Durán, J., Palma, J.H.N., Paulo, J.A., Oliveira, T.S., Cirou, E., Hannachi, Y., Pantera, A., Wartelle, R., Kay, S., Malignier, N., Van Lerberghe, P., Tsonkova, P., Mirck, J., Rois, M., Kongsted, A.G., Thenail, C., Luske, B., Berg, S., Gosme, M., Vityi, A., 2018. How is agroforestry perceived in Europe? An assessment of positive and negative aspects by stakeholders. Agrofor. Syst. 92, 829–848. https://doi.org/10.1007/s10457-017-0116-3

Garnier, J., Anglade, J., Benoit, M., Billen, G., Puech, T., Ramarson, A., Passy, P., Silvestre, M., Lassaletta, L., Trommenschlager, J.M., Schott, C., Tallec, G., 2016. Reconnecting crop and cattle farming to reduce nitrogen losses to river water of an intensive agricultural catchment (Seine basin, France): Past, present and future. Environ. Sci. Policy 63, 76–90. https://doi.org/10.1016/j.envsci.2016.04.019

Glatz, P.C., Ru., Y.J., Miao., Z.H., Wyatt., S.K., Rodda., B.J., 2005a. Integrating Free-Range Hens into a Regenerated Medic Pasture. Int. J. Poult. Sci. 4, 670–675. https://doi.org/10.3923/ijps.2005.670.675

Glatz, P.C., Ru, Y.J., Miao, Z.H., Wyatt, S.K., Rodda, B.J., 2005b. Integrating poultry into a crop and pasture farming system. Int. J. Poult. Sci. 4, 187–191. https://doi.org/10.3923/ijps.2005.187.191

Gomez-Zavaglia, A., Mejuto, J.C., Simal-Gandara, J., 2020. Mitigation of emerging implications of climate change on food production systems. Food Res. Int. 134, 109256. https://doi.org/10.1016/j.foodres.2020.109256

Hammershøj, M., Steenfeldt, S., 2012. The effects of kale (Brassica oleracea ssp. acephala), basil (Ocimum basilicum) and thyme (Thymus vulgaris) as forage material in organic egg production on egg quality. Br. Poult. Sci. 53, 245–256. https://doi.org/10.1080/00071668.2012.681770

Hazard, L., Steyaert, P., Martin, G., Couix, N., Navas, M.L., Duru, M., Lauvie, A., Labatut, J., 2018. Mutual learning between researchers and farmers during implementation of scientific principles for sustainable development: The case of biodiversity-based agriculture. Sustain. Sci. 13, 517–530. https://doi.org/10.1007/s11625-017-0440-6

Hermansen, J.E., Strudsholm, K., Horsted, K., 2004. Integration of organic animal production into land use with special reference to swine and poultry. Livest. Prod. Sci. 90, 11–26. https://doi.org/10.1016/j.livprodsci.2004.07.009

Hilaire, C., Mathieu, V., Joly, T., Mirabito, L., 2001. Le poulet label, un auxiliaire sélectif. Infos-Ctifl 170, 38–40.

Hilimire, K., 2012. The grass is greener: Farmers' experiences with pastured poultry. Renew. Agric. Food Syst. 27, 173–179. https://doi.org/10.1017/S1742170511000287

Hilimire, K., Gliessman, S.R., Muramoto, J., 2013. Soil fertility and crop growth under poultry/crop integration. Renew. Agric. Food Syst. 28, 173–182. https://doi.org/10.1017/S174217051200021X

Horsted, K., Hammershøj, M., Hermansen, J., 2006. Short-term effects on productivity and egg quality in nutrient-restricted versus non-restricted organic layers with access to different forage crops. Acta Agric. Scand. Sect. A - Anim. Sci. 56, 42–54.

https://doi.org/10.1080/09064700600866072

Horsted, K., Hermansen, J.E., 2007. Whole wheat versus mixed layer diet as supplementary feed to layers foraging a sequence of different forage crops. Animal 1, 575–585. https://doi.org/10.1017/S175173110769418X

Horsted, K., Hermansen, J.E., Hansen, H., 2007a. Botanical composition of herbage intake of free-range laying hens determined by microhistological analysis of faeces. Arch. fur Geflugelkd. 71, 145–151.

Horsted, K., Hermansen, J.E., Ranvig, H., 2007b. Crop content in nutrient-restricted versus non-restricted organic laying hens with access to different forage vegetations. Br. Poult. Sci. 48, 177–184. https://doi.org/10.1080/00071660701227501

Hostalnou, E., 2021. Synthèse de la récolte européenne 2020 Prévisions de la récolte 2021 : Abricot.

Hsu, J.F., Chen, C., Liao, P.C., 2010. Elevated PCDD/F levels and distinctive PCDD/F congener profiles in free range eggs. J. Agric. Food Chem. 58, 7708–7714. https://doi.org/10.1021/jf100456b

Ipek, A., Sozcu, A., 2017. The effects of access to pasture on growth performance, behavioural patterns, some blood parameters and carcass yield of a slow-growing broiler genotype. J. Appl. Anim. Res. 45, 464–469. https://doi.org/10.1080/09712119.2016.1214136

Jones, T., Feber, R., Hemery, G., Cook, P., James, K., Lamberth, C., Dawkins, M., 2007. Welfare and environmental benefits of integrating commercially viable free-range broiler chickens into newly planted woodland: A UK case study. Agric. Syst. 94, 177–188. https://doi.org/10.1016/j.agsy.2006.08.007

Jurjanz, S., Germain, K., Juin, H., Jondreville, C., 2015. Plant and soil intake by organic broilers reared in tree- or grass-covered plots as determined by means of n-alkanes and of acid-insoluble ash. Animal 9, 888–898. https://doi.org/10.1017/S1751731114002870

Kruschwitz, A., Zupan, M., Buchwalder, T., Huber-Eicher, B., 2008. Prelaying behaviour of laying hens (Gallus gallus domesticus) in different free range settings. Arch. fur Geflugelkd. 72, 84–89.

Kudryavtseva, A.D., Shelepchikov, A.A., Brodsky, E.S., 2020. Free-range chicken eggs as a bioindicator of dioxin contamination in Vietnam, including long-term Agent Orange impact. Emerg. Contam. 6, 114–123. https://doi.org/10.1016/j.emcon.2020.02.003

Larsen, H., Cronin, G., Smith, C.L., Hemsworth, P., Rault, J.L., 2017. Behaviour of free-range laying hens in distinct outdoor environments. Anim. Welf. 26, 255–264.

https://doi.org/10.7120/09627286.26.3.255

Lavigne, A., Lavigne, C., 2013. Associer production fruitière et élevage de volaille : Une méthode innovante pour contrôler l’enherbement. Maurice, José.

Le Page, C., Abrami, G., Barreteau, O., Becu, N., Bommel, P., Botta, A., Dray, A., Monteil, C., Souchère, V., 2014. Models for Sharing Representations, in: Étienne, M. (Ed.), Companion Modelling: A Participatory Approach to Support Sustainable Development. Springer Netherlands, Dordrecht, pp. 69–101. https://doi.org/10.1007/978-94-017-8557-0_4

Leolini, L., Moriondo, M., Fila, G., Costafreda-Aumedes, S., Ferrise, R., Bindi, M., 2018. Late spring frost impacts on future grapevine distribution in Europe. F. Crop. Res. 222, 197–208. https://doi.org/10.1016/j.fcr.2017.11.018

Lin, C., Hsu, J.-F., Liao, P.-C., 2012. Coexposure of Dioxin-like Polychlorinated Biphenyls and Polychlorinated Dibenzo- p -dioxins and Dibenzofurans in Free-Range Hens and Implications Derived from Congener Profile Analysis. J. Agric. Food Chem. 60, 1963–1972. https://doi.org/10.1021/jf204468s

Liu, M., Wang, B., Osborne, C.P., Jiang, G., 2013. Chicken Farming in Grassland Increases Environmental Sustainability and Economic Efficiency. PLoS One 8, 1–7. https://doi.org/10.1371/journal.pone.0053977

Lolli, S., Grilli, G., Ferrari, L., Ferrari, P., Ferrante, V., 2019. Effect of range use on endo- and ectoparasite infestation in italian organic egg production. Ital. J. Anim. Sci. 18, 690–695. https://doi.org/10.1080/1828051X.2018.1564377

López-Sánchez, A., Perea, R., Roig, S., Isselstein, J., Schmitz, A., 2020. Challenges on the conservation of traditional orchards: Tree damage as an indicator of sustainable grazing. J. Environ. Manage. 257. https://doi.org/10.1016/j.jenvman.2019.110010

Lorenz, C., Kany, T., Grashorn, M.A., 2013. Method to estimate feed intake from pasture in broilers and laying hens. Arch. fur Geflugelkd. 77, 160–165.

Martin, G., Moraine, M., Ryschawy, J., Magne, M., 2016. Crop–livestock integration beyond the farm level: a review. Agron. Sustain. Dev. https://doi.org/10.1007/s13593-016-0390-x

Martinelli, G., Vogel, E., Decian, M., Farinha, M.J.U.S., Bernardo, L.V.M., Borges, J.A.R., Gimenes, R.M.T., Garcia, R.G., Ruviaro, C.F., 2020. Assessing the eco-efficiency of different poultry production systems: an approach using life cycle assessment and economic value added. Sustain. Prod. Consum. 24, 181–193. https://doi.org/10.1016/j.spc.2020.07.007

Massaccesi, L., Cartoni Mancinelli, A., Mattioli, S., De Feudis, M., Castellini, C., Dal Bosco, A., Marongiu, M.L., Agnelli, A., 2019. Geese Reared in Vineyard: Soil, Grass and Animals Interaction. Animals 9, 179. https://doi.org/10.3390/ani9040179

Maurer, V., Hertzberg, H., Heckendorn, F., Hördegen, P., Koller, M., 2013. Effects of paddock management on vegetation, nutrient accumulation, and internal parasites in laying hens. J. Appl. Poult. Res. 22, 334–343. https://doi.org/10.3382/japr.2012-00586

Mayton, E.L., Smith, E. V., King, D., In, G., Control, T.H.E., L, C.R., 1945. Nutgrass Eradication Studies IV. Use of Chickens and Geese in the Control of Nutgrass, Cyperus Rotundus. Jounal Am. Soc. Agron. 37, 785–791. https://doi.org/10.2134/agronj1945.00021962003700100001x

Meng, L., Mao, P., Guo, Q., Tian, X., 2016. Evaluation of Meat and Egg Traits of Beijing-you Chickens Rotationally Grazing on Chicory Pasture in a Chestnut Forest. Rev. Bras. Ciência Avícola 18, 1–6. https://doi.org/10.1590/1806-9061-2015-0081

Miao, Z.H., Glatz, P.C., Ru, Y.J., Wyatt, S.K., Rodda, B.J., 2005. Integrating free-range hens into a wheat stubble. Int. J. Poult. Sci. 4, 526–530. https://doi.org/10.3923/ijps.2005.526.530

Mugnai, C., Sossidou, E.N., Dal Bosco, A., Ruggeri, S., Mattioli, S., Castellini, C., Bosco, D., Ruggeri, S., Castellini, C., 2014. The effects of husbandry system on the grass intake and egg nutritive characteristics of laying hens. J. Sci. Food Agric. 94, 459–467. https://doi.org/10.1002/jsfa.6269

Nagle, T.A.D.D., Glatz, P.C., 2012. Free range hens use the range more when the outdoor environment is enriched. Asian-Australasian J. Anim. Sci. 25, 584–591. https://doi.org/10.5713/ajas.2011.11051

Nair, P.K.R., 1993. An introduction to agroforestry. Kluwer Academic Publishers.

Naylor, R., 2005. AGRICULTURE: Losing the Links Between Livestock and Land. Science (80-.). 310, 1621–1622. https://doi.org/10.1126/science.1117856

Orefice, J., Carroll, J., Conroy, D., Ketner, L., 2017. Silvopasture practices and perspectives in the Northeastern United States. Agrofor. Syst. 91, 149–160. https://doi.org/10.1007/s10457-016-9916-0

Pantera, A., Burgess, P.J., Mosquera Losada, R., Moreno, G., López-Díaz, M.L., Corroyer, N., McAdam, J., Rosati, A., Papadopoulos, A.M., Graves, A., Rigueiro Rodríguez, A., Ferreiro-Domínguez, N., Fernández Lorenzo, J.L., González-Hernández, M.P., Papanastasis, V.P., Mantzanas, K., Van Lerberghe, P., Malignier, N., 2018. Agroforestry for high value tree systems in Europe. Agrofor. Syst. 92, 945–959. https://doi.org/10.1007/s10457-017-0181-7

Paolotti, L., Boggia, A., Castellini, C., Rocchi, L., Rosati, A., 2016. Combining livestock and tree crops to improve sustainability in agriculture: A case study using the Life Cycle Assessment (LCA) approach. J. Clean. Prod. 131, 351–363. https://doi.org/10.1016/j.jclepro.2016.05.024

Pedersen, H.L., Olsen, A., Horsted, K., Korsgaard, M., Pedersen, B., 2004. Combined production of broilers and fruits, in: Ecofruit - 11th International Conference on Cultivation Technique and Phytopathological Problems in Organic Fruit-Growing.

Phillips, H.N., Heins, B.J., 2021. Effects of Outdoor Stocking Density on Growth, Feather Damage and Behavior of Slow-Growing Free-Range Broilers. Animals 11, 688. https://doi.org/10.3390/ani11030688

Phillips, H.N., Moon, R.D., Sorge, U.S., Heins, B.J., 2020. Efficacy of Broilers as a Method of Face Fly (Musca autumnalis De Geer) Larva Control for Organic Dairy Production. Animals 10, 2429. https://doi.org/10.3390/ani10122429

Piskorska-Pliszczynska, J., Mikolajczyk, S., Warenik-Bany, M., Maszewski, S., Strucinski, P., 2014. Soil as a source of dioxin contamination in eggs from free-range hens on a Polish farm. Sci. Total Environ. 466–467, 447–454. https://doi.org/10.1016/j.scitotenv.2013.07.061

Polder, A., Müller, M.B., Brynildsrud, O.B., de Boer, J., Hamers, T., Kamstra, J.H., Lie, E., Mdegela, R.H., Moberg, H., Nonga, H.E., Sandvik, M., Skaare, J.U., Lyche, J.L., 2016. Dioxins, PCBs, chlorinated pesticides and brominated flame retardants in free-range chicken eggs from peri-urban areas in Arusha, Tanzania: Levels and implications for human health. Sci. Total Environ. 551–552, 656–667. https://doi.org/10.1016/j.scitotenv.2016.02.021

Ponte, P.I.P., Prates, J.A.M., Crespo, J.P., Crespo, D.G., Mourão, J.L., Alves, S.P., Bessa, R.J.B., Chaveiro-Soares, M.A., Gama, L.T., Ferreira, L.M.A., Fontes, C.M.G.A., 2008a. Restricting the Intake of a Cereal-Based Feed in Free-Range-Pastured Poultry: Effects on Performance and Meat Quality. Poult. Sci. 87, 2032–2042. https://doi.org/10.3382/ps.2007-00522

Ponte, P.I.P., Rosado, C.M.C., Crespo, J.P., Crespo, D.G., Mourão, J.L., Chaveiro-Soares, M.A., Brás, J.L.A., Mendes, I., Gama, L.T., Prates, J.A.M., Ferreira, L.M.A., Fontes, C.M.G.A., 2008b. Pasture Intake Improves the Performance and Meat Sensory Attributes of Free-Range Broilers. Poult. Sci. 87, 71–79. https://doi.org/10.3382/ps.2007-00147

Qingyan, M., Zewei, M., Zhaoqian, W., 2012. Developing Mechanism of Rubber-tea-chicken Agro-forestry Model in Tropical Area of China. Chinese J. Popul. Resour. Environ. 10, 100–106. https://doi.org/10.1080/10042857.2012.10685089

Rivera-Ferre, M.G., Lantinga, E.A., Kwakkel, R.P., 2007. Herbage intake and use of outdoor area by organic broilers: effects of vegetation type and shelter addition. NJAS - Wageningen J. Life Sci. 54, 279–291. https://doi.org/10.1016/S1573-5214(07)80020-0

Rocchi, L., Paolotti, L., Rosati, A., Boggia, A., Castellini, C., 2019. Assessing the sustainability of different poultry production systems: A multicriteria approach. J. Clean. Prod. 211, 103–114. https://doi.org/10.1016/j.jclepro.2018.11.013

Röhrig, N., Hassler, M., Roesler, T., 2020a. Capturing the value of ecosystem services from silvopastoral systems: Perceptions from selected Italian farms. Ecosyst. Serv. 44, 101152. https://doi.org/10.1016/j.ecoser.2020.101152

Röhrig, N., Hassler, M., Roesler, T., 2020b. Silvopastoral production as part of alternative food networks: Agroforestry systems in Umbria and Lazio, Italy. Agroecol. Sustain. Food Syst. 00, 1–19. https://doi.org/10.1080/21683565.2020.1835783

Singh, M., Durali, T., Cowieson, A.J., 2016. Use of n-alkanes for determination of Kikuyu grass (Pennisetum clandestinum) intake in free-range broilers. Anim. Prod. Sci. 56, 1152–1160. https://doi.org/10.1071/AN14778

Singh, M., Ruhnke, I., De Koning, C., Drake, K., Skerman, A.G., Hinch, G.N., Glatz, P.C., 2017. Demographics and practices of semi-intensive free-range farming systems in Australia with an outdoor stocking density of ≤1500 hens/hectare. PLoS One 12, 1–19. https://doi.org/10.1371/journal.pone.0187057

Skřivan, M., Englmaierová, M., 2014. The deposition of carotenoids and α-tocopherol in hen eggs produced under a combination of sequential feeding and grazing. Anim. Feed Sci. Technol. 190, 79–86. https://doi.org/10.1016/j.anifeedsci.2014.01.009

Skřivan, M., Pickinpaugh, S.H., Pavlů, V., Skřivanová, E., Englmaierová, M., 2015. A mobile system for rearing meat chickens on pasture. Czech J. Anim. Sci. 60, 52–59. https://doi.org/10.17221/7974-CJAS

Smith, J., Pearce, B.D., Wolfe, M.S., 2013. Reconciling productivity with protection of the environment: Is temperate agroforestry the answer? Renew. Agric. Food Syst. 28, 80–92. https://doi.org/10.1017/S1742170511000585

Soudet, T., Epaminondas, M., Chafik, Y., 2021. La reconnexion verger-élevage. https://doi.org/10.15454/9bww-wg14

Stadig, L.M., Rodenburg, T.B., Ampe, B., Reubens, B., Tuyttens, F.A.M., 2017. Effects of shelter type, early environmental enrichment and weather conditions on free-range behaviour of slow-growing broiler chickens. Animal 11, 1046–1053. https://doi.org/10.1017/S1751731116002172

Stadig, L.M., Tuyttens, F.A.M., Rodenburg, T.B., Ampe, B., Reubens, B., Stadig, L.M., Tuyttens, F.A.M., Rodenburg, T.B., 2018. Interactions between broiler chickens , soil parameters and short rotation coppice willow in a free-range system. Agroecol. Sustain. Food Syst. 00, 1–22. https://doi.org/10.1080/21683565.2018.1557777

Stephens, R.D., Petreas, M.X., Hayward, D.G., 1995. Biotransfer and bioaccumulation of dioxins and furans from soil: chickens as a model for foraging animals. Sci. Total Environ. 175, 253–273. https://doi.org/10.1016/0048-9697(95)04925-8

Strankowski, K.J., Stanley, C.W., 1981. Determination of Residues of Mesurol and Its Sulfoxide and Sulfone in Plant, Animal, and Soil Samples. J. Agric. Food Chem. 29, 1034–1037. https://doi.org/10.1021/jf00107a036

Su, H., Liu, W., Xu, H., Yang, J., Su, B., Zhang, X., Wang, R., Li, Y., 2018. Introducing Chicken Farming into Traditional Ruminant-Grazing Dominated Production Systems for Promoting Ecological Restoration of Degraded Rangeland in Northern China. L. Degrad. Dev. 29, 240–249. https://doi.org/10.1002/ldr.2719

Sun, T., Liu, Z., Long, R., 2014. Persistence of foraging chickens on grasshopper populations: a case study in Northwest China. Biocontrol Sci. Technol. 24, 1206–1208. https://doi.org/10.1080/09583157.2014.926859

Theofel, C.G., Williams, T.R., Gutierrez, E., Davidson, G.R., Jay-Russell, M., Harris, L.J., 2020. Microorganisms move a short distance into an almond orchard from an adjacent upwind poultry operation. Appl. Environ. Microbiol. 86, 1–14. https://doi.org/10.1128/AEM.01905-20

Timmermans, B., Bestman, M., 2016. Quality of apple trees and apples in poultry free range areas, 3rd European Agroforestry Conference.

Van Overmeire, I., Waegeneers, N., Sioen, I., Bilau, M., De Henauw, S., Goeyens, L., Pussemier, L., Eppe, G., 2009. PCDD/Fs and dioxin-like PCBs in home-produced eggs from Belgium: Levels, contamination sources and health risks. Sci. Total Environ. 407, 4419–4429. https://doi.org/10.1016/j.scitotenv.2008.11.058

Vanalli, C., Casagrandi, R., Gatto, M., Bevacqua, D., 2021. Shifts in the thermal niche of fruit trees under climate change: The case of peach cultivation in France. Agric. For. Meteorol. 300, 108327. https://doi.org/10.1016/j.agrformet.2021.108327

Vries, M. De, Kwakkel, R.P., Kijlstra, A., 2006. Dioxins in organic eggs: a review. NJAS - Wageningen J. Life Sci. 54, 207–221. https://doi.org/10.1016/S1573-5214(06)80023-0

Waegeneers, N., Hoenig, M., Goeyens, L., De Temmerman, L., 2009. Trace elements in home-produced eggs in Belgium: Levels and spatiotemporal distribution. Sci. Total Environ. 407, 4397–4402. https://doi.org/10.1016/j.scitotenv.2008.10.031

Westaway, S., Kling, C., Smith, J., 2018. A comparison of the performance of three sward mixtures sown under trees in a silvopoultry system in the UK. Agrofor. Syst. 92, 1009–1018. https://doi.org/10.1007/s10457-017-0142-1

Wiedemann, S., Pratt, C., Bliefield, N., Mayer, D.G., Redding, M.R., McGahan, E., 2018. Establishing soil nutrient distribution zones across free range egg farms to guide practical nutrient management strategies. Agric. Ecosyst. Environ. 257, 20–29. https://doi.org/10.1016/j.agee.2018.01.021

Xu, H., Su, H., Su, B., Han, X., Biswas, D.K., Li, Y., 2014. Restoring the degraded grassland and improving sustainability of grassland ecosystem through chicken farming: A case study in northern China. Agric. Ecosyst. Environ. 186, 115–123. https://doi.org/10.1016/j.agee.2014.02.001

Yates, C., Dorward, P., Hemery, G., Cook, P., 2006. The economic viability and potential of a novel poultry agroforestry system. Agrofor. Syst. 69, 13–28. https://doi.org/10.1007/s10457-006-9015-8

Yu, C., Jiang, X., Du, H., Li, Q., Zhang, Z., Qiu, M., Chen, T., Xia, B., Song, X., Hu, C., Xiong, X., Yang, L., Peng, H., Chen, J., Yang, C., 2020. Effects of free-range broiler production on vegetation characteristic and soil physicochemical property of the stocking areas in China. Agrofor. Syst. 94, 675–685. https://doi.org/10.1007/s10457-019-00438-9

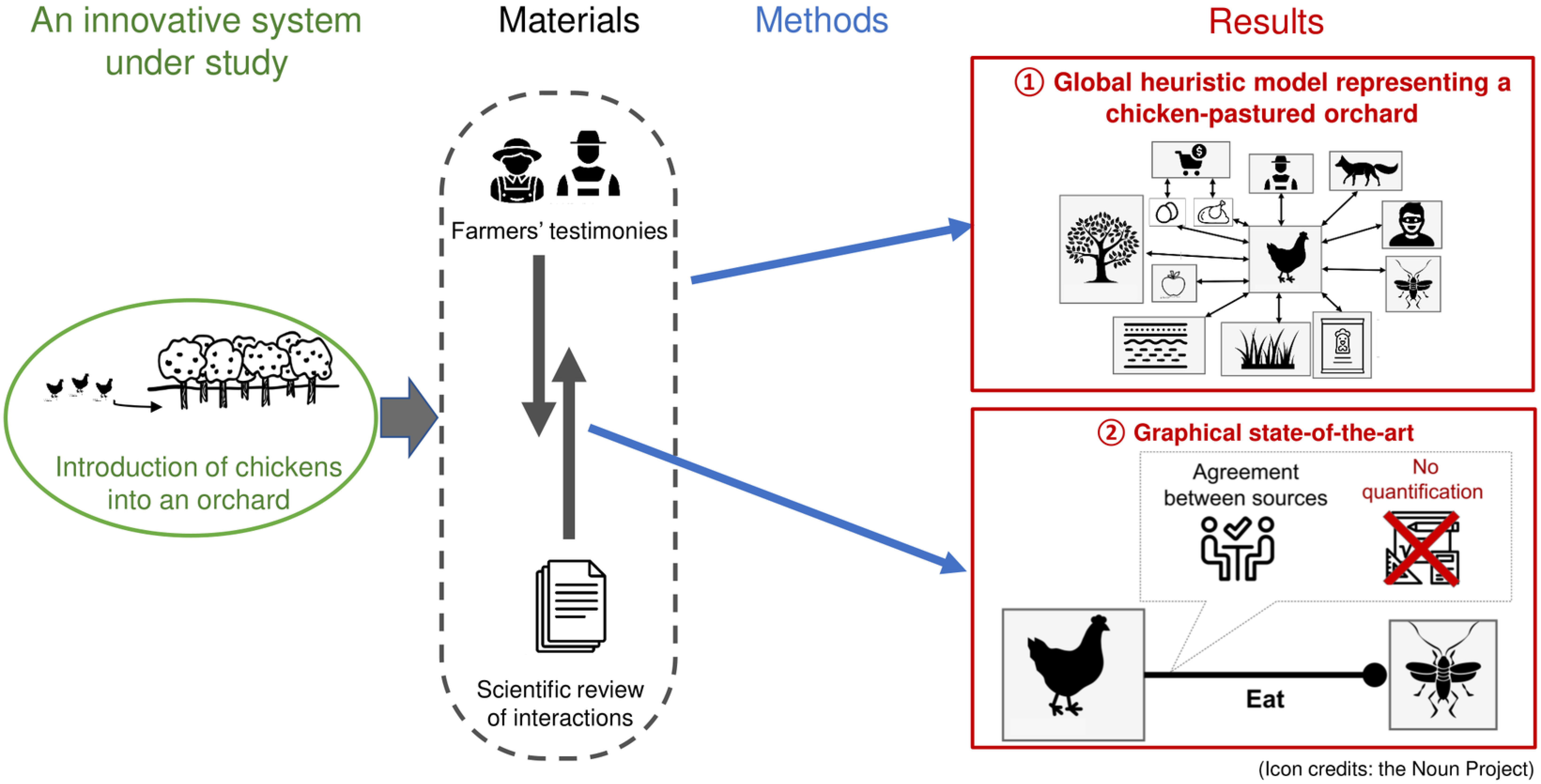
Zafeiraki, E., Costopoulou, D., Vassiliadou, I., Leondiadis, L., Dassenakis, E., Hoogenboom, R.L.A.P., van Leeuwen, S.P.J., 2016. Perfluoroalkylated substances (PFASs) in home and commercially produced chicken eggs from the Netherlands and Greece. Chemosphere 144, 2106–2112. https://doi.org/10.1016/j.chemosphere.2015.10.105

Zeltner, E., Hirt, H., 2008. Factors involved in the improvement of the use of hen runs. Appl. Anim. Behav. Sci. 114, 395–408. https://doi.org/10.1016/j.applanim.2008.04.007

Zhang, L.-X., Hu, Q.-H., Wang, C.-B., 2013. Emergy evaluation of environmental sustainability of poultry farming that produces products with organic claims on the outskirts of mega-cities in

China. Ecol. Eng. 54, 128–135. https://doi.org/10.1016/j.ecoleng.2013.01.030

Zhang, L., Zhou, L., Wei, J., Xu, H., Tang, Q., Tang, J., 2020. Integrating cover crops with chicken grazing to improve soil nitrogen in rice fields and increase economic output. Sci. Total Environ. 713, 135218. https://doi.org/10.1016/j.scitotenv.2019.135218


An innovative system under study
Materials
Methods
Results
Introduction of chickens into an orchard
Farmers' testimonies
Scientific review of interactions
① Global heuristic model representing a chicken-pastured orchard
② Graphical state-of-the-art
Agreement between sources
No quantification
Eat
(Icon credits: the Noun Project)