Beekeeping and agropastoralism interactions through floral resources in the French Mount Lozère

Gabriel Gonella, Estelle Leoni, Léo Mouillard-Lample, Claire Aubron, Axel Decourtye, Marc Deconchat, Cécile Barnaud

Agronomy for Sustainable Development (2024) 44:49
https://doi.org/10.1007/s13593-024-00985-1

RESEARCH ARTICLE

Beekeeping and agropastoralism interactions through floral resources in the French Mount Lozère

Gabriel Gonella[1] · Estelle Leoni[1] · Léo Mouillard-Lample[2] · Claire Aubron[3] · Axel Decourtye[4] · Marc Deconchat[1] · Cécile Barnaud[1]

Accepted: 9 September 2024 / Published online: 4 October 2024

Abstract

Beekeeping has faced increasing difficulties during the past decades, among which is the decline in floral resources. Agriculture provides essential floral resources for beekeeping, but some farming practices have also been shown to be responsible for their decline. To provide floral resources for beekeeping, what type of agricultural transformation should be promoted, and how? To answer these questions, we still lack knowledge about the floral resources that are used by beekeeping and about the technical-economic obstacles that farmers face in implementing more favorable farming practices, particularly in agropastoral settings. To help fill these gaps, we develop a novel approach that frames both agropastoral farming and beekeeping as farming systems, by characterizing the beekeeping systems of a given place, the floral resources they use, and the impacts these farming systems have on floral resources. This approach is applied to the agropastoral landscapes of Mount Lozère, southern France, using a methodology based on semi-structured interviews with farmers and beekeepers addressing the agronomical functioning of their farms. We demonstrate that the floral resources used by beekeepers on Mount Lozère are threatened by the current dominant agricultural development paths, which seek to maximize the material productivity of labor. Such paths lead to the intensification of agricultural practices in harvested areas and the extensification of rangelands. These pathways are reinforced by the low remuneration of agropastoral labor and by the current rules of the European Union Common Agricultural Policy. "Frugal" farming, a farming system based on reduced inputs and investments, and labor-intensive practices, namely, a labor-intensive use of pasture, seems an effective way to produce floral resources. Both, agropastoral farmers and beekeepers, would benefit from an increase in the number of agricultural workers in agropastoral landscapes. This calls for public policies that promote a better remuneration of agropastoral labor, either directly or by driving market mechanisms.

Keywords Farming system · Agrarian system · Agropastoral landscape · Sustainable resources management · Beekeeping · Floral resources

1 Introduction

Floral resources, i.e., the nectar, pollen, and honeydew collected by honey bees as feed, are central to beekeeping (Decourtye et al. 2010; Bretagnolle and Gaba 2015; Kouchner et al. 2019). In mainland France, agricultural floral resources, i.e., the floral resources provided by landscapes that are shaped by agricultural activities, are important as they represent a large share of the floral resources exploited by beekeeping. Specifically, more than half of the honey produced in 2021 relied on agricultural floral resources, which include, in decreasing order of importance, sunflower, rapeseed, lavender, mountain, chestnut tree, and alfalfa honey (FranceAgriMer 2023). However, various indicators suggest that floral resources, including those stemming from

✉ Gabriel Gonella
gabriel.gonella@inrae.fr

1 INP, INRAE, UMR Dynafor, 31326 Castanet-Tolosan, France

2 INRAE, UR Abeilles et Environnement, 84914 Avignon, France

3 CIRAD, INRAE, Institut Agro, UMR Selmet, 34060 Montpellier, France

4 ITSAP – Institut de l'Abeille, 84914 Avignon, France

agriculture, have been declining since the Second World War (Potts et al. 2010; Richner et al. 2015; Goulson et al. 2015; Bretagnolle and Gaba 2015; Aviron et al. 2023). The scientific literature shows that the reduction in the diversity of agricultural landscapes—including the diminution of the area of semi-natural elements and the loss of melliferous species biodiversity—has led to both a quantitative and qualitative reduction of floral resources (Requier et al. 2015; Alaux et al. 2017; Simanonok et al. 2020) and significant resource gaps (Requier et al. 2015; Timberlake et al. 2019; Simanonok et al. 2020). The decline in diversity is proposed as one of the major drivers of the current difficulties of the beekeeping sector (Decourtye et al. 2010; Potts et al. 2010; Bretagnolle and Gaba 2015). It therefore seems crucial to better understand the agricultural drivers of this decline.

While there is an increasing body of literature highlighting the importance of agricultural floral resources for beekeeping, there is still a need to address the following questions: in order to provide floral resources for beekeeping, what type of agricultural transformation should be promoted, and how should it be promoted? Yet to answer these questions, we lack knowledge on two important elements of agricultural floral resources. First, there is a need to understand how beekeeping uses agricultural floral resources and to assess the impact of the transformations of these resources on beekeeping. Second, there is a need to understand how agriculture produces these floral resources, notably by identifying the driving forces behind the transformations of agricultural floral resources and the levers and obstacles in the adoption of farming practices that are more favorable to beekeeping.

Little is known about the floral resources that are really used by beekeeping, especially at the level of beekeeping operations. Indeed, the impacts of the changes in agricultural floral resources on beekeeping have been mainly assessed by two strands of research. The first assesses these impacts on the physiology of honey bee colonies. Certain studies have shown that agricultural landscapes with few floral resources make it difficult for honey bees to forage (Danner et al. 2016, 2017) and heavily affect the ability of managed honey bee colonies to overwinter or to fight diseases (Baude et al. 2016; Alaux et al. 2017; Dolezal et al. 2019; Simanonok et al. 2020). Another strand of research has addressed the consequences of the changes in agricultural floral resources on beekeeping at a broader regional or national scale. It has been shown that such changes have put national beekeeping sectors at risk (Durant 2019; Binimelis and Wickson 2019). In turn, it has been shown that commercial beekeeping has adapted to these new patterns of floral resources through mechanisms that reinforce its dependence on agriculture, such as transhumance to mass-flowering crops (Guillerme and Maire 2018), or the involvement in pollination markets (Durant 2019). Given that research has been focusing on opposing ends of the scale (national/regional scale or the colony level), very little research addresses the way beekeepers actually use agricultural floral resources at the operational scale (Adam et al. 2016; Adam 2019; Kouchner et al. 2019; Kouchner 2019).

Concerning the production of agricultural floral resources, the literature points out several agricultural policies and market mechanisms responsible for large-scale transformations of agricultural landscapes, such as the conversion of meadows to crops. While the presence of meadows and wooded habitats is known to enhance the provision of floral resources in agricultural landscapes (Smart et al. 2019; St. Clair et al. 2020; Langlois et al. 2020; Rivers-Moore et al. 2020), current agricultural dynamics have led to a reduction of the area suitable for honey production (Malkamäki et al. 2016; Otto et al. 2016). Such dynamics have also led to a transformation of the temporal patterns of floral resources, moving from floral resources available all year long to poorly diversified mass-flowering floral resources available over short periods of time (Malkamäki et al. 2016; Durant 2019). At plot scale, certain studies addressed the negative impact of practices such as pesticide use (Decourtye et al. 2019), early mowing (Fluri and Frick 2002; Hernandez et al. 2023), or the positive impact of various plot-scale floral resource management practices (Requier and Leonhardt 2020; Nichols et al. 2022; Hernandez et al. 2023) including flower strips (Baden-Böhm et al. 2022) or intercropping (Decourtye et al. 2010). As outlined above, research has largely concentrated on broader regional or local plot level, with little investigation at the farm scale. As a result, little is known about the technical-economic obstacles that farmers face in implementing farming practices more favorable to floral resources.

Furthermore, the literature on agricultural floral resources presented above tends to focus on lowland farming rather than mountain farming. Mountainous agropastoral landscapes, characterized by the presence of meadows and semi-natural habitats (Rieutort 2006), may constitute a refuge for beekeeping operations facing agricultural intensification in lowlands. In fact, interviewed beekeepers frequently present them as such. In spite of being potential refuges for beekeeping, agropastoral landscapes are currently undergoing agrarian changes that also seem adverse to beekeeping. Permanent meadows and rangelands are in decline, and these areas tend either to be converted into croplands or temporary meadows, or abandoned and colonized by woods (Oteros-Rozas et al. 2013; Aubron et al. 2016, 2019; Garambois et al. 2020). This article addresses the two abovementioned gaps by drawing on research focusing upon the agropastoral floral resources of Mount Lozère, in the south of France (Fig. 1). More specifically, we address the following questions: (i) what are the floral resources used by beekeepers on the Mount Lozère? (ii) What are the impacts of agropastoral farming on these floral resources? (iii) What are the drivers

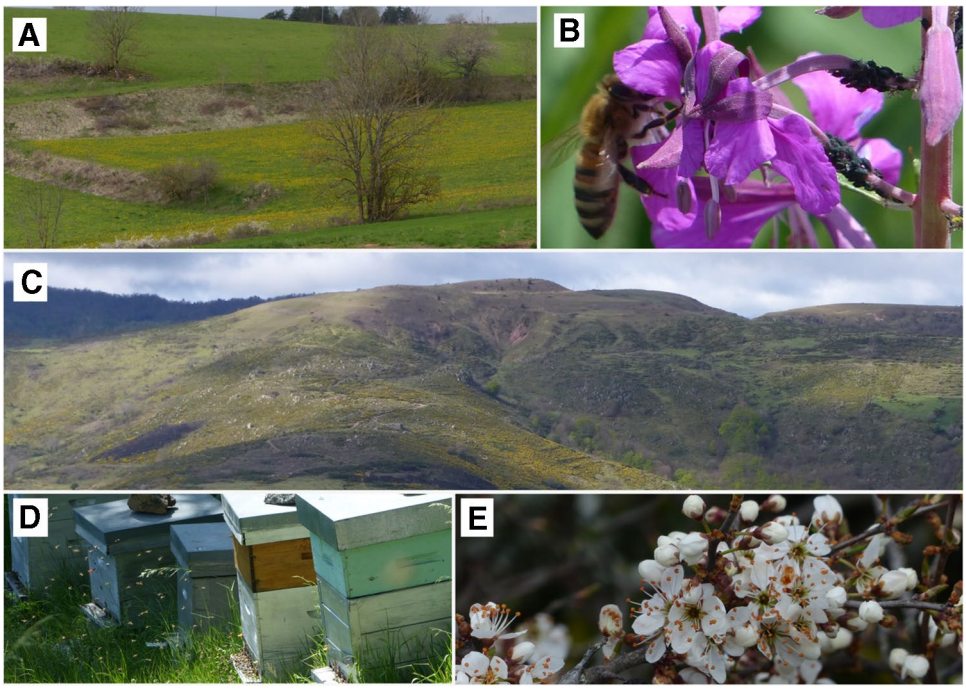

Fig. 1 Agricultural landscapes and floral resources on the Mount Lozère. **A** Temporary meadows covered with dandelion (*Taraxacum* spp.) on a calcareous plateau in early spring (April). **B** Bee foraging fireweed (*Epilobium angustifolium*) during late summer (end of June) in a C-like landscape. **C** Typical landscape of Mount Lozère in early June: rangelands with flowering common broom (*Cytisus scoparius*) on the lower left, permanent meadows, nowadays mainly grazed, on the flat area on the lower right, steep slopes in between colonized by spontaneous woods, summer pastures on the top, over ca. 1300 m, and planted pine forests in the background on the left. **D** Bee hives in a permanent meadow in June. **E** Blackthorn (*Prunus spinosa*) flowers in hedgerows in April. Photo credit: Gabriel Gonella.

that lead farmers to adopt practices that have a negative or positive impact on floral resources? More generally, what are the technical-economic levers and obstacles to the enhancement of floral resource provision in agropastoral landscapes? To explore these questions, we first outline a novel conceptual framework that considers both agropastoral farming and beekeeping as farming systems. The methodology is then presented, which comprises a landscape analysis followed by two rounds of semi-structured interviews with farmers and beekeepers. Finally, key findings are outlined and their contribution to the extension and the development of both beekeeping and agropastoral farming is discussed.

2 Material and methods

2.1 A conceptual framework based on floral resources to analyze the interactions between farming and beekeeping

This study is based on an original conceptual framework (Fig. 2) that draws on farming systems research (Darnhofer et al. 2012; Ison 2012). Farming systems are defined as groups of farms that share similar technical and economical characteristics. In other words, they reflect the "structural and functional organization that underpins production processes" (Lacoste et al. 2018). Commonly used variables to describe farming systems include a farm's production means, such as land, workforce, and equipment (Reboul 1976; Cochet 2012). In this study, an agropastoral farming system typology is built in order to illustrate the diversity of the main agronomical processes at play in the study site that influence the provision of floral resources. A beekeeping system typology is also built to illustrate the diversity of uses of these floral resources.

Our conceptual framework has three main objectives. First, it frames the analysis of farming and the way it shapes landscapes with varying floral resources. Second, it frames the analysis of beekeeping as a set of practices that intend to use floral resources provided by agricultural landscapes. Third, it frames the analysis of the interactions between farming and beekeeping through floral resources as two activities that rely on and transform the same agricultural landscapes.

Landscapes are defined as a mosaic of agricultural and non-agricultural lands. From an apicultural point of view, this can be seen as the juxtaposition of landscape elements that provide floral resources and where beekeepers install apiaries. From an agricultural point of view, landscapes are seen as a set of exploited and unexploited lands for farming.

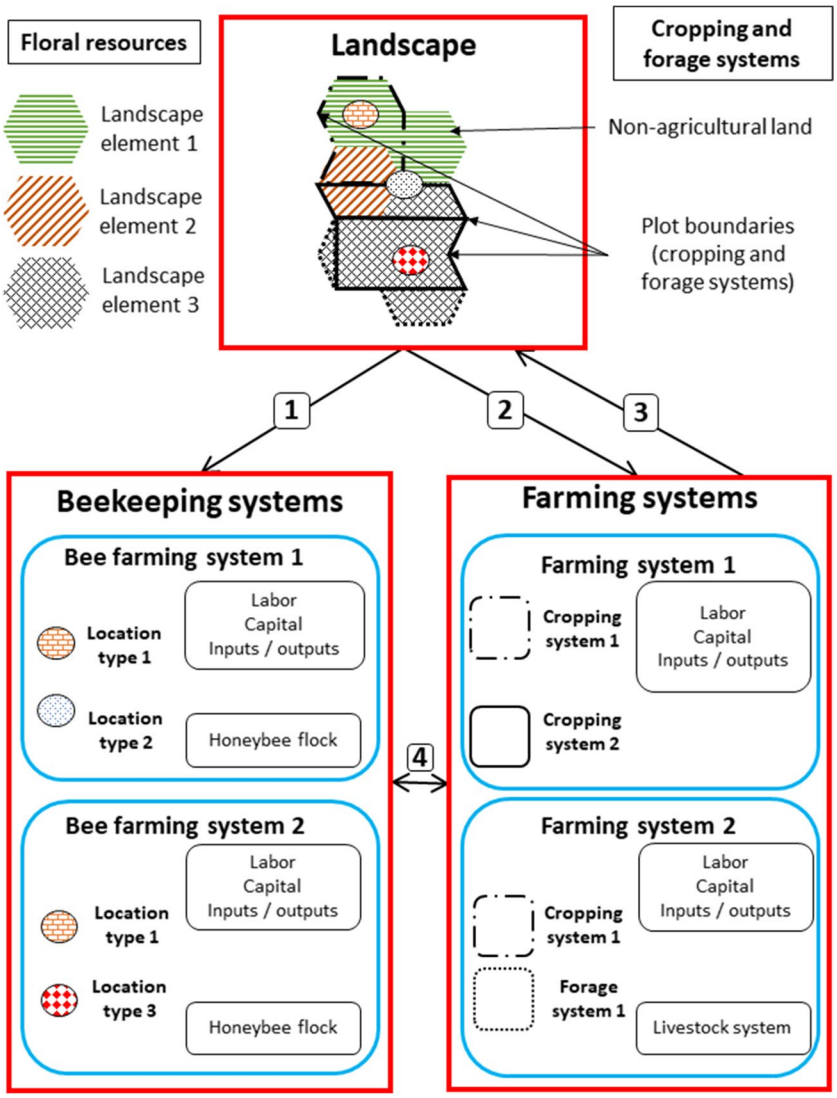

Fig. 2 Conceptual framework of farming/beekeeping interactions through floral resources. The framework represents three main systems: landscapes (top box), beekeeping systems (left box), and agricultural farming systems (right box). The interactions between these systems through floral resources are represented by arrows that show an asymmetry between them: beekeeping systems rely on agricultural landscapes on which they have no direct influence (1), while farming systems both rely (2) and act on (3) agricultural landscapes. Direct interactions between farming systems and beekeeping systems are also represented (4). These may involve social interactions between farmers and beekeepers, or direct impacts of agriculture on honey bees such as pesticide use. This study focuses on floral resources and did not consider these direct interactions.

Farming systems shape agricultural landscapes through farming practices, and this framework pays special attention to the **forage system** within agropastoral farming systems. In our study, drawing on Sébillotte's **cropping system** concept, forage systems refer to a plot that represents a group of agricultural lands that share similar biophysical characteristics (soil, location in the landscape, and slope), and on which farmers apply the same management sequences in order to produce feed for animals (Sébillotte 1974). This comprises permanent meadows, grazed rangelands, and crops. In combination with farmers' objectives and other elements of farming systems, such as herds and livestock practices, available labor force, equipment, and land, forage systems offer insights into the rationales of farming practices.

Beekeeping systems are also framed as farming systems. Their specificities nonetheless justify the definition of particular concepts. **Floral resources** are the pollen, nectar, and honeydew exploited by beekeeping. They are characterized by two features: the type of **landscape element** that produces them, e.g., meadows or chestnut tree (*Castanea sativa*) woods; and the period(s) at which the resources are available, i.e., their phenology.

Beekeeping systems exploit floral resources by means of **apiary locations**, i.e., the places where beekeepers place the hives. Still drawing on the cropping system concept, we build a typology of apiary locations. This is achieved through the identification of similar apicultural characteristics shared by groups of apiary locations, in particular, the landscape elements present in a honey bee foraging range around the apiary location. These landscape elements, in turn, determine the floral resources available at each period in a season.

Apiary locations are where honey bee colonies are installed, and the colonies are managed by following a specific set of practices including transhumance circuits,

feeding, or reproduction management. These practices aim to control the colonies' population, growth, and health condition, in order to obtain from them a production (e.g., honey and swarms) or services (e.g., pollination and education).

Various apiary locations and management types are combined in beekeeping systems, in accordance with the available labor force, equipment, and the beekeeper's objectives. These combined elements offer insights into the rationale underlying the use of floral resources in a given agricultural landscape.

2.2 Field work

2.2.1 Study site

Mount Lozère (Fig. 3) is a granitic massif ranging from 500 to 1699 m in altitude. It has a sub-Mediterranean climate marked by cold winters, dry summers, and abundant precipitation during inter-seasons. A part of Mount Lozère is located in the core zone of the Cévennes National Park.

Beekeeping has long been an important activity on Mount Lozère (Lehébel-Péron et al. 2016). However, professional beekeeping, i.e., practiced by beekeepers for whom beekeeping is the main source of income, only really gained importance after the Second World War (Lehébel-Péron 2014; Lehébel-Péron et al. 2016). As it does not require access to land, beekeeping is appealing to newcomers that have the intention to gain a living from agriculture yet have limited access to land. Currently, the number of beekeepers that live on the study site is estimated between 100 and 150, but precise figures are difficult to obtain due to a lack of reliable publicly available data (Lehébel-Péron 2012a, b). A majority of these beekeepers manage less than 50 hives, with only 5

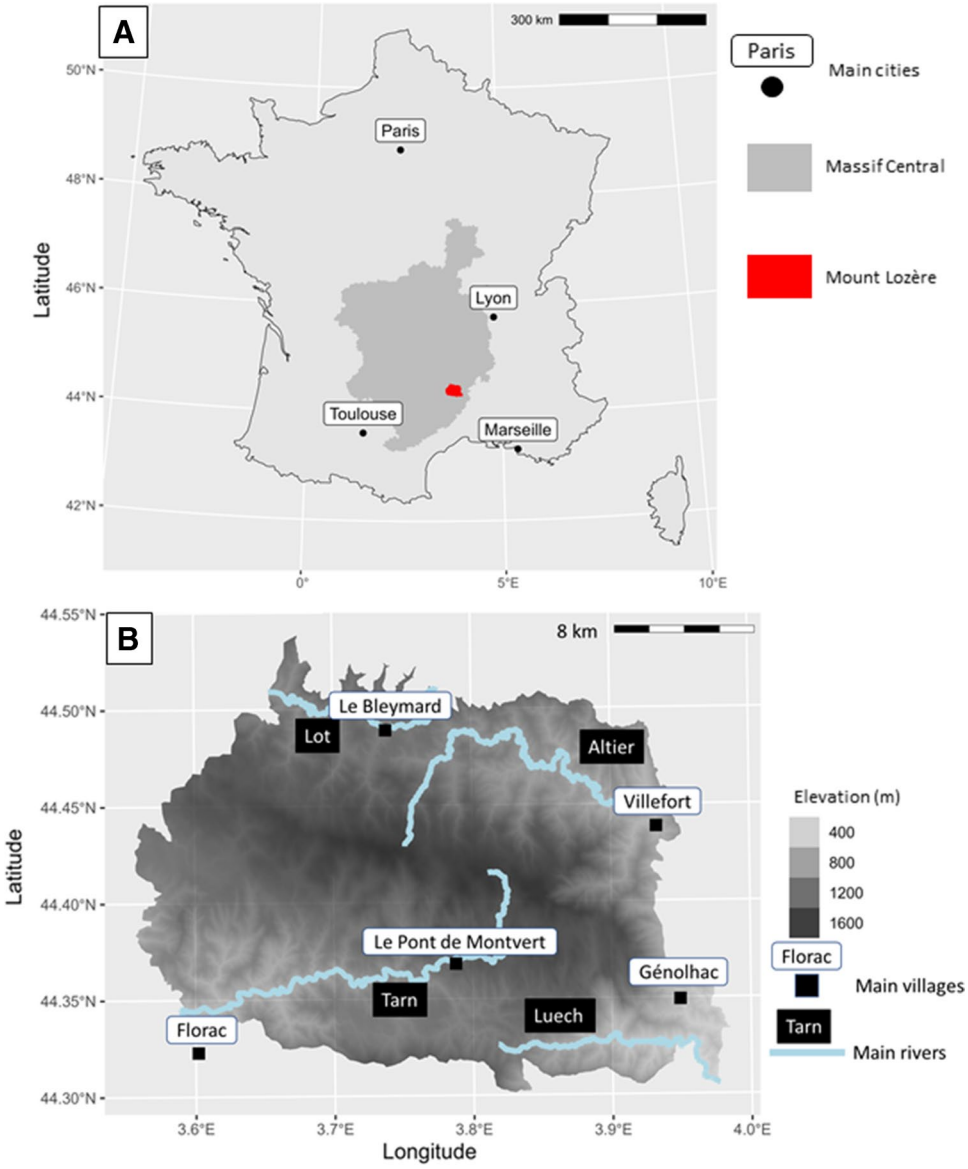

Fig. 3 Location of Mount Lozère in the Massif Central in France and topographic map of the mount Lozère. All maps are oriented towards the geographical north. **A** Location of the Mount Lozère (red) in the Massif Central (grey), in France. **B** Map of Mount Lozère. Color gradient stands for elevation. The blue lines show the course of the 4 main rivers surrounding the Mount Lozère.

beekeeping operations identified as having more than 200 hives, a threshold commonly recognized by beekeepers as the minimum to make a living out of beekeeping. However, these numbers do not reflect the use of floral resources by beekeepers, as numerous transhumant beekeepers use apiaries on Mount Lozère in order to benefit from the "common heather" (*Calluna vulgaris*) honey flow (Lehébel-Péron 2012b).

Mount Lozère landscapes are typical of agropastoralism (Rieutort 2006), mixing rangeland used for livestock grazing, cropland (where temporary meadows are grown in rotation with cereals), permanent meadows, and non-agricultural lands such as shrublands and spontaneous or planted forests. Both permanent and temporary meadows are mown for the production of hay to feed animals in winter. Mount Lozère farming is dominated by suckler cow husbandry (production of young calves exported for further fattening), although other types of farming are also represented, such as dairy cow, suckler sheep, dairy goat for cheese production, orchards, and vegetable gardens. In 2020, there were 110 farms on Mount Lozère, approximatively one-third of the 1970 levels, while the number of agricultural workers decreased by more than half during the same period according to data from the French general agricultural census (RGA) carried out in 2020 (MASA 2024). Between 1970 and 2010, the area per farm doubled, and the livestock they each managed nearly tripled (Lepart et al. 2016). This illustrates a sharp increase in the material productivity of agricultural labor (i.e., the amount of agricultural products produced per worker) observed at national level in France (Charroin et al. 2012). These processes have been accompanied by significant land use changes, marked by the intensification of land cultivated by mechanized means for forage production and a trend towards the abandonment of other types of land (Garambois et al. 2020). Land abandonment may be exacerbated by the sharp decline in the number of animals reared on Mount Lozère over the last decade, with the number of cows falling from around 7000 in 2010 to ca. 5000 in 2020 (Aubron and Nozières-Petit 2023). Abandoned land is subject to woody encroachment, a process that is generally negatively perceived by local farmers (Blanc 2014; Moreau et al. 2019).

2.2.2 Data collection and analysis

This study was based on semi-structured interviews and landscape observations. All interviews were recorded and partially transcribed, with the informed consent of the participants. Data analysis aims to build a farming systems typology, as described in the conceptual framework section, and a mapping of the floral resources of the Mount Lozère. The first phase of field work was carried out between February and May 2021 and aimed to understand the landscapes of Mount Lozère, their floral resources, and their agrarian history. Based on these landscape observations, we formulated a number of hypotheses concerning the agricultural dynamics on Mount Lozère. Attention was paid to the spatial repartition of agricultural lands, to the presence of cattle, and to signs of past agricultural activities such as dry-stone walls or irrigation canals. Through these observations, we also formulated a hypothesis on the repartition of floral resources on Mount Lozère.

These observations were complemented by 22 semi-structured interviews with local stakeholders such as retired farmers and beekeepers, natural park managers, and agricultural advisors. We recruited interviewees thanks to contacts at the Cévennes National Park, from markets or events, by meeting farmers and beekeepers on their farms and apiaries, and by snowball sampling. These interviews addressed the past changes of agricultural land use, the evolution of floral resources and beekeeping activity on Mount Lozère, and the current challenges of Mount Lozère agriculture and beekeeping as perceived by the interviewees. This led us to refine our hypothesis about the agricultural dynamics played out on Mount Lozère and their impacts on floral resources and which then led to the production of an initial farming system and beekeeping system typology.

The second phase of field work was carried out between May 2021 and February 2022. It aimed to understand farming and beekeeping practices, as well as their underlying rationales. We conducted semi-structured interviews with farmers and beekeepers still in activity. These interviews addressed the technical-economic functioning of their farms, including farming practices, floral resource use, location of apiaries and plots, technical farm functioning, and economic data. In particular, technical-economic interviews were conducted with farmers and/or beekeepers from 38 agropastoral farms, 16 beekeeping operations, including 7 non-professional beekeeping operations, and 3 farms operating both agropastoral and beekeeping activities. Interviewees were chosen according to our first iteration of farm typology, in order to represent the diversity of farming and beekeeping on Mount Lozère. As new interview data were gathered, the farming system typology was subsequently modified during this phase. Sampling stopped when new interviews did not challenge the soundness of our farming system typology.

The floral resources utilized in beekeeping were identified through the knowledge and practices of beekeepers. This was obtained by asking beekeepers to list their apiary locations on Mount Lozère. For each apiary location, we then asked at which periods they were exploited and the species or landscape elements that produced the main floral resources at these locations. We mapped floral resources and apiary location types by crossing land cover data provided by the French National Geographic Institute (IGN 2023) and

the agricultural land parcel information system (Cantelaube and Carles 2015; IGN 2017).

3 Results: beekeeping and agropastoralism on Mount Lozère

In this section, we first give a general overview of Mount Lozère landscapes and floral resources. We then describe the beekeeping systems of Mount Lozère in order to present the main floral resources that they use. Finally, we show how agropastoral farming systems on the Mount Lozère contribute (or not) to the provision of these floral resources.

3.1 The floral resources of Mount Lozère and their uses by beekeeping

3.1.1 Mount Lozère agricultural landscapes and floral resources

Six landscape elements (Fig. 4) provide floral resources which enable beekeepers to produce 4 main types of honey: "Spring," "Chestnut," "Mountain," and "Heather" honeys. The apiary location types used by beekeepers are described in supplementary materials 1 and 2 and mapped in supplementary material 3. Three altitudinal zones explain the structure of both floral resources and the agricultural activities on Mount Lozère. This structure appears on the map of landscape elements (Fig. 5A).

Valley bottoms and slopes, under ca. 900 m (the limit of the chestnut tree repartition range), usually present acidic soils. They are occupied by chestnut tree forests, other types of deciduous forests, mountain heathlands, and permanent meadows in flat valley bottoms. They are mostly uncultivated, though sometimes grazed. In late summer (late June to mid-July), chestnut tree forests give rise to the late chestnut tree honey flow of Mount Lozère. It is uncommon to produce "chestnut tree" honey on Mount Lozère, but this honey flow is temporally complementary to the more important and reliable "chestnut tree" honey flow of the nearby Cévennes valleys, which occurs in June. "Late chestnut tree" apiary locations on Mount Lozère also give access to spring floral resources between April and May, due to the presence of certain melliferous trees such as *Prunus avium* and *Robinia pseudoacacia*. This "late" spring honey flow occurs up to 2 months after spring honey flows in lower-lying areas, e.g., in the lowland "garrigues" of the south of France. They are therefore little used by commercial beekeepers.

Between ca. 900 and 1300 m altitude lie calcareous and granitic plateaus punctuated with slopes. This zone is typical of the agropastoral mosaic of arable crops and temporary meadows, permanent meadows, and rangelands in mountain heathlands and woods (Fig. 5B). Overall, the plateaus are the most prone to arable crops, particularly those that are calcareous. Early meadow species and melliferous bushes in mountain heathlands generate a late spring honey flow between April and May. This is used by beekeepers to feed colonies that overwinter on Mount Lozère and allow for their growth. Spring honey is harvested in favorable years. This zone is also the one that gives rise to the "mountain" honey flow in June. Beekeepers use these honey flows across two different types of apiary locations: those dominated by mountain heathlands, in which spontaneous vegetation is the most important for the honey flow (bushes such as *Prunus spinosa* in spring, herbaceous species such as *Knautia* spp., brambles—*Rubus* spp.—and isolated trees in summer), and those with high shares of temporary meadows, with a higher importance of melliferous species encountered in arable lands (e.g., dandelion—*Taraxacum* spp.—in spring, and alfalfa—*Medicago sativa*—in summer).

The top of Mount Lozère, over ca. 1300 m altitude, is mainly occupied by managed coniferous forests, wetlands, and heather heathlands mostly managed by the French national forest agency (ONF), a public institution (Fig. 5B). They are used by farmers as summer pastures, especially the heathlands. This zone gives rise to the "common heather" honeyflow, which beekeepers use through heather heathland locations. Beekeepers cannot overwinter their colonies at these locations because of low temperatures and the lack of spring floral resources. Such locations thus require transhumance. "Common heather" is the most well-known honey flow of Mount Lozère and attracts beekeepers far away from the study site. It is however highly uncertain and puts colonies at risk of varroa infestations, as late honey flows delay acaricide treatments.

Overall, Mount Lozère is characterized by a continuous supply of floral resources, except for a gap in May and a peak in June. It is worth noting that Mount Lozère honey flows are also uncertain, as illustrated by Fig. 6. Both these characteristics contrast with the floral resources commonly used by commercial beekeepers, usually abundant, reliable, but short-lasting, for example, rapeseed or lavender honey flows.

3.1.2 Beekeeping systems and the use of agropastoral floral resources

We identified six beekeeping systems which differ according to the professional status of beekeepers, the types of colony management they implement, the floral resources they use, and the type of honey they produce, i.e., "mountain," "late chestnut tree," "common heather," and/or "spring." To facilitate the comparisons, beekeeping systems are represented by operations with only one worker. This situation corresponds to the majority of the encountered beekeeping operations. They are presented in descending order of colony number.

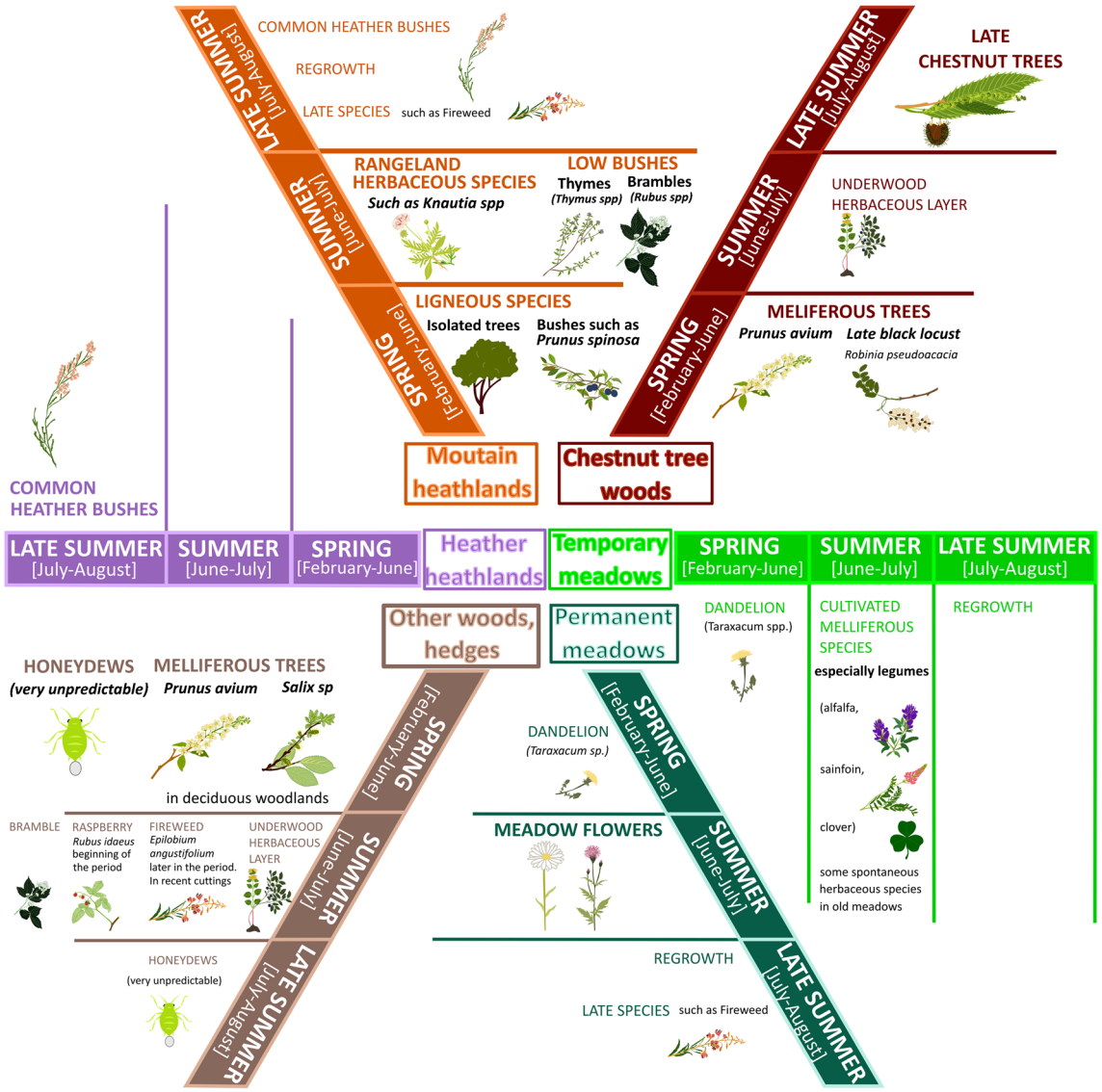

Fig. 4 Floral resources provided by the various landscape elements of Mount Lozère. The six landscape elements on Mount Lozère that provide floral resources are represented in the center. Each landscape element provides distinct floral resources over the course of the year, divided into three periods, from the center (spring) to the periphery (late summer), for a total of 16 floral resources.

1) Transhumant professional, on heather heathlands, is the largest system modeled here. It comprises 500 colonies. Most of the apiary locations, as well as the main site of the beekeeping operation, are not situated on Mount Lozère (Fig. 6A). The transhumance of colonies to Mount Lozère occurs only in the summer to take advantage of the heather honey flow.
2) Transhumant professional with high share of "mountain" honey is a medium-size system of around 300 colonies. The main site of the beekeeping operation is located on or near the Mount Lozère. In this system, colonies are exclusively wintered away from Mount Lozère, either at lower altitudes, in the Cévennes valleys or in the lowland garrigues up to 2 h drive away from the main site. This allows colonies to take advantage of early spring blooms, from the end of February onwards. This system mainly relies economically on the production of chestnut tree honey in the Cévennes valleys, which are located not far from Mount Lozère yet out of the study area (Fig. 6B). The Cévennes chestnut tree honey flow occurs in June, competing with the "mountain flowers" honey flow. However, around 75 colonies (25% of the total flock) are moved to Mount Lozère in early summer for the production of mountain honey. Then, 50 of these colonies are then moved at the end of the summer to the common heather heathlands at the top of Mount Lozère

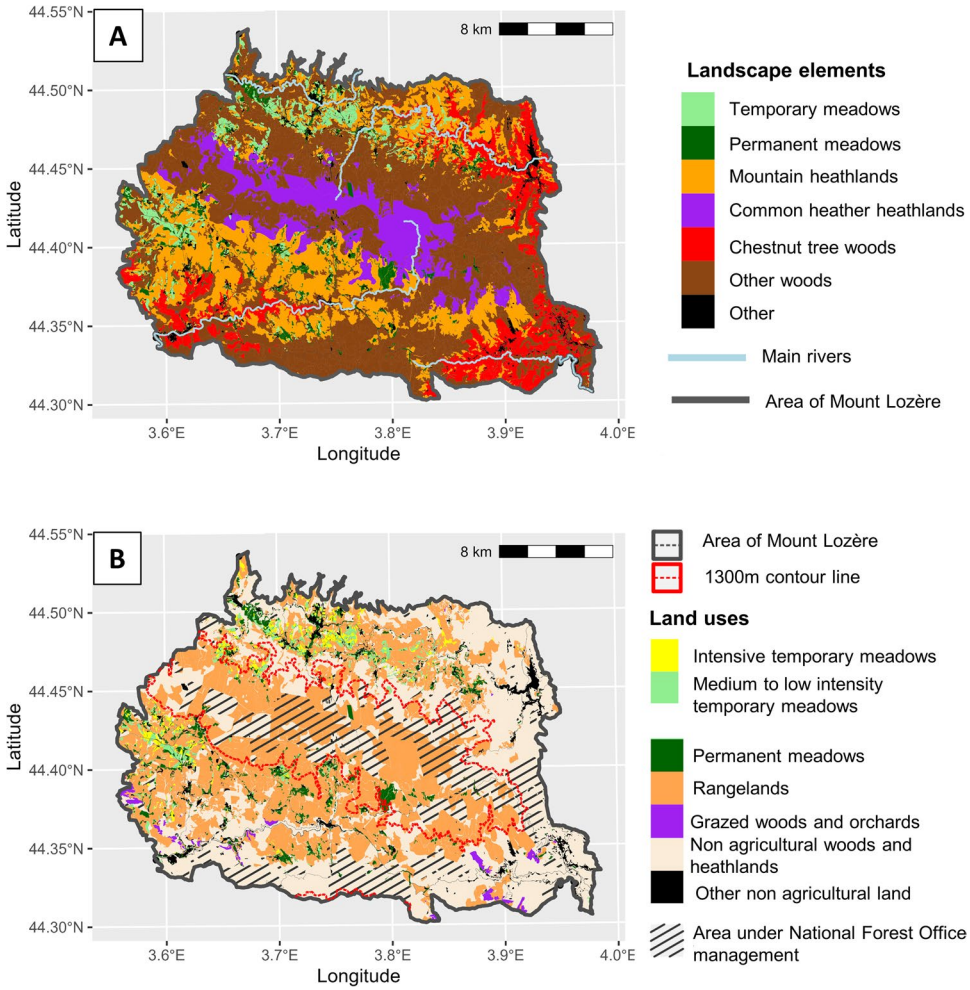

Fig. 5 Land uses on Mount Lozère. Both maps are oriented to the geographic north. **A** Apicultural uses of Mount Lozère. This map shows the areas of the main landscape elements that produce floral resources for beekeeping. **B** Agropastoral and forestry uses of Mount Lozère.

(Fig. 6A). This system thus takes advantage of the much looked-after but uncertain common heather honey flow.

3) Transhumant professional with late chestnut trees system is also a medium-size system of ca. 300 colonies, similar to the previous system, except that it has a greater reliance on transhumance (to the *Robinia pseudoacacia* honey flow in spring, for example), which results in a greater diversity of honeys produced. The mountain honey thus accounts for a lesser part of its production (Fig. 6B). Like the previous one, this system mainly relies on the chestnut tree honey from the Cévennes valleys, but it also uses locations with chestnut trees on Mount Lozère during the late summer. This practice both prolongs the chestnut tree honey flow of the Cévennes valleys and provides floral resources to prepare the colonies for winter. Then, 100 colonies are sent to the common heather honey flow, i.e., twice as many as in the previous system.
4) Sedentary professional is the smallest system among the professional systems described here, with 200 colonies. Its main site is located on mount Lozère. It is a sedentary system, which means that it does not practice transhumance (Fig. 6A). As a consequence, the selection of apiary locations in this system is driven by a continuous availability of floral resources over the course of the year. Notably, spring resources are of great importance to this system, as they are necessary to feed the colonies that overwinter on Mount Lozère and allow their growth so that they benefit from the "mountain flowers" and "late chestnut tree" honey flows. In addition, there are fewer logistical constraints on the choice of locations than in transhumant systems. Indeed, the absence of transhumance reduces the number of handling operations (hive moving), and the vehicles used are smaller. From an economical point of view, this system mainly relies on chestnut honey produced in the Cévennes valleys (Fig. 6B). The absence of transhumance prevents the use of common heather heathland locations which are too poor in floral resources before summer. Mount Lozère locations dominated by heathlands and meadows

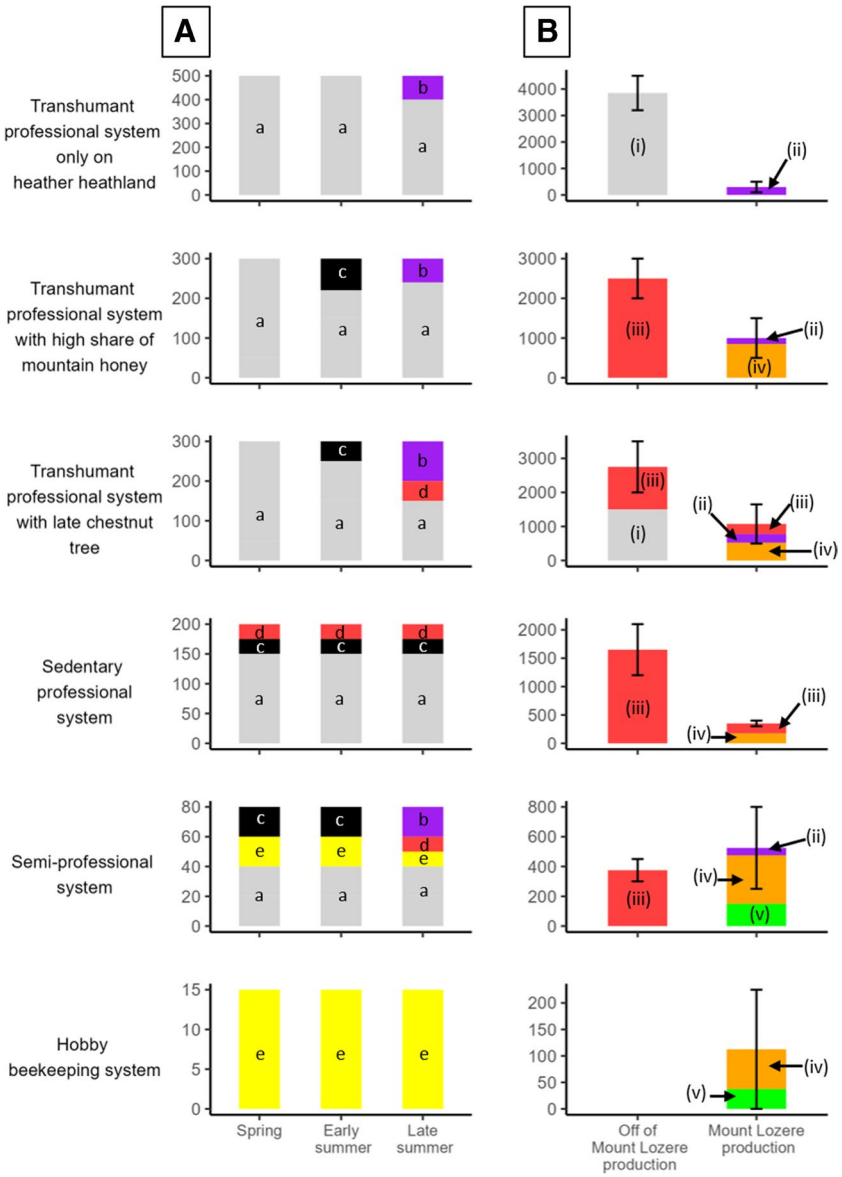

Fig. 6 Use of apiary locations and production of beekeeping systems on Mount Lozère. **A** Number of colonies on each location type, by season, for each beekeeping system. Colors and letters show the repartition of the colonies among location types, as follows: a (grey): locations off of Mount Lozère, b (purple): summit locations with heather, c (black): locations dominated by mountain heathlands, d (red): locations with chestnut trees, and e (yellow): locations with temporary meadows. **B** Quantity of honey produced (kg) on or off of Mount Lozère, by each beekeeping system. The error bars represent the maximum and minimum expected production. Colors and roman numbering show the contribution of each type of honey to the total production, as follows: (ii) (purple): heather honey, (iii) (red): chestnut honey, (iv) (orange): mountain honey, (v) (green): spring honey, and (i) (grey): other honey.

are also less advantageous, as the first important honey flows rarely occur here before June. As a consequence, on Mont Lozère, the lower-lying apiary locations with chestnut trees are the most suitable in this system.

5) Partly transhumant semi-professional is a rather small system with 80 colonies, whose main site is located in the study area. It does not generate enough income for the beekeeper to make a living and is combined with other activities that generate income, such as an agricultural or craft business, or a salaried job. As a consequence, the working time invested in this system by the beekeeper is limited. This limitation, combined with a low capital (i.e., beekeeper does not own a vehicle specifically adapted to the transhumance and transportation of hives) and the types of apiary locations used (often inherited, with a good resource continuity all over the year but not always easily accessible by transhumance vehicles), explains the combination of transhumant and sedentary colonies in this system. Most of the transhumance incurs very short distances, to access heather heathlands or late chestnut trees, both found on Mount Lozère. Because of a high share of the colonies (50%) overwintering on Mount Lozère (Fig. 6A), spring floral resources are considered important in this system and spring honey is produced during favorable years. Overall, the honey production in this system mostly relies on Mount Lozère floral resources. It is noteworthy that this system uses apiary locations surrounded by a large number of temporary meadows.

6) Hobby beekeeping is the smallest system encountered, with only one apiary comprised of 15 colonies, located close to the beekeepers' house in a village, therefore sur-

rounded by temporary meadows that give rise to spring and "mountain flowers" honey flows.

Beyond the differences in the use of floral resources among beekeeping systems, this typology reveals that, except for the first system (transhumant professional on heather heathlands), they have a common interest in the "mountain flowers" honey flow (Fig. 6, supplementary material 1 and 3). In terms of the interactions between agropastoralism and beekeeping, both the "mountain flowers" honey flow's spatial distribution (between ca. 900 and 1300 m altitude) and its temporality (limited to June) make it of particular interest for the study. Mount Lozère areas below 1300 m altitude are indeed mainly managed by agropastoralism, and the main agropastoral practices that shape floral resources (e.g., mowing and grazing) also occur around June, resulting in particularly intense interactions between farming and beekeeping.

This honey flow is favored by:

- Diversified permanent meadows that flower in June
- Heathlands with a dominant and diversified herbaceous layer, brambles, and some melliferous trees
- Temporary meadows with melliferous species, mainly legumes such as alfalfa, clover (*Trifolium* spp.), or sainfoin (*Onobrychis viciifolia*), flowering in June
- Open undergrowth in woods with a flowering herbaceous layer and brambles

From here on in, the term "floral resources" refers to the floral resources that give rise to the "mountain flowers" honey flow. In the following section, we examine the agronomical reasons of the implementation of farming practices that are more or less favorable to these floral resources on Mount Lozère.

3.2 Impacts of agropastoral farming systems on floral resources

Farming practices that are favorable to the production of floral resources are different in rangelands, croplands, permanent meadows, and uncultivated lands. While intensive management of rangelands (with high pastoral load and mechanical control of scrub encroachment) is favorable to the maintenance of an herbaceous layer that gives rise to the mountain honey flow, intensive management of permanent meadows and croplands (high levels of synthetic or liquid manure fertilization that favors grasses over flowering species, early mowing that depletes flowers before June, shorter rotations with more cereals compared to meadows, and short-lasting temporary meadows) is unfavorable to the production of floral resources. In the long term, the replacement of permanent meadows by croplands and the abandonment of rangelands are also unfavorable for floral resources (see supplementary material 2).

A typology of the farming systems found on Mount Lozère and their significance for the production of floral resources are outlined. For each farming system, the technical-economic constraints that drive farmers' decisions in the implementation of farming practices that are more or less favorable to floral resources are then presented.

3.2.1 Agropastoral farming systems on Mount Lozère and their contributions to the production of floral resources

We identified five agropastoral farming systems (Table 1) that have distinct impacts on floral resources (supplementary material 2 and 4): suckler calf with medium-intensity croplands, suckler calf with low-intensity croplands, suckler calf with intensive use of rangelands, dairy, and organic meat and cereal.

1) Suckler calf farming system with medium-intensity croplands is the most common farming system on Mount Lozère. It is moderately favorable to the production of floral resources. It maintains large areas of rangelands at the altitudinal zone where "mountain honey" is produced, through practices such as grazing, the grinding of bushes in areas that can be managed with mechanized equipment, and the use of large pastoral burnings. It also benefits from summer pastures, which are situated at the summit of Mount Lozère. Grazing intensity is intermediate in the rangelands of the "mountain honey" production zone. They are grazed by the whole herd between May and June, with medium pastoral loads and a grazing period extending from May to October (supplementary material 5). The combination of intermediate grazing intensity, burnings, and destruction of woody shrubs results in an intermediate intensity of rangeland management that maintains a state of vegetation suited to the production of floral resources. This farming system has a relatively large area of permanent meadows, in part managed quite intensively with synthetic fertilizers, liquid manure, and early mowing. Croplands are managed intensively in this farming system in order to maintain high yields and reduce feed purchase. They are planted with non-melliferous seed mixes, thus producing few floral resources. Alfalfa is often sown but mown too early to be of benefit to beekeepers. However, this system has no access to the most intensive croplands on Mount Lozère, which are found on calcareous plateaus (intensive temporary meadows in Fig. 5B). This limits both the frequency of cereal seeding and of ploughing in the rotations.

Table 1 Characteristics of the five agropastoral farming systems of Mount Lozère. This table indicates, for each farming system, the type of herd and its size, and the area managed for each type of land use (cropland, permanent meadows, rangelands, and summer pastures). The letters indicate whether the management of croplands, permanent meadows, and rangelands is favorable to the production of floral resources (H), moderately favorable (M), or unfavorable (L). The effect of farmers' management in summer pastures is not represented, as summer pastures are out of the range of the "mountain flower" honey flow. *Livestock units are calculated for the animals that graze the rangelands in the mountain honey production zone in June. Livestock units are calculated with the following equivalences: 1 LU per dairy cow, 1.05 LU per suckler cow with calf, 0.6 and 0.8 LU per replacement heifer of more than 1 and more than 2 years, respectively, 0.2 LU per suckler ewe with lamb, and 0.07 LU per replacement ewe lamb

Farming system	Herd (number of mothers, breed, and livestock unit grazing)	Area of croplands (quality for floral resources)	Area of permanent meadows (quality for floral resources)	Area of rangelands (quality for floral resources)	Area of summer pastures
Suckler calves with medium-intensity croplands	60 Limousine cows 84 LU	20 ha (M)	30 ha (M)	120 ha (M)	60 ha
Suckler calves with low-intensity croplands	25 Aubrac cows 32 LU	10 ha (H)	20 ha (H)	100 ha (L)	30 ha
Suckler calves with intensive use of rangelands through labor	50 Aubrac cows 69 LU	0 ha (H)	25 ha (H)	75 ha (H)	75 ha
Dairy	30 Montbéliardes and 10 Aubrac cows 17 LU	35 ha (L)	20 ha (L)	75 ha (L)	0 ha
Organic meat and grain	350 blanches du massif central ewes 59 LU	80 ha (L)	30 ha (L)	100 ha (H)	0 ha

This system and its development path illustrate a recent agrarian dynamic in the study area, and one which has been marked by an increase in the material productivity of labor, made possible by an increase in land and herd size per agricultural worker. As a result, there is increased pressure on available working time in the farming systems that have followed this development path. Intensive croplands are the most productive forage systems per working time and thus have been generally favored wherever technically possible, and the share of distributed forage in the diet has risen at the cost of grazing in rangelands. The augmentation of material productivity per agricultural worker thus results in a moderately favorable management of floral resources, both in croplands, permanent meadows, and rangelands.

2) Suckler calf farming system with low-intensity croplands has followed a similar development path to the previous system, though farmers implementing this system halted investment decades ago and have also reduced herd size. They have maintained their rangeland, as this represents a major revenue source through subsidies provided by the European Union Common Agricultural Policy (CAP), and which are proportional to the area of land. This system maintains large areas of extensively used rangelands with low herd size, resulting in a lower pastoral load than in the previous system. Such rangeland management is not particularly favorable for floral resources. This low herd size also results in reduced fodder needs. Combined with the low investments in equipment for crops, it results in a high proportion of permanent meadows and quite extensive management of croplands and permanent meadows, with all meadows mown later and maintained with low use of mineral fertilizers and liquid manure. Croplands are managed with 1 to 2 years of cereals followed by 4 years of temporary meadows. The increase in age of temporary meadows is favorable to floral resources. This is because it both reduces the proportion of cereals (not melliferous) in the cultivated area and because older meadows develop a more melliferous flora. Overall, this system, with favorable cropland and meadow management and unfavorable rangeland management, is moderately favorable to floral resources.

This system illustrates two main drivers of the management of floral resources by agropastoralism on Mount Lozère. First, it shows that the limitation of production costs and investments, which limit the management intensity of both meadows and croplands, is favorable to the production of floral resources. Second, it illustrates that while providing subsidies in proportion to a farm's area, the CAP encourages farmers to manage large areas of rangelands with management methods that are not particularly favorable to the production of floral resources. In this system, this is because of a decrease in herd size.

3) Suckler calf farming system with intensive use of rangeland through manual labor is the most favorable system for the production of floral resources. The farmers

using this system settled more recently, have had few opportunities to access croplands that can be worked with machines, and so have made little investment in mowing equipment. Rangelands are more intensively managed, with an intermediary pastoral load, frequent, and long grazing periods, and labor-intensive practices involving hand-tool clearing and small pastoral burnings (supplementary material 5). Such rangelands are favorable to the production of spring and early summer floral resources, as labor-intensive practices allow the selection of spring flowering melliferous shrubs. There are no croplands, and the permanent meadows are extensively managed.

As in the previous system, the limitation of investments and production costs is favorable to the production of floral resources as it limits the management intensity of croplands and permanent meadows. In this system, the resulting limitation of distributed fodder in the diet is compensated by a high proportion of grazing through an increase in rangeland management intensity, which is favorable to the production of floral resources. This is made at the cost of important working time spent in the management of rangelands.

4) Dairy farming is a system that has expanded onto highly mechanizable croplands with increased management intensity to produce high amounts of forage. This forage is then used in combination with significant amounts of both purchased and farm concentrates to feed a dairy herd to obtain high physical productivity. A suckler herd uses forage from permanent meadows and rangelands and which would not enable the expected milk yields. This is the only system in the area that has not abandoned dairy production over the course of recent decades. It maintains a medium proportion of extensively used rangelands with low pastoral loads, coupled with the intensive management of its permanent meadows and croplands, which results in poor production of floral resources.
5) Organic meat and cereal farming with intensive use of rangelands through mechanization is a system that has also expanded into productive croplands and increased cereal production through mechanization. The production of cereal is central to increasing the value of this system's products. The cereal is sold for human consumption and used to fatten lambs, and the organic label enhances the product value. It sets up highly contrasting forage systems in terms of the production of floral resources. On the one hand, its croplands, dominated by cereals, do not produce floral resources and its permanent meadows are mown relatively early. On the other, the rangelands, mostly mechanizable, are intensively used with a high number of animals per rangeland area, and mechanical grinding is practiced, which maintains them in a state of vegetation which is of interest for the production of early summer floral resources. Of all systems within this typology, it has the highest area of croplands when compared to both rangelands and permanent meadows.

Rather than augmenting material labor productivity, this system relies on increasing its product value. This is achieved through the intensification of croplands to produce cereal, which is then either fed to animals destined for meat production, or is sold directly. This system is thus less dependent on CAP subsidies and intensively manages a small proportion of rangelands. The limited rangeland area allows a more frequent grinding of shrubs. Moreover, there is a high number of animals per rangeland area to graze (Suppl. Mat. 4). Both frequent grinding and high pastoral loads are favorable to the production of floral resources. However, this is made at the cost of croplands and meadows intensification, which are unfavorable to the production of floral resources.

3.3 Technical-economic levers and obstacles for the production of floral resources on Mount Lozère

There are two main agrarian tendencies and drivers of the production of floral resources in agropastoral landscapes. First, the augmentation of production per agricultural worker has relied both on crop and meadow intensification and on rangeland extensification, which overall leads to an unfavorable trend for the production of floral resources. Second, the CAP mechanisms encourage farmers to maintain large areas of rangelands in a moderately favorable state of vegetation for the production of floral resources. Here, rangeland is neither totally abandoned nor encroached upon. This state does not maximize the production of floral resources.

Of the five farming systems described in our typology, three overcome these limitations: the suckler calf farming system with intensive use of rangelands through manual labor, the suckler calf farming system with extensive use of meadows, and the organic meat and cereal farming system. They do so through various mechanisms, such as the increase of the economic value of crop and animal products through cropland intensification, the limitation of costs and investments with a revenue sustained by CAP subsidies proportional to the area of land, and the limitation of costs and investments thanks to important working time devoted to rangeland management. However, there are several obstacles in the way to engaging farmers to take up those alternative development paths. For example, cropland intensification is restricted by the available mechanizable land on Mount Lozère (see Fig. 5). In addition, the augmentation of working time devoted

to rangeland management and the reduction of costs and investments, both more favorable methods to contribute to floral resource production, are probably not in line with farmers' professional expectations, due to the time-consuming nature of such farming practices.

4 Discussion: using farming system research to understand and manage floral resources

Our conceptual framework, based on a farming system approach, offers new insights into floral resource management and technical-economic interactions between agropastoralism and beekeeping, and, more broadly, between agriculture and beekeeping. This can add to the existing body of knowledge gained through other approaches. For example, ecological approaches can be useful for predicting the influence of agricultural practices on floral resources (Shapira et al. 2020; Duquette et al. 2022) or on honey bee physiology (Alaux et al. 2017). Experimental approaches can contribute to the development of alternative farming practices more favorable for floral resources (Allier et al. 2017). However, these approaches, while they often propose transformations of agricultural practices, do not take into account the material conditions of farmers, beekeepers, and their farms. This makes it difficult to assess the levers and obstacles in implementing their proposals. Adopting a farming systems approach fills this gap. Thanks to our conceptual framework, we reveal the beekeepers' interests in terms of floral resources management and the diversity of interests within the range of beekeeping systems. We also identified ways to improve the production of floral resources through agropastoralism. It would therefore be of valuable use to develop and implement our conceptual framework in further case studies to guide apicultural transformations in different agricultural contexts.

4.1 Handling the diversity of beekeeping

Our approach has proved particularly pertinent in accommodating the diversity of beekeeping and floral resources. In the following paragraphs, we will discuss how the framework can be used to establish a typology of floral resources, establish their different values according to the beekeeping systems, and identify the resulting diverging interests of beekeepers in terms of the management of floral resources at the landscape scale.

4.1.1 Diversity of floral resources

Consistent with results in other contexts (Smart et al. 2021), we found that within the study area, agropastoral landscapes are characterized by a continuous provision of floral resources over the course of the beekeeping season (except for a gap in May, and with a peak in June), yet with low productivity and high uncertainty. This contrasts strongly with landscapes that provide mass-blooming floral resources over short periods coupled with longer resource gap periods, such as open-field landscapes with oleaginous crops (Requier et al. 2015; Guillerme and Maire 2018) or, to a lesser extent, the Cévennes valleys dominated by chestnut trees (Mouillard-Lample et al. 2023) and heather heathlands. Fostered by our conceptual framework, the attention paid to landscapes in relation to their uses by beekeeping allows to identify such patterns. Developing our approach in other contexts would allow for national and international comparisons which would therefore be of great use to guide apicultural transformations and adapt them to local contexts while benefitting from experiences in comparable contexts.

4.1.2 Diversity of beekeeping systems and their preferences for floral resources

Our conceptual framework also puts forth that all beekeeping systems do not have the same preferences for the different types of floral resources, and so provides a basis to explore the underlying technical-economic mechanisms. For example, professional beekeeping systems seem to focus on the reduction of uncertainties in the resources they exploit. Indeed, professional beekeeping in France has developed to adapt to mass-blooming floral resources that are predictable, abundant but short-lasting (Guillerme and Maire 2018; Dupré 2020). Our study confirmed this tendency, by showing the reduced interest of professional beekeepers for the uncertain but long-lasting "mountain" honeyflow, and their preference for the predictable Cévennes "chestnut" honey flow. Moreover, we have also revealed existing strategies to cope with the remaining uncertainties of floral resources, such as transhumance and the multiplication of the floral resources used. This exploration of reducing the uncertainty of floral resources may be explained by the fact that professional beekeepers' revenue entirely relies on the production of beekeeping products.

Our approach also offers original insights into other apicultural rationalities. This is illustrated by semi-professional beekeeping systems, whose technical-economic constraints shape an apicultural production marked by less working time and fewer investments. Long-lasting floral resources near the main site of the beekeeping operation are more

advantageous to these systems, in order for them to avoid the practice of transhumance and long travel distances that are costly and time-consuming. Uncertainty of floral resources is less important to these systems, as beekeepers mainly rely on alternative sources of income to make a living.

4.1.3 Diversity of beekeeping systems and their diverging interests for landscape management

Finally, our conceptual framework offers insights into the co-existence of various beekeeping systems in the same landscapes. Since beekeeping systems have different preferences regarding the characteristics of the floral resources they exploit, they are likely to have divergent interests in landscape management. In our study, for example, transhumant beekeeping is mainly interested in the June honey flow, produced by herbaceous landscape elements, while sedentary beekeeping needs a spring honey flow produced by ligneous species.

Beekeeping systems' diverging interests in floral resources have been observed in other studies focusing on the Cévennes (Mouillard-Lample et al. 2023), other regions of France (Dupré 2020), and in Morocco (Adam 2019). An increase in landscape-based case studies that identify the different interests of beekeeping systems, by taking into account favored or excluded beekeepers, would therefore help to guide overall apicultural transformations in any given place.

4.2 Agropastoralism for floral resources and for rural development: same drivers and shared interests?

Our research provided original insights into the way agropastoralism shapes floral resources. They show a decline in floral resources, as in intensive agriculture contexts (Carvell et al. 2006; Naug 2009; Ollerton et al. 2014; Requier et al. 2015), in part due to agricultural changes such as the intensification of meadows (mechanization and use of inputs). The decline in floral resources in rangelands is a specific feature of agropastoral landscapes and is due to their abandonment or reduced use, leading to scrub encroachment. Both dynamics are linked to labor issues and particularly to the fact that meadows have a higher material productivity per working time than rangelands (Aubron et al. 2016).

Among the five agropastoral farming systems described here, the one with intensive use of rangeland through manual labor and that seems the most favorable to the production of floral resources is precisely the system following an opposite rationale. It invests labor in an intensive use of rangelands, meadows are used extensively, there is little investment in mechanizations, and few inputs are purchased. By so doing, they show characteristics of "frugal systems" (Garambois et al. 2020), which reduce production costs by including a high proportion of grazing in the diet. In addition to being favorable to the production of floral resources, the development of such systems would also contribute to maintaining more jobs per hectare at the landscape scale and supporting landscape preservation (Morsel 2024).

However, the development of frugal systems faces obstacles such as competition with other systems or activities for the access to land or to high value-added markets (Aubron et al. 2014; Sendyka and Makovicky 2018; Garambois et al. 2020). A transition to frugal farming systems would need changes in the mechanisms of markets and public policies such as the CAP that have not been favorable for frugal farming systems over the past decades (Gautier 2017; Aubron et al. 2019; Morsel and Garambois 2022; Morsel 2024). The transition would also need to address a lack of adapted technical support and issues such as farm debt, which encourages high gross production. Finally, a farmers' will to change may be an obstacle to change, as the sociotechnical transformations needed for the transition to frugal farming systems (reduced physical production and changes in the organization of labor linked to the augmentation of pasture in the diet) may not match their professional aspirations (Lémery 2003; Coquil et al. 2017).

Broadly speaking, it seems that both the production of floral resources and frugal farming in agropastoral settings would benefit from mechanisms promoting labor-intensive practices, such as favoring grazing and small rather than large pastoral burnings in the management of rangelands. This meets a broader issue related to agroecological transitions, which is often supposed to require a reduction in material labor productivity (Mouratiadou et al. 2024). This reduction goes against the tendency of the augmentation of material labor productivity pursued in Europe since the second half of the twentieth century, which is accompanied by mechanization and increase in farm size. Reversing this tendency is often presented as necessary to the augmentation of the ecological, economic, and social (Charroin et al. 2012; Timmermann and Félix 2015; Devienne et al. 2016, pp. 90–97; Ploeg 2021) benefits of labor in agroecological farms.

4.3 Considering interactions between agriculture and beekeeping

The focus of this study was to investigate indirect interactions between farming and beekeeping through floral resources, rather than direct interactions such as pollination and pesticide use. However, they should be taken into account, especially in non-agropastoral contexts, where crop and fruit pollination and pesticide application are of greater importance. While Mount Lozère farmers currently have little interest in changing their practices to enhance

floral resource provision, this may not be the case in other agropastoral contexts. One positive example of agropastoral context where direct interactions between agriculture and beekeeping are seen as important by the actors is that of the dairy production for Tomme des Bauges cheese, in the Bauges Massif in France. Here, the floral diversity of meadows and rangeland plays a key role in the organoleptic quality of the cheese. The pollination of meadows is then perceived by livestock farmers as an important issue. This has encouraged local farmers to enroll in "flowering meadows" contests and to increased cooperation between farmers and beekeepers (De Sainte Marie and Nguyen Ba 2018). In turn, this cooperation potentially contributes to the brand image of the cheese.

5 Conclusion: a systemic approach to the interactions between agriculture and beekeeping based on floral resources

Knowledge about the floral resources that are used by beekeeping, and about the technical-economic obstacles that farmers face in implementing farming practices favorable to the provision of floral resources, is still lacking. This is especially true in agropastoral settings. With this study, we aim at filling these gaps to identify pathways to the enhancement of floral resource provision in agropastoral landscapes. We therefore presented a framework based on a farming systems approach. We have proven that this approach is effective at identifying levers and obstacles to floral resource enhancement for different types of agropastoral farming systems. It also allows for an analysis of the diverse interests and needs regarding floral resources within the beekeeping sector. Beyond the case of agropastoralism, the resulting insights complement other studies on the interactions between beekeeping and agriculture in general. By focusing on farming systems, a "macro" analysis of global factors, such as European policies and markets, and a "micro" analysis of local factors, such as specific landscapes and agrarian history, can be brought together to understand how farming practices are implemented (Aubron et al. 2016) and how their implementation impacts on floral resources.

In particular, our results show that a transition to more frugal systems, implementing labor-intensive and time-consuming practices, would certainly enhance the production of floral resources. Such alternative scenarios would, however, require key changes in the rules of agricultural markets and of the CAP, to counter the dominant structural trends of twentieth-century agricultural development towards higher material productivity of agricultural labor and decrease in the number of agricultural workers.

Beekeepers and agropastoral farmers have few levers to change the CAP and the functioning of international markets. However, even within the limits set by these, they have the possibility to improve floral resources at the landscape scale. Direct social interactions between farmers and beekeepers may be a way for these actors to identify their interdependencies and build shared representations of common interests. Such interactions may pave the way to the establishment of collective action at the landscape scale, a key lever to foster agroecological transitions (Coquil et al. 2013, communication at the 2013 *Rencontres autour de la recherche sur les ruminants*; Barnaud et al. 2018). However, more knowledge is needed about the levers and obstacles for both farmers and beekeepers to engage in these interactions, as well as their motivations to do so, in relation to their interests, knowledges, and values.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s13593-024-00985-1.

Acknowledgements The authors would like to thank Claire Cantraine for her work on Fig. 4 and Elise Bradbury and Jill Tellier for reviewing the English language. We also thank the reviewers for their valuable comments that greatly improved the quality of this work.

Authors' contributions Corresponding author: G.G.; conceptualization: G.G., M.D., A.D., L.M.L, C.A., and C.B.; investigation: G.G., E.L., and L.M.L.; data analysis: G.G.; writing original draft: G.G.; writing—review and editing: G.G., L.M.L., C.A., A.D., M.D., and C.B.; supervision: C.B.

Funding Open access funding provided by Institut National Polytechnique de Toulouse. Fundings provided by the École Normale Supérieure de Lyon for the salaries of two PhD students and by INRAE (French National Institute for the Research in Agronomy and Environment) for fieldwork.

Data availability Interview data is confidential. It will be deposited on the dedicated platform of the French Institute for Agricultural Research (INRAE) and the metadata will be made accessible. Maps were obtained by using publicly available data.

Code availability R codes used to obtain the maps will be made available on demand to the corresponding author.

Declarations

Ethics approval Not applicable.

Consent to participate All the research participants gave their informed consent to participate in this study.

Consent for publication The authors confirm that all the participants gave their informed consent to participate in the study.

Conflict of interest The authors declare no competing interests.

References

Adam A, Michon G, Alifriqui M, et al (2016) Des terroirs apicoles aux territoires mellifères? Reconfiguration des pratiques et des espaces apicoles du Sud marocain. In: Les terroirs au Sud, vers un nouveau modèle ? IRD Editions. IRD, Université Mohammed V, Marseille, pp 125–144

Adam A (2019) Faire son miel de la diversité: éléments pour une géohistoire rurale des apicultures méditerranéennes (Corse et sud-ouest du Maroc). PhD thesis, Université Paul Valéry

Alaux C, Allier F, Decourtye A et al (2017) A 'Landscape physiology' approach for assessing bee health highlights the benefits of floral landscape enrichment and semi-natural habitats. Sci Rep 7:40568. https://doi.org/10.1038/srep40568

Allier F, Alaux C, Aupinel P, et al (2017) Tester une innovation technique favorable aux abeilles mellifères par des approches participative et expérimentale – Projet InterAPI 1. Innov Agron 55:13–28. https://doi.org/10.15454/1.513774634157859E12

Aubron C, Peglion M, Nozières M-O, Boutonnet J-P (2014) Démarches qualité et pastoralisme en France. J Alp Res Rev Géographie Alp. https://doi.org/10.4000/rga.2442

Aubron C, Noël L, Lasseur J (2016) Labor as a driver of changes in herd feeding patterns: evidence from a diachronic approach in Mediterranean France and lessons for agroecology. Ecol Econ 127:68–79. https://doi.org/10.1016/j.ecolecon.2016.02.013

Aubron C, Nozières-Petit M-O (2023) Causses et Cévennes: l'agropastoralisme menacé? https://idele.fr/umt_pasto/dossiers-et-publications/detail-article?tx_atolidelecontenus_publicationdetail%5Baction%5D=showArticle&tx_atolidelecontenus_publicationdetail%5Bcontroller%5D=Detail&tx_atolidelecontenus_publicationdetail%5Bpublication%5D=19139&cHash=4461b6eaaec1e4f5712351329ff61b9f. Accessed 22 Jan 2023

Aubron C, Garambois N, Nozières-Petit M-O (2019) L'économie agropastorale revisitée - Formes et conditions de développement de systèmes agropastoraux conciliant création de richesse et d'emplois et entretien des écosystèmes. Cardère, Association Française de Pastoralisme, Montpellier

Aviron S, Berry T, Leroy D et al (2023) Wild plants in hedgerows and weeds in crop fields are important floral resources for wild flower-visiting insects, independently of the presence of intercrops. Agric Ecosyst Environ 348:108410. https://doi.org/10.1016/j.agee.2023.108410

Baden-Böhm F, Thiele J, Dauber J (2022) Response of honeybee colony size to flower strips in agricultural landscapes depends on areal proportion, spatial distribution and plant composition. Basic Appl Ecol 60:123–138. https://doi.org/10.1016/j.baae.2022.02.005

Barnaud C, Corbera E, Muradian R et al (2018) Ecosystem services, social interdependencies, and collective action: a conceptual framework. Ecol Soc 23:1–14. https://doi.org/10.5751/ES-09848-230115

Baude M, Kunin WE, Boatman ND et al (2016) Historical nectar assessment reveals the fall and rise of floral resources in Britain. Nature 530:85–88. https://doi.org/10.1038/nature16532

Binimelis R, Wickson F (2019) The troubled relationship between GMOs and beekeeping: an exploration of socioeconomic impacts in Spain and Uruguay. Agroecol Sustain Food Syst 43:546–578. https://doi.org/10.1080/21683565.2018.1514678

Blanc J (2014) La difficile «naturalisation» du causse Méjean. Logiques de participation et dynamiques d'appropriation des enjeux de gestion de la biodiversité dans le Parc national des Cévennes (France). Rev D'ethnoécologie 6. https://doi.org/10.4000/ethnoecologie.1925

Bretagnolle V, Gaba S (2015) Weeds for bees? A review. Agron Sustain Dev 35:891–909. https://doi.org/10.1007/s13593-015-0302-5

Cantelaube P, Carles M (2014) Le Registre Parcellaire Graphique: des données géographiques pour décrire la couverture du sol agricole. Cah Tech INRA Méthodes et techniques N° Spécial: GPS & SIG. https://hal.inrae.fr/hal-02639660

Carvell C, Roy DB, Smart SM et al (2006) Declines in forage availability for bumblebees at a national scale. Biol Conserv 132:481–489. https://doi.org/10.1016/j.biocon.2006.05.008

Charroin T, Veysset PP, Devienne S, et al (2012) Productivité du travail et économie en élevages d'herbivores: définition des concepts, analyse et enjeux. INRA Prod Anim 25:193. https://doi.org/10.20870/productions-animales.2012.25.2.3208

Cochet H (2012) The systeme agraire concept in francophone peasant studies. Geoforum 43:128–136. https://doi.org/10.1016/j.geoforum.2011.04.002

Coquil X, Dedieu B, Béguin P (2017) Professional transitions towards sustainable farming systems: the development of farmers' professional worlds. Work 57:325–337. https://doi.org/10.3233/WOR-172565

Coquil X, Lusson JM, Beguin P, Dedieu B (2013) Itinéraires vers des systèmes autonomes et économes en intrants: motivations, transition, apprentissages

Danner N, Molitor AM, Schiele S et al (2016) Season and landscape composition affect pollen foraging distances and habitat use of honey bees. Ecol Appl 26:1920–1929. https://doi.org/10.1890/15-1840.1

Danner N, Keller A, Härtel S, Steffan-Dewenter I (2017) Honey bee foraging ecology: season but not landscape diversity shapes the amount and diversity of collected pollen. PLoS ONE 12:e0183716. https://doi.org/10.1371/journal.pone.0183716

Darnhofer I, Gibbon D, Dedieu B (2012) Farming systems research: an approach to inquiry. In: Darnhofer I, Gibbon D, Dedieu B (eds) Farming systems research into the 21st century: the new dynamic. Springer, Netherlands, pp 3–31

De Sainte Marie C, Nguyen Ba S (2018) Des prairies fleuries: réconcilier production et conservation de la biodiversité sur les surfaces herbagères. https://doi.org/10.15454/1.5421029801614294E12

Decourtye A, Mader E, Desneux N (2010) Landscape enhancement of floral resources for honey bees in agro-ecosystems. Apidologie 41:264–277. https://doi.org/10.1051/apido/2010024

Decourtye A, Alaux C, Le Conte Y, Henry M (2019) Toward the protection of bees and pollination under global change: present and future perspectives in a challenging applied science. Curr Opin Insect Sci 35:123–131. https://doi.org/10.1016/j.cois.2019.07.008

Devienne S, Garambois N, Mischler P, et al (2016) Les exploitations d'élevage herbivore économes en intrants (ou autonomes): Quelles sont leurs caractéristiques? Comment accompagner leur développement? https://agriculture.gouv.fr/les-exploitations-delevage-herbivore-economes-en-intrants-ou-autonomes-quelles-sont-leurs. Accessed 4 Jun 2024

Dolezal AG, Clair ALS, Zhang G et al (2019) Native habitat mitigates feast–famine conditions faced by honey bees in an agricultural landscape. Proc Natl Acad Sci 116:25147–25155. https://doi.org/10.1073/pnas.1912801116

Dupré L (2020) Prendre place dans les territoires. Études Rural 28–47. https://doi.org/10.4000/etudesrurales.23448
Duquette CA, Hovick TJ, Geaumont BA et al (2022) Spatially discrete disturbance processes enhance grassland floral resources. J Appl Ecol 59:1700–1708. https://doi.org/10.1111/1365-2664.14178
Durant JL (2019) Where have all the flowers gone? Honey bee declines and exclusions from floral resources. J Rural Stud 65:161–171. https://doi.org/10.1016/j.jrurstud.2018.10.007
Fluri P, Frick R (2002) Honey bee losses during mowing of flowering fields. Bee World 83:109–118. https://doi.org/10.1080/0005772X.2002.11099550
FranceAgriMer (2023) Fiche filière apiculture. https://www.franceagrimer.fr/fam/content/download/70360/document/FICHE_FILIERE_APICULTURE_2023.pdf?version=5. Accessed 27 Feb 2023
Garambois N, Aubron C, Morsel N et al (2020) The limits of coexistence: the development of "frugal" systems in agro-pastoral regions. Rev Agric Food Environ Stud. https://doi.org/10.1007/s41130-020-00107-x
Gautier G (2017) Influence de la Politique agricole commune sur les pratiques pastorales des Causses et des Cévennes. https://enpc.hal.science/hal-01882960. Accessed 29 Dec 2023
Goulson D, Nicholls E, Botías C, Rotheray EL (2015) Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. Science 347. https://doi.org/10.1126/science.1255957
Guillerme S, Maire E (2018) L'évolution des pratiques apicoles et agricoles en zones de grandes cultures: l'exemple du Gers. In: Les abeilles, des ouvrières agricoles à protéger. Éditions France agricole, Paris
Hernandez J, Varennes Y-D, Aebi A et al (2023) Agroecological measures in meadows promote honey bee colony development and winter survival. Ecosphere 14:e4396. https://doi.org/10.1002/ecs2.4396
IGN (2017) Registre parcellaire graphique (RPG): contours des parcelles et îlots culturaux et leur groupe de cultures majoritaire. http://data.europa.eu/88u/dataset/58d8d8a0c751df17537c66be. Accessed 8 Jun 2023
IGN (2023) BD TOPO® | Géoservices. https://geoservices.ign.fr/bdtopo. Accessed 8 Jun 2023
Ison R (2012) Systems practice: making the systems in farming systems research effective. In: Darnhofer I, Gibbon D, Dedieu B (eds) Farming systems research into the 21st century: the new dynamic. Springer, Netherlands, pp 141–157
Kouchner C, Ferrus C, Blanchard S et al (2019) Bee farming system sustainability: an assessment framework in metropolitan France. Agric Syst 176:102653. https://doi.org/10.1016/j.agsy.2019.102653
Kouchner C (2019) Impact des stratégies de renouvellement du cheptel sur la durabilité des exploitations apicoles
Lacoste M, Lawes R, Ducourtieux O, Flower K (2018) Assessing regional farming system diversity using a mixed methods typology: the value of comparative agriculture tested in broadacre Australia. Geoforum 90:183–205. https://doi.org/10.1016/j.geoforum.2018.01.017
Langlois A, Jacquemart A-L, Piqueray J (2020) Contribution of extensive farming practices to the supply of floral resources for pollinators. Insects 11:818. https://doi.org/10.3390/insects11110818
Lehébel-Péron A, Travier D, Renaux A et al (2016) De la ruche-tronc à la ruche à cadres : ethnoécologie historique de l'apiculture en Cévennes. Rev D'ethnoécologie. https://doi.org/10.4000/ethnoecologie.2531
Lehébel-Péron A (2012a) Are official statistics on beekeeping reliable in France? The Mount-Lozère massif as an example
Lehébel-Péron A (2012b) Activité apicole du massif du Mont Lozère: état des connaissances. Centre d'Ecologie Fonctionnelle et Evolutive
Lehébel-Péron A (2014) L'abeille noire et la ruche-tronc: approche pluridisciplinaire de l'apiculture traditionnelle cévenole: histoire, diversité et enjeux conservatoires. These de doctorat, Montpellier 2
Lémery B (2003) Les agriculteurs dans la fabrique d'une nouvelle agriculture. Sociol Trav 45:9–25. https://doi.org/10.4000/sdt.30813
Lepart J, Bonnel C, Lhuillier C, Marty P (2016) Conservation de la nature et dynamiques agricoles dans le territoire d'un Parc National: difficile convergence. https://doi.org/10.4000/dynenviron.1165
Malkamäki A, Toppinen A, Kanninen M (2016) Impacts of land use and land use changes on the resilience of beekeeping in Uruguay. For Policy Econ 70:113–123. https://doi.org/10.1016/j.forpol.2016.06.002
MASA (2024) Agreste, la statistique agricole. In: Agreste. https://agreste.agriculture.gouv.fr/agreste-web/. Accessed 23 May 2024
Moreau C, Barnaud C, Mathevet R (2019) Conciliate agriculture with landscape and biodiversity conservation: a role-playing game to explore trade-offs among ecosystem services through social learning. Sustainability 11
Morsel N, Garambois N (2022) Agroecology in the Limousin Mountains: relocating and diversifying food production to encourage employment and conserve semi-natural spaces. J Alp Res Rev Géographie Alp. https://doi.org/10.4000/rga.10633
Morsel N (2024) Les systèmes agro-pastoraux économes: élevage et agro-écologie en régions de moyenne montagne et de piémont méditerranéen. These de doctorat, université Paris-Saclay
Mouillard-Lample L, Gonella G, Decourtye A et al (2023) Competition between wild and honey bees: floral resources as a common good providing multiple ecosystem services. Ecosyst Serv 62:101538. https://doi.org/10.1016/j.ecoser.2023.101538
Mouratiadou I, Wezel A, Kamilia K et al (2024) The socio-economic performance of agroecology. A review. Agron Sustain Dev 44:19. https://doi.org/10.1007/s13593-024-00945-9
Naug D (2009) Nutritional stress due to habitat loss may explain recent honeybee colony collapses. Biol Conserv 142:2369–2372. https://doi.org/10.1016/j.biocon.2009.04.007
Nichols RN, Wood TJ, Holland JM, Goulson D (2022) Role of management in the long-term provision of floral resources on farmland. Agric Ecosyst Environ 335:108004. https://doi.org/10.1016/j.agee.2022.108004
Ollerton J, Erenler H, Edwards M, Crockett R (2014) Extinctions of aculeate pollinators in Britain and the role of large-scale agricultural changes. Science 346:1360–1362. https://doi.org/10.1126/science.1257259
Oteros-Rozas E, Martin-Lopez B, Lopez CA et al (2013) Envisioning the future of transhumant pastoralism through participatory scenario planning: a case study in Spain. Rangel J 35:251–272
Otto CRV, Roth CL, Carlson BL, Smart MD (2016) Land-use change reduces habitat suitability for supporting managed honey bee colonies in the Northern Great Plains. Proc Natl Acad Sci 113:10430–10435. https://doi.org/10.1073/pnas.1603481113
Potts SG, Biesmeijer JC, Kremen C et al (2010) Global pollinator declines: trends, impacts and drivers. Trends Ecol Evol 25:345–353. https://doi.org/10.1016/j.tree.2010.01.007
Reboul C (1976) Mode de production et systèmes de culture et d'élevage. Économie Rurale 112:55–65. https://doi.org/10.3406/ecoru.1976.2413
Requier F, Leonhardt SD (2020) Beyond flowers: including non-floral resources in bee conservation schemes. J Insect Conserv 24:5–16. https://doi.org/10.1007/s10841-019-00206-1
Requier F, Odoux J-F, Tamic T et al (2015) Honey bee diet in intensive farmland habitats reveals an unexpectedly high flower richness and a major role of weeds. Ecol Appl 25:881–890. https://doi.org/10.1890/14-1011.1

Richner N, Holderegger R, Linder HP, Walter T (2015) Reviewing change in the arable flora of Europe: a meta-analysis. Weed Res 55:1–13. https://doi.org/10.1111/wre.12123

Rieutort L (2006) Transhumance et gestion des territoires montagnards: l'exemple des hautes terres lozériennes. In: Transhumance et estivage en Occident: Des origines aux enjeux actuels. Presses universitaires du Midi, p 367

Rivers-Moore J, Andrieu E, Vialatte A, Ouin A (2020) Wooded semi-natural habitats complement permanent grasslands in supporting wild bee diversity in agricultural landscapes. Insects 11:812. https://doi.org/10.3390/insects11110812

Sébillotte M (1974) Agronomie et agriculture : essai d'analyse des tâches de l'agronome. Cah ORSTOM 24:3–25

Sébillotte M (1978) Itinéraires techniques et évolution de la pensée agronomique. CR Acad Agric 64:906–914

Sendyka P, Makovicky N (2018) Transhumant pastoralism in Poland: contemporary challenges. Pastoralism 8:1–14. https://doi.org/10.1186/s13570-017-0112-2

Shapira T, Henkin Z, Dag A, Mandelik Y (2020) Rangeland sharing by cattle and bees: moderate grazing does not impair bee communities and resource availability. Ecol Appl 30:e02066. https://doi.org/10.1002/eap.2066

Simanonok MP, Otto CRV, Smart MD (2020) Do the quality and quantity of honey bee-collected pollen vary across an agricultural land-use gradient? Environ Entomol 49:189–196. https://doi.org/10.1093/ee/nvz139

Smart AH, Otto CRV, Gallant AL, Simanonok MP (2021) Landscape characterization of floral resources for pollinators in the Prairie Pothole Region of the United States. Biodivers Conserv. https://doi.org/10.1007/s10531-021-02177-9

Smart MD, Otto CRV, Lundgren JG (2019) Nutritional status of honey bee (Apis mellifera L.) workers across an agricultural land-use gradient. Sci Rep 9:16252. https://doi.org/10.1038/s41598-019-52485-y

St. Clair AL, Zhang G, Dolezal AG, et al (2020) Diversified farming in a monoculture landscape: effects on honey bee health and wild bee communities. Environ Entomol 49:753–764.https://doi.org/10.1093/ee/nvaa031

Timberlake TP, Vaughan IP, Memmott J (2019) Phenology of farmland floral resources reveals seasonal gaps in nectar availability for bumblebees. J Appl Ecol 56:1585–1596. https://doi.org/10.1111/1365-2664.13403

Timmermann C, Félix GF (2015) Agroecology as a vehicle for contributive justice. Agric Hum Values 32:523–538. https://doi.org/10.1007/s10460-014-9581-8

van der Ploeg JD (2021) The political economy of agroecology. J Peasant Stud. https://doi.org/10.1080/03066150.2020.1725489