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Understanding the rationale and advantages of a traditional Mediterranean intercropping system in the nineteenth century

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Abstract

Traditional agricultural systems in Mediterranean Europe were characterised by diversity and multifunctionality, and polycultures played a fundamental role in them. Some of these farm systems and the traditional agricultural practices linked to them have now largely disappeared, but they are increasingly recognised as a valuable source of agroecological knowledge. In this study, we seek to recover the long-lost experience from a traditional Mediterranean intercropping system that combined the cultivation of vines and cereals. Using local historical resources available for a Catalan village for the second half of the nineteenth century, we compare the characteristics and functioning of intercropping and monocultures of vines and cereals using socioeconomic and agrarian metabolism indicators, and discuss the advantages of the traditional intercropping system as an adaptation to the productive limitations of the agroecosystem (particularly in terms of soil quality and productivity, and availability of labour and draft force), but also as a peasant economy strategy that responded to a multifunctional balancing rationale. This way, this research contributes to recovering the knowledge and experience of a long-lasting traditional crop system that had been used until the second half of the twentieth century, and provides an understanding of the rationale and advantages of traditional Mediterranean crop systems beyond productivity and profit maximisation strategies.

Keywords Intercropping · Agroecology · Traditional agricultural systems · Peasant economy · LER · Mediterranean

Abbreviations

AFEROI	Agroecological final EROI
BR	Biomass reused
EFEROI	External final EROI
EI	External inputs
EROI	Energy return on investment
FEROI	Final EROI
FP	Final produce
IER	Income equivalent ratio
IFEROI	Internal final EROI
L-FEROI	Final EROI on labour
LER	Land equivalent ratio
NPPact	Actual net primary productivity
NPPEROI	Net primary productivity EROI
RY	Relative yield
TP	Total produce
UhP	Unharvested phytomass

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Introduction

Agricultural landscapes have been shaped by a long history of interaction between humans and ecosystems. In Mediterranean Europe, this co-evolution process gave rise, particularly from the fifteenth century, to what are now considered traditional agricultural landscapes, characterised by a mosaic of diverse land uses in which mixed farm systems and polycultures played a fundamental role (Barbera and Cullotta 2016; Blondel 2006; Pinto-Correia and Vos 2004). These landscapes reached their peak in the second half of the nineteenth century but have now largely disappeared due to the spread of industrial agricultural systems throughout the twentieth century (Vos and Meekes 1999). However, the interest to recover and preserve traditional landscapes, and the agricultural practices and knowledge linked to them, is

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growing nowadays as they are deemed a useful reservoir of practices to enhance sustainability and resilience in the current context of global environmental crisis (Altieri 2004; Barthel et al. 2013; Eichhorn et al. 2006; Kremenet al. 2012; Zimmerer et al. 2022).

Traditional agricultural polycultures have been largely studied in Latin America and other tropical regions (Brooker et al. 2014; Himmelstein et al. 2017; Jodha 1980; Koohafkan and Altieri 2011; Liebman 2018; Perfecto and Vandermeer 2010; Winkel et al. 2020), but the study of these crops systems in Europe has grown in the last decades (Agnoletti and Emanueli 2016; Eichhorn et al. 2006; Moreno et al. 2018; Nerlich et al. 2013; Rigueiro-Rodríguez et al. 2008). In Mediterranean Europe, the *coltura promiscua* in Italy (which combined tree crops with grains usually in terraced lands) (Barbera and Cullotta 2012; Paris et al. 2019), and the *montados* and *dehesas* in Portugal and Spain (a savannah-like system that integrated usually cork and holm oaks together with livestock, and periodically cultivated cereals) (Blondel 2006; Joffre et al. 1999; Olea and San Miguel-Ayanz 2006) are well-known examples of traditional agroecosystems that have persisted until today. However, beyond these living reservoirs, historical records can be used to gain access to other traditional crop systems that have now vanished. The study of these disappeared agricultural practices can bring back some of the knowledge embedded in these agroecosystems, and provide relevant insights on the advantages of traditional agricultural practices (Krčmářová and Arnold 2016; Pleasant and Burt 2010).

Generally, traditional Mediterranean polycultures included diverse combinations of woody crops (typically olives, vines, and other fruit trees, as well as more vigorous trees such as oaks), grown together with grains and combined with livestock pasturing and browsing. One of these traditional agricultural systems is the intercropping of vines and cereals, which could be found in diverse Mediterranean agroecosystems in Spain, France, and Italy -where it had a long history connected with the *coltura promiscua* (Federico and Martinelli 2018; Sereni 1997). In Spain, historical records provide evidence of diverse variations of this intercropping system (including olives, almond trees as well as different annual crops) being found throughout the nineteenth century and well into the second half of the twentieth century, when it co-existed with the initial introduction of industrial agricultural inputs and machinery (Federico and Martinelli 2018; Infante-Amate et al. 2016; Junta Consultiva Autonómica 1889; Pastor 2016). Although this crop system vanished from agricultural landscapes by the end of the twentieth century, historical studies have indicated the importance of this crop system for maintaining the complexity, multifunctionality and long-term sustainability of traditional agroecosystems in Catalonia (Díez et al. 2018; Gardeñes i Rosell and Vicedo i Rius 1993; Tello 1995). However, little is known about the advantages of the intercropping pattern that could explain why this particular crop distribution was implemented and maintained throughout time (Federico and Martinelli Lasheras 2020).

Understanding the rationale of traditional intercropping systems

Traditional polycultures and intercropping systems are deemed beneficial for multiple reasons (Brooker et al. 2014; Gliessman 1985; Innis 1997). From a socioeconomic perspective, polycultures were a fundamental element for multifunctionality in traditional agricultural management. Diversified cropland produce contributed to meet the various needs of the farm and the farming community: products and by-products could be commercialised, used to satisfy the food, fuel and other material needs of the household, as well as provide animal feed and resources for cropland fertilisation. Furthermore, polycultures allowed farmers to reduce risks and make better use of limited resources, such as land and labour. The combination of crops with varying resilience to adverse climate events and diseases could provide some relief against the failure of one crop, and mixing different crops in the same plot was also a useful strategy for a more intensive use of cropland that could increase the production obtained per unit of land cultivated (Martin-Guay et al. 2018). Additionally, labour seasonality was reduced by combining crops with different growing calendars, enabling a better adjustment of the yearly agricultural tasks to the labour force available in the farming household or community (Krčmářová and Arnold 2016; Plieninger et al. 2006).

From an agroecological perspective focused on ecological processes, polycultures favoured a better use of nutrients and water cycles when the crops grown together had different root systems and growing calendars, as each crop would make use of nutrients and water resources in different soil niches and at different times of the year. Moreover, thanks to facilitation processes between the crops, their mixed cultivation could create better environmental conditions for their growing (Vandermeer 1992, 2009); for instance, this could occur when the combination of crops increased associated biodiversity, favouring pollination and pest control by attracting or repelling some insects. Additionally, and especially in Mediterranean agroecosystems, facilitation processes occurred when the cultivation of woody crops contributed to stabilize terraced lands and favoured the growth of the associated crop providing climatic protection against wind or frost (Altieri and Nicholls 2002; Malézieux et al. 2009; Tamburini et al. 2020; Zuazo et al. 2009).

Ultimately, the socioeconomic and agroecological advantages of diversified crop systems are closely connected, mainly because agroecological advantages enabled socioeconomic benefits in terms of increased production, risks protection, and optimised use of resources. However, there is a significant difference among these types of advantages: while the agroecological advantages of intercropping and polycultures stem from ecological processes facilitated by the interaction of different crops in the same field, most socioeconomic advantages do not require that the different crops are grown following an intercropped or mixed cultivation pattern and similar benefits could result from the cultivation of the same crops in different separated plots. In this respect, the only specific socioeconomic advantage of polycultures and intercropping would be an increased cropland productivity ensued from facilitation and reduced competition processes among the crops. While analyses of the productivity of traditional polycultures show that intercropping and mixed crop systems tend to have greater biomass productivity than the respective monocultures (Brooker et al. 2014; Martin-Guay et al. 2018; Vandermeer 1992), detailed analyses that further explore possible socioeconomic advantages of these crop systems are scarce (Infante-Amate et al. 2016; Krčmářová and Arnold 2016; Pleasant and Burt 2010).

Thus, our study seeks to explore the advantages and rationale of the traditional intercropping of vines and cereals with a double purpose. On the one hand, by analysing a long-lasting but now lost crop system, we aim to recover the agricultural knowledge embedded in this crop system and contribute to enlarge the repertoire of Mediterranean traditional agricultural practices beyond those still-living and well-known examples. On the other hand, we want to examine specific advantages of the intercropping pattern that help explain why this crop system was used, with diverse crop variations, throughout different times and places. To further explore potential advantages and understand the intercropping system beyond conventional indicators and approaches, we use an agroecological analytical framework built on agrarian metabolism and peasant economy approaches, as explained below. Then, the rest of the paper is structured as follows: after introducing the historical context of our case study, and explaining the use of sources and the methodology applied in our analysis, we present the results obtained for the socioeconomic and biophysical indicators that compare the intercropping system with the respective monocultures. We then discuss the advantages of intercropping corresponding to these results and in accordance with a peasant economy rationale. Finally, after providing some insights about the relevance beyond our specific case study, we conclude by highlighting the contribution of our analysis for understanding the advantages and rationale of Mediterranean traditional crop systems.

Traditional agricultural systems, peasant economy, and agrarian metabolism

The use of polycultures and intercropping systems in the management of traditional agricultural systems was linked to the pursuit of a sustained production and long-term welfare of the farming community, diminishing risks and losses, and optimising the use of the available local resources (Krčmářová and Arnold 2016; Pinto-Correia and Vos 2004; Plieninger et al. 2006). This management strategy differs from that of industrialised farm systems mainly based on profit maximization, market incentives, use of external inputs, and productive specialisation, for which monocultures are more advantageous. Thus, as peasant studies have long argued, conventional notions of efficiency and productive rationality based on capitalist industrial criteria are not adequate to understand these forms of agricultural production (Chayanov 1986a; Shanin 1972). Peasant economy approaches advance an alternative economic framework better adapted to understand the rationale of peasant agricultural systems, and well suited for our analysis of a traditional polyculture in a context in which agriculture was not yet industrialised, and market integration was limited (although expanding).

Given the heterogeneous and dynamic character of peasantries and peasant societies, there has been a long debate among social scientists to define what is peasant (Edelman 2013). Some authors have suggested to understand peasantry as a "process" (Shanin 1973, p. 64) or a gradient, in which the definition of a peasant mode of production works as an analytical category that integrates some fundamental characteristics used to distinguish diverse middle points between peasant and capitalist modes of agricultural production (Toledo 1995; Van der Ploeg 2009). According to the peasant economy framework, peasant agriculture is aimed primarily at the autonomy, self-subsistence and reproduction of the family farm, with limited market integration, and diversity and multifunctionality as key elements of their productive strategy (Wolf 1966; Shanin 1973; Chayanov 1986b; Van der Ploeg 2009, 2013). The centre of the peasant economy is the household, which constitutes a unit of both production and consumption and is mainly managed with family labour (Chayanov 1986b; Wolf 1966, pp. 12–15). This core characteristic entails that, although peasant farms exist within larger capitalist economies and contexts to which they are connected, the organisation of their productive process is not subject to the same economic principles (Chayanov 1986b; Friedmann 2019; Shanin 1973). Peasant production is determined by an artful adjustment of diverse interconnected balances (Chayanov 1986b; Van der Ploeg 2013). As originally advanced by Chayanov, the consumption needs and the labour availability of the household must be balanced considering that there is a minimum volume of production required to meet the fundamental needs of the family, and a maximum level of production achievable considering the labour force of the family (Chayanov 1986b, p. 53). In connection with this labour-consumption balance, the peasant farm decides its labour investment levelling the utility and drudgery involved in the work processes, so that once the farming household has achieved a satisfactory volume of production, the incentive to increase its labour investment decreases (Chayanov 1986b, p. 87; Van der Ploeg 2013, p. 2). In addition to these fundamental chayanovian balances, Van der Ploeg (2013) introduced more recently an expanded array of balances that further connect peasant economy with agroecology approaches (McCune et al. 2019). Understanding agriculture as a process of co-production in which both people and living nature are continuously being produced and transformed, one of the expanded balances integrates the need to satisfy human needs and the need to produce and reproduce the natural resources and services from which agriculture depends. This human-living nature balance entails a relation of reciprocity and continued mutual transformation that highlights the dynamic character of agricultural production (Van der Ploeg 2013, pp. 48–54). Additionally, the production-reproduction balance focuses on the levelling of the extraction of resources and the need to sustain the productive capacity of all the elements involved in agricultural production (Van der Ploeg 2013, pp. 54–56); meanwhile, the balance between internal and external resources contrasts the recycling of internal resources and the resort to external inputs and outputs in the functioning of the farm, also in connection with the production and reproduction processes (Van der Ploeg 2013, pp. 56–60).

Peasant studies and agroecology have been closely connected since its origins, linked to agrarian movements that opposed and resisted the processes of agricultural industrialisation and capitalist modernisation (Giraldo and Rosset 2018; González de Molina and Guzmán 2017; Sevilla Guzmán and Woodgate 2013). Their connection has grown recently as traditional agricultural systems and peasant agriculture gained attention in the search for more sustainable ways of food production (Bernstein et al. 2018; Friedmann 2019; Van der Ploeg 2009). Furthermore, the balancing rationale of peasant agriculture can be connected with recent agroecological approaches that focus on the biophysical analysis of agricultural systems from a historical perspective, studying the flows of energy and materials that shape the functioning of agroecosystems, i.e. the social metabolism of agriculture or agrarian metabolism.

Agrarian metabolism analyses are built on an understanding of agroecosystems which considers, firstly, that agricultural management involves flows of energy and materials that are introduced and extracted, as well as recycled and maintained within the agroecosystem. Secondly, it considers agriculture as a process of production and re-production in which the productive capacity of agricultural resources such as soils, livestock, as well we the farming community, needs to be maintained. Thirdly, agrarian metabolism acknowledges that the functioning of agroecosystems depends not only on those flows of energy and materials managed by humans, but also on ecological processes and services that are not directly managed by farmers (Guzmán and González de Molina 2015; Tello et al. 2016; Tello and González de Molina 2023). Consequently, agrarian metabolism analyses distinguish diverse flows of energy and materials that shape the functioning of agroecosystems, and use a set of interrelated Energy Return on Investment ratios (EROIs) to analyse the energy efficiency of agroecosystems considering their capacity to satisfy human needs, the use of internal and external resources, and their capacity to maintain associated biodiversity. The application of this methodology to the historical analysis of diverse agroecosystems in Spain has shown the importance of an integrated land and livestock management (Marco et al. 2018), multifunctionality (Infante-Amate et al. 2016), as well as crop and landscape diversity (Marull et al. 2015, 2016; Fullana Llinas et al. 2021) for the sustainability of traditional agricultural systems. Furthermore, agrarian metabolism analyses of Spanish agroecosystems from a historical perspective have shown sharp differences in the biophysical functioning of traditional and industrialised agricultural systems, mainly derived from the dependence on local resources, and the agricultural diversity and internal loops of the former in contrast with the high specialisation and reliance on external inputs of the latter -which ultimately led to important social and environmental problems (Díez et al. 2018; González de Molina et al. 2020; Marco et al. 2018).

The analytical frameworks of agrarian metabolism and peasant economy share a common understanding of the functioning and management of agroecosystems that is useful for the analysis of traditional agricultural practices, such as the intercropping of vines and cereals. Both approaches acknowledge that agriculture involves co-production processes in which both humans and nature play a fundamental role, and require reproduction processes to maintain the productive capacity of the agroecosystem. Furthermore, peasant economy and agrarian metabolism share an understanding of agroecological management as a complex and dynamic process, in which different dimensions, sometimes opposed, are intertwined and need to be balanced. Finally, as integrated in agroecology, agrarian metabolism and peasant economy offer an alternative perspective on the functioning of agricultural systems that highlights the relevance of dimensions beyond conventional economic and monetary categories,

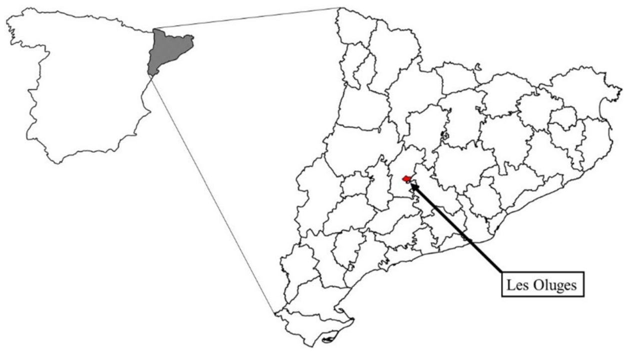

Fig. 1 Map showing the location of Les Oluges, Catalonia, Spain

providing space for a new understanding of the potential advantages and rationale of traditional agricultural practices.

The agroecosystem of Les Oluges in the nineteenth century

Les Oluges is located in La Segarra County (Lleida province), in the inner part of Catalonia (Spain) (Fig. 1). The climate of this area is Dry Mediterranean Continental, with low average annual rainfall (below 500 mm), a period of water stress that runs from April to October (Garrabou and Naredo 1999), cold and foggy winters, hot and dry summers, and frequent adverse climate events that jeopardize harvests. Thus, traditional agricultural practices in Les Oluges were adapted to low cropland productivity and high climate variability and risks.

Traditionally, agriculture in Les Oluges has focused on cereals production. Vine and olive cultivation expanded in some regions of Catalonia throughout the seventeenth and eighteenth centuries driven by the favourable prices over cereals and the increase of exports over the Atlantic (Badia-Miró and Tello 2014). However, the cultivation of cereals prevailed in La Segarra until the nineteenth century, when the progressive expansion of vineyards started mainly making use of sloped and deforested lands, as well as poor soils that were less suitable for cereals cultivation (Gardeñes i Rosell and Vicedo i Rius 1993). The spread of vine cultivation peaked in the second half of the nineteenth century, driven by the vineyard boom caused by the *phylloxera* plague that began in France in 1863, but also favoured by the development of railway connections between Lleida and Barcelona from 1856 (Badia-Miró et al. 2010). The *phylloxera* plague destroyed French vineyards, leading to a shortfall of French production and exports that increased wine prices. Catalan farmers, mostly in the coastal territories but also in the inner Catalonia, took advantage of these favourable market conditions by expanding their own wine production. In La Segarra, the largest agricultural and vineyard surfaces were achieved in the last third of the nineteenth century by means of a remarkable transformation of woodland into cropland. However, the vineyard expansion halted by the end of the century. In 1894, the *phylloxera* plague that had continued spreading over Europe reached La Segarra, destroying most of the vines and bringing an end to the vineyard boom (Gardeñes i Rosell and Vicedo i Rius 1993).

The spread of vine cultivation in La Segarra occurred in a context of relatively high population density that facilitated the fulfilment of the higher labour demands of viticulture compared with cereals. In 1870, Les Oluges had 42 inhabitants/km^2 (795 inhabitants in total), a quite optimal population density for viticulture (Badia-Miró and Tello 2014; Díez et al. 2018). Rural population peaked in the mid-nineteenth century and started to decrease afterwards due to the increased urbanisation and industrialisation (Vilá and Vernet 1971). The turn-of-the-century agricultural crisis caused by the *phylloxera* intensified the process of rural depopulation, which continued throughout the twentieth century (Díez et al. 2018).

Vine expansion throughout the nineteenth century did not entail a decrease in cereals cultivation in La Segarra, on the contrary, cereal farming also increased in response to the higher need of grains that a growing population and urban demand entailed. Cereal monocultures were cultivated in soils of better quality, but grains were also intercropped with vines in those soils of lesser quality. The intercropping of vines with cereals and olive trees could be found in La Segarra before the nineteenth century, but the spread of vineyards increased the prevalence of this cultivation pattern (Gardeñes i Rosell and Vicedo i Rius 1993). The intercropping system exemplifies the *motto* with which traditional agricultural practices in this area have been characterised: *a little bit of everything, and as much grain as possible* (Badia-Miró et al. 2010; Vilar 1987). Low cropland productivity constrained agricultural possibilities; the limited agricultural production obtained was mostly aimed to self-consumption, and the small surplus was sold in local and regional markets of the inner part of Catalonia (Gardeñes i Rosell and Vicedo i Rius 1993). Cereals were essential for the sustenance of the family and the draft force; wine was also aimed to self-consumption, but the spread of vineyards in La Segarra was driven by an increased market orientation (Garrabou and Pujol 1987). Although vine cultivation shrunk in Les Oluges after the *phylloxera* crisis, the intercropping system was not abandoned. Intercropping was maintained until the mid-twentieth century introducing a greater variety of crop combinations that included vines, olives and almond trees together with cereals (Fig. 2), and only after the spread of agricultural mechanization from the 1960s onwards, intercropping started to vanish. By the end of the twentieth century, the agricultural landscape of Les

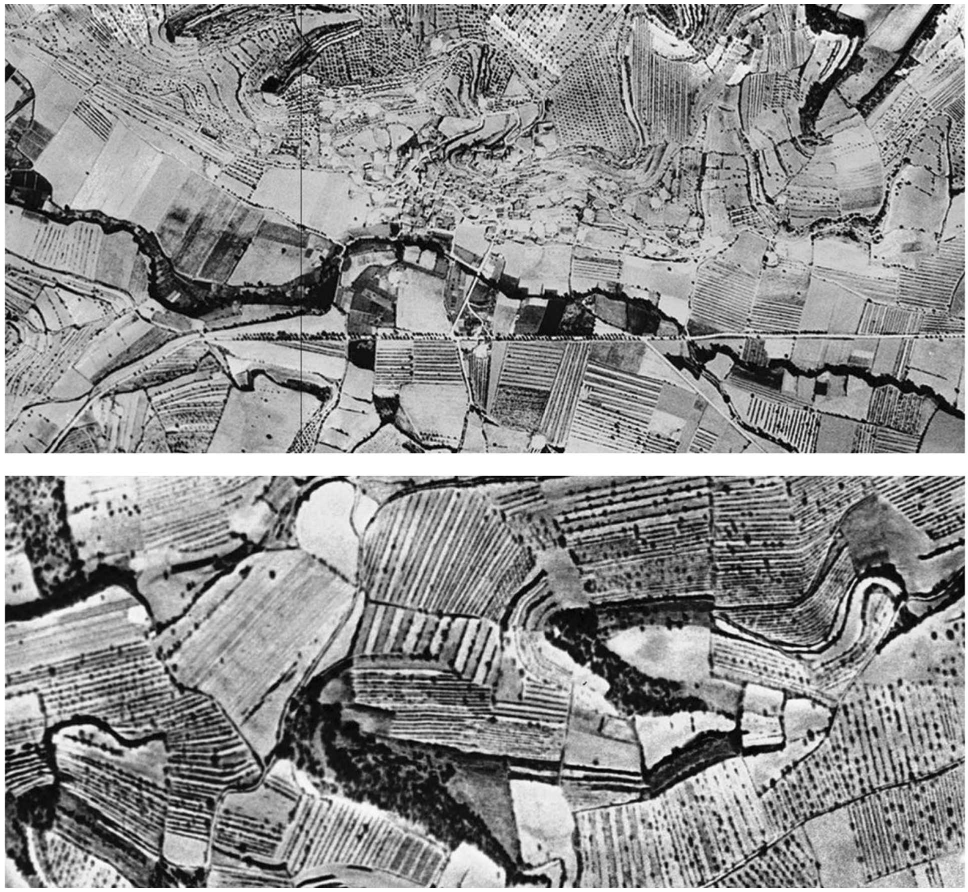

Fig. 2 Aerial pictures of Les Oluges in 1956 showing a general overview of the urban area of the village and its surrounding cropland (top image) and a detailed view of the intercropping system (bottom image). Orthophotos of Catalonia in 1956–1957 from the Institut Cartogràfic i Geològic de Catalunya (ICGC), under licence CC BY-NC-SA 4.0

Oluges was dominated by cereals monocultures (Díez et al. 2018).

From the twelfth and thirteenth centuries, the settlement pattern in this region was characterized by the prevalence of small villages, and medium and small peasant properties (Vilá and Vernet 1971). In the nineteenth century, land property in La Segarra was mainly owned by small and medium landowners, with inequalities revolving mostly around access to best quality soils rather than the amount of land owned. Most farmers cultivated their own land, but smaller landowners usually combined the work in their own properties with work as tenant farmers and sharecroppers (Garrabou et al. 2014). Generally, agricultural work was carried out with family labour, including women and children. Women's agricultural work was fundamental for the reproduction of the farming household. In addition to household chores, and care of vegetable gardens and domestic livestock, some agricultural tasks were traditionally considered female work, such as weeding, and grape and olive harvest. Female agricultural tasks were considered less arduous and were paid at half the salary of a man; however, women collaborated also with other more demanding activities when needed, such as cereals harvest and fertilizing tasks (Vicedo i Rius 2002). Additionally, low cropland productivity and the small size of peasant properties hindered the economic and social reproduction of farming households in Les Oluges; thus, collaboration among farmers was widespread, either by the exchange of animal force for human-working days, joining the draft force owned by different farmers for specific tasks, or exchanging working days among farmers (Vicedo i Rius 1993, 2002). Sharecropping and casual wage work in agriculture and other economic activities were also relevant sources of additional income (Garrabou et al. 2014).

Traditional agricultural management in Les Oluges was adapted to the socioeconomic context and environmental constraints that limited agricultural productivity. Multifunctionality and integrated management of farmland sustained the productive capacity of the agroecosystem. Woodland was a key resource in the nineteenth century used for multiple purposes (Díez et al. 2018). Firstly, deforested soils enabled agricultural expansion and the spread of vine cultivation. Secondly, scrubland and woodland were used for livestock grazing, providing important supplementary feed given the low cropland productivity. Furthermore, biomass from woodland was used for *formiguers*, a traditional fertilization technique that consisted on heaps of shrubs and small tree branches under a soil cover which were built and burned in cropland and then buried for fertilization (Olarieta et al.

2011). Last but not least, woodland provided fuel for domestic use and food from hunting and gathering. Livestock was also an important element in the integrated management of farmland; by pasturing and grazing in the different land uses, nutrients from woodland, pastureland, and cereal monocultures were recycled and reintroduced in cropland as manure (Díez et al. 2019). Barnyard animals consisted mainly on sheep and swine, together with small domestic livestock. In addition, the most abundant draft animals in Les Oluges were donkeys, followed by mules, and few oxen and horses (Díez et al. 2018). The relatively limited number of strongest draft animals and the abundance of donkeys (less powerful, but also less-demanding animals) indicates the adaptation to the limited productivity of farmland, and explains the need for collaboration between farmers for carrying out those more demanding tasks in terms of draft force (Vicedo i Rius 1993).

Traditional agricultural practices persisted by the mid-twentieth century in Les Oluges, when agricultural management combined traditional and industrial practices. While intercropping and animal draft force were still widely used, fossil-fuelled machinery as well as industrial fertilisers and biocides started to be introduced, reducing the use of woodland and biomass recycling for maintaining the productive capacity of the agroecosystem. However, by the end of the last century, agricultural management was completely industrialised, with an intensive use of industrial inputs and abandoning the integrated management of farmland (Díez et al. 2018).

Sources and methodology

The main historical record used for this research is the *Cartilla Evaluatoria* of Les Oluges of 1883 (Junta Municipal de Amillaramientos 1883), a local agricultural survey that accounts for the produce and costs of each crop system. Additionally, we estimated the distribution of land uses in Les Oluges using the *Amillaramiento* (the municipal land-use register) of 1860, and obtained the information about the draft force composition from the cattle census of 1865. Despite the different years of the historical records, their combination provides a reasonable approximation to the functioning of the agroecosystem in the second half of the nineteenth century. Our analysis is largely based on the description of the crop management practices provided in the *Cartilla*, made during the vineyard boom driven by the *phylloxera* crisis. Given the context of vineyard boom, a larger surface cultivated with vines at the expense of woodland could be expected in the 1880s compared to 1860, but the management practices registered in 1883 can be considered relatively stable throughout these decades. Additionally, the spread of vines cultivation and agricultural surface in the last decades of the nineteenth century would have increased draft force requirements; however, given the small changes in population density and the large prevalence of donkeys (the cattle census includes 146 donkeys, 56 mules, 18 oxen and 2 horses), a similar draft force composition can be assumed throughout those decades.

The *Cartilla* and the *Amillaramiento* were created by the municipal authorities to gather information for levying taxes. For the *Amillaramiento*, each landowner had to declare their owned land; thus, some concealment of information can be expected. In the *Amillaramiento* of Les Oluges, the total surface registered was lower than the real area of the municipality (with 345 hectares missing, 18% of the total farmland). Previous studies indicate that, in Catalonia, the concealed area was usually woodland, although concealment of cropland area was not rare (Pro Ruiz 1995). Another form of concealment expected in the *Amillaramiento* is an over-abundance of lower quality soils, since landowners would tend to declare having lands of lower quality to reduce their tax burden (Segura i Mas 1990). Thus, an under-representation of soils of best quality and woodland can be expected in our analysis, affecting particularly large landowners who tended to grab best quality soils and woodland. However, considering the widespread use of intercropping in Les Oluges, these concealments do not affect significantly our analysis.

These caveats do not affect the *Cartilla*, which was elaborated by a group of experts (usually long-experienced farmers from the municipality) who classified the farmland of the municipality according to different land uses (crop systems, woodland, and pastures) and soil qualities. These experts estimated the produce (i.e., main products and by-products) and requirements (i.e., days of human and animal work per task, fertilization, seeds, transport…) of the crop systems according to the production obtained in the last 8–10 years, the type of crop, and the quality of the soil (Junta Municipal de Amillaramientos 1883; Segura i Mas 1990). Thus, the *Cartilla* provides a detailed description of the general management and performance of each crop system at that time.

The methodology applied in our study compares the cultivation of vines and cereals in intercropping and monoculture systems, combining conventional measures and approaches used to assess intercropping systems (Vandermeer 1992; Weigelt and Jolliffe 2003), with more recently developed methodologies linked to agroecology (Migliorini et al. 2018) and agrarian metabolism (Guzmán et al. 2018). According to the historical sources, the following assumptions are applied in our analysis: (i) cereals and vines in intercropping took up half of the cultivated surface respectively; (ii) the practice of biennial fallow entailed that half of the cereals' surface was left uncultivated every year, both in monoculture and intercropping; (iii) given that donkeys were the most abundant draft force, animal needs in our estimations consider the feed and bed needs of a donkey throughout a year; (iv)

Table 1 Socioeconomic indicators used for the comparative analysis of intercropping and monoculture systems

Socioeconomic indicators			
Relative yield	RY_i	$RY_i = \frac{P_i}{M_i}$	(Vandermeer 1992, 2009; Weigelt and Jolliffe 2003; Martin-Guay et al. 2018)
Land equivalent ratio	LER	$LER = RY_i + RY_j = \frac{P_i}{M_i} + \frac{P_j}{M_j}$	
Income equivalent ratio	IER_i	$IER_i = \frac{IP}{IM_i}$	(Vandermeer 1992; Weigelt and Jolliffe 2003; Himmelstein et al. 2017)
	IER_{ij}	$IER_{ij} = \frac{IP}{(IM_i*0.5)+(IM_j*0.5)}$	

Pi is the yield per hectare of the crop i in polyculture; Mi is the yield per hectare of the crop i in monoculture; IPi and IMi are the economic performance (income or profit) per hectare of crop i in polyculture and monoculture respectively

formiguers used in cereals monoculture were built using biomass obtained from woodland, while in vines monoculture and intercropping systems, *formiguers* were built using rests of vine pruning.

The socioeconomic indicators used in our analysis are described in Table 1. The most widespread measure for evaluating the productive advantage of intercropping systems is the Land Equivalent Ratio (LER), which is the sum of relative yields (RY_i) for each crop. RY_i compares the yield per hectare of a crop in polyculture (P_i) and monoculture (M_i). Thus, the LER compares the relative land requirements of intercropping and the respective monocultures, measuring how much land would be needed to obtain the same yield in monocultures as in intercropping (Vandermeer 1992; Weigelt and Jolliffe 2003; Martin-Guay et al. 2018). A LER above 1 indicates that the intercropping system is more productive or has advantage over the monoculture system. In our case, RY_i and LER were calculated considering the energy content ($MJ \times ha^{-1}$) of the main produce and the by-products of each crop under monoculture and polyculture systems according to the information provided by Les Oluges' *Cartilla* (Díez et al. 2018; Paffarini et al. 2012). Additionally, we estimated the Income Equivalent Ratio (IER) (Vandermeer 1992), which compares the economic performance of polyculture (IP) and monoculture systems (IM_i). A value higher than 1 indicates that intercrop is advantageous over monoculture. From the information registered in the *Cartilla* for each crop system, we computed this indicator in two ways: first, according to the income (I-IER) (the value of the products and by-products obtained, without considering the expenses, in $pesetas \times ha^{-1}$) and secondly, considering the profit of each crop system (P-IER) (i.e., the taxable income indicated in the *Cartilla* which refers to the income minus the expenses, in $pesetas \times ha^{-1}$). Additionally, in both cases these indicators compare the monetary return of one hectare of intercropping and one hectare of each of monocultures (IER_i), as well as one hectare of intercropping compared to the sum of half hectare of cereals monoculture and half hectare of vines monoculture (IER_{ij}).

For the agrarian metabolism analysis, we carried out a biophysical characterisation of the yearly functioning of intercropping and monocultures according to the traditional management practices applied in each crop system. Following the methodology developed in previous studies of historical agrarian metabolism (Galán et al. 2016; Guzmán et al. 2018; Guzmán and González de Molina 2015; Tello et al. 2015, 2016), we determined the energy flows involved in each crop system considering their source and purpose, and assessed each crop system's energy efficiency according to a set of Energy Return On Investment ratios (EROIs). Table 2 shows the definition of the energy flows and EROIs employed in our analysis. Furthermore, we estimated the nutrient balances of each crop system to assess the sustenance of their productive capacity considering the traditional soil fertility practices used in each case. Following previous works (Díez et al. 2019; Galán 2017; García-Ruiz et al. 2012), and according to the general assumptions mentioned above, the nutrient balances were estimated considering human outputs (crops extraction from main produce and by-products) and inputs (seeds, buried biomass, manure and *formiguers*), as well as natural outputs (Nitrogen gaseous losses) and inputs (atmospheric deposition, symbiotic and non-symbiotic fixation).

The set of EROIs gives an account of the energy efficiency of crop systems acknowledging the interconnection of ecological and social dimensions, as well as productive and reproductive processes (Burandt and Mölders 2017). The NPPact EROI (NPPEROI), Biodiversity EROI and Agroecological EROI (AFEROI) assess the energy return of crop systems considering that their productive capacity depends not only on the flows of energy managed by humans, but also on the maintenance of ecosystem services and associated biodiversity that can be sustained by the Unharvested Phytomass (UhP). Thus, these three agroecological EROIs assess the overall productive capacity of the crop system (NPPEROI), the potential to host farm-associated biodiversity and provide ecosystem services (Biodiversity EROI), and the agroecological capacity of the crop system to satisfy human needs (AFEROI). A second sub-set of EROIs with greater focus on the human perspective is integrated by the Final EROI (FEROI), Internal and External Final EROIs (IFEROI and EFEROI respectively), and the Final EROI on

Table 2 Agrarian metabolism indicators defined for each crop system

Agrarian metabolism				
Energy flows		Definition	Description	
Actual Net primary productivity	NPPact	Total phytomass biologically produced in the crop system throughout a year	NPPact = TP + UhP	(Vitousek et al. 1986; Krausmann et al. 2013; Tello et al. 2015; Galán et al. 2016)
Unharvested phytomass	UhP	Above- and below-ground phytomass that remains in the agroecosystem independently of human aims	Includes: animal losses, adventitious grasses, and roots	(Guzmán and González de Molina 2015; Soto et al. 2016; Tello et al. 2016; Díez et al. 2018; Marco et al. 2018; Fullana Llinas et al. 2021)
Total produce	TP	Phytomass produced in the crop system that is managed by humans either aimed to satisfy human needs or reinvested for the maintenance of the crop system	TP = FP + BR	
Final produce	FP	Energy produced in the crop system and harvested to satisfy human needs	Includes: grain, wine, grapevine pomace, as well as wood available from vine pruning and strain replacement	
Biomass reused	BR	Energy produced in the crop system and reinvested either as feed or to maintain soil fertility	Includes: seeds, straw, husk, stubble, fallow grasses, strain replacement as well as vine pruning and leaves	
External inputs	EI	Energy from sources outside the crop system that is invested in the crop system	Includes: labour, external feed (straw), and woodland biomass	
EROIs				
NPPact EROI		NPPEROI	$NPPEROI = \frac{NPP_{act}}{BR+EI+UhP}$	(Guzmán and González de Molina 2015; Díez et al. 2018; Guzmán et al. 2018)
Biodiversity EROI		Biodiversity EROI	$Biodiversity\ EROI = \frac{UhP}{BR+EI+UhP}$	
Agroecological final EROI		AFEROI	$AFEROI = \frac{FP}{BR+EI+UhP}$	
Final EROI		FEROI	$FEROI = \frac{FP}{BR+EI}$	(Tello et al. 2015, 2016; Galán et al. 2016)
Internal final EROI		IFEROI	$IFEROI = \frac{FP}{BR}$	
External final EROI		EFEROI	$EFEROI = \frac{FP}{EI}$	
Final EROI on labour		L-FEROI	$L - FEROI = \frac{FP}{L}$	(Marco et al. 2018; Fullana Llinas et al. 2021)

A detailed description of the EROIs is provided in the main text

Table 3 Land uses in Les Oluges in the second half of the nineteenth century, in hectares (ha)

Land uses (ha)			Land qualities			Total (ha)
			Q1/Wheat	Q2/Barley	Q3/Rye	
Farmland	Cropland	Vegetable gardens	3.03	1.25	0.00	4.28
		Cereals	47.29	114.02	160.20	321.52
		Vines and cereals	27.42	156.96	355.87	540.25
		Olive orchards	0.00	0.00	0.18	0.18
		Olive trees and cereals	0.65	7.84	13.62	22.12
		Cereals, vines and olive trees	0.00	0.00	0.15	0.15
		Total cropland	77.44	280.07	530.02	888.50
	Permanent pastureland*					155.80
	Woodland		16.42	128.16	341.27	485.84
	Total farmland					1530.14

*No qualities were assigned to pastureland in Les Oluges' *Cartilla Evaluatoria* and *Amillaramiento*

Labour (L-FEROI). These EROIs assess the energy return of the agroecosystem considering the different flows of energy managed by humans in the form of external inputs (EI), biomass reused (BR), and labour[1] (L) in relation to the energy appropriated by humans for their own consumption (FP).

Results

Land uses and crop systems' distribution

The distribution of land uses in Les Oluges (Table 3) differentiates three soil qualities for cropland and woodland, from best (Q1) to lowest quality (Q3). Most cropland was classified as second (Q2) and third (Q3) qualities (32% and 60% respectively). These soil qualities did not indicate only soil properties and were also linked to the type of crop grown in each piece of land. According to the *Cartilla*, soils of first quality (Q1) were those cultivated with wheat, soils of second quality (Q2) were grown with barley, and third quality soils (Q3) were grown with rye. This crop distinction was applied both in monocultures and intercropping systems.

Intercropping of vines and cereals, and cereals monoculture were the most widespread crop systems (61% and 36% of cropland, respectively). Additional intercropping systems were found in Les Oluges, such as the intercropping of olive trees and cereals, as well as the intercropping of vines, olives and cereals. These followed the same pattern as the intercropping of vines and cereals, but were found in a very limited share of cropland (2%). Although the *Cartilla* provides a produce and costs estimation of vines and olive trees monocultures, there was no monoculture of vines in Les Oluges according to the *Amillaramiento*, and olive orchards were very scarce. Finally, woodland and pastureland comprised 42% of the total farmland.

The distribution of farmland and crop systems among the 213 landowners listed in Les Oluges' *Amillaramiento* (Figs. 3 and 4) shows the abundance of small and medium landowners (with 66% of the landowners having less than 5 ha of farmland). The weak correlation between the amount of farmland owned and its composition, both in terms of cropland and woodland shares in farmland ($R^2 = 0.1114$ and $R^2 = 0.0973$ respectively) (Fig. 3), as well as considering the shares of cereals monoculture and intercropping in the cropland owned ($R^2 = 0.0834$ and $R^2 = 0.0365$ respectively) (Fig. 4), indicates that the use of intercropping was not significantly linked with the amount of land owned by the farmer. Since large landowners tended to grab best quality soils and woodland, their farmland resources were more adequate for cereals monoculture, holding those soils more suitable for cereals and having access to woodland biomass for building *formiguers*. Those 73 landowners with more than 5 ha of cropland had 87% (281 ha) of cereals monoculture and 72% (387 ha) of intercropping. However, both large and small landowners in Les Oluges had significant shares of intercropping: 71% of the landowners had at least half of their cropland with intercropping, and only 10 landowners had no intercropping in their cropland.

Comparing intercropping and monoculture systems: socioeconomic indicators

LER and IER indicators compare the efficiency of intercropping and the respective monocultures for each soil quality. In terms of land requirements, the LER for all soil qualities are equal or close to 1 (Table 4), indicating that vines and cereals had a similar yield performance in monoculture and intercropping. There was only a reduced disadvantage in Q1 and Q3 for intercropping.

[1] Labour requirements are estimated considering the different time requirements and energy intensity of the agricultural tasks (FAO et al. 2004).

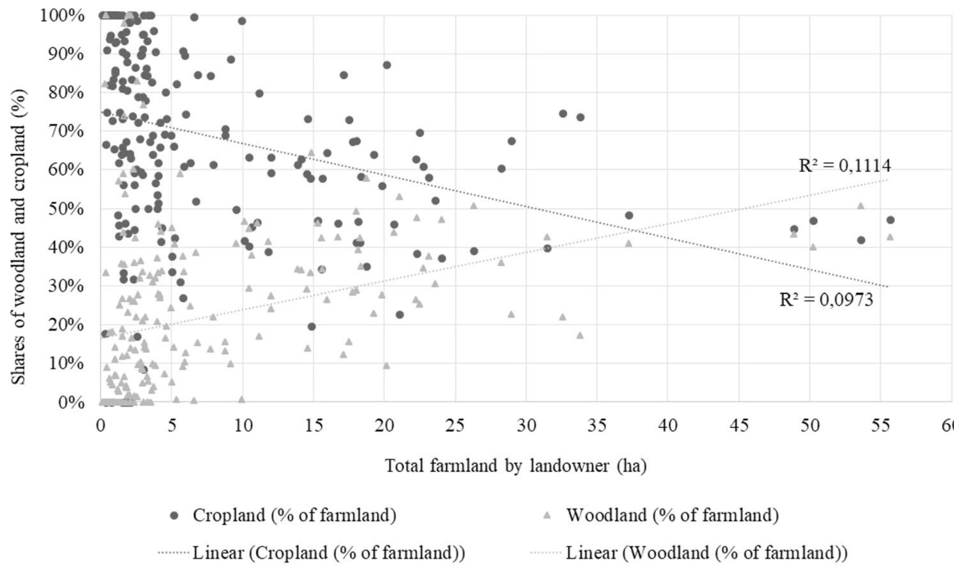

Fig. 3 Correlation among the total farmland owned by each landowner (in hectares) and the respective shares of cropland and woodland

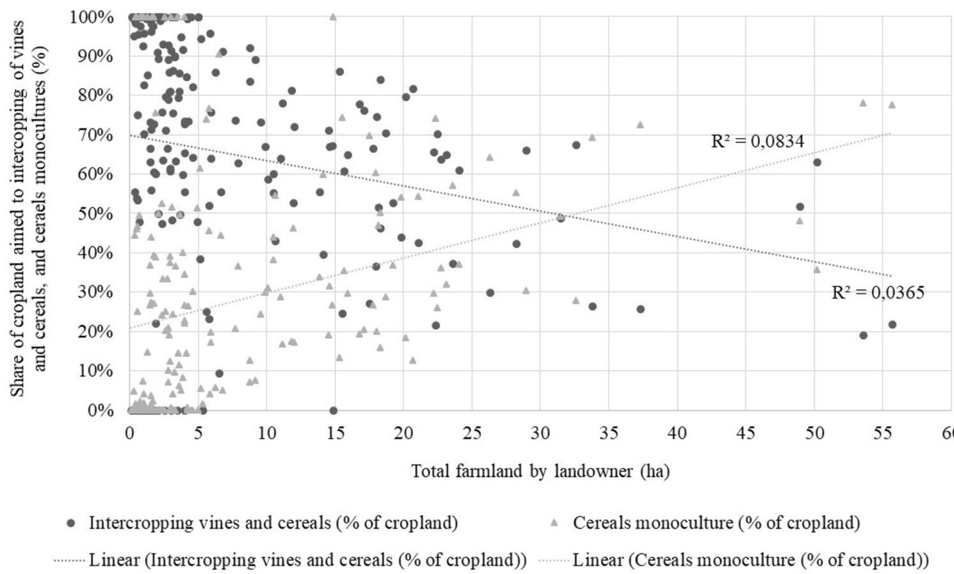

Fig. 4 Correlation among the total farmland owned by each landowner (in hectares) and the respective shares of cropland aimed to intercropping of vines and cereals, and to monoculture of cereals

However, there were sharper differences between monocultures and intercropping systems in monetary terms (Table 4). Comparing the profit provided by one hectare of intercropping and one hectare of each of the monocultures, intercropping had a clear advantage over cereals monoculture (P-$IER_{Cereals}$) but was not in advantage compared with vines (P-IER_{Vines}). The P-$IER_{CerealsVines}$ shows that one hectare of intercropping provided higher profit than the cultivation of the same land with separated crops (half hectare of cereals monoculture and half hectare of vines monoculture). This profit advantage was larger in soils of lower qualities (Q2 and Q3). When the IER is calculated considering only the income (without expenses) from each crop system, the results obtained are the opposite. The I-IER shows some advantage for intercropping only compared with the monoculture of vines (I-IER_{Vines}) in Q1 and Q3. However, the I-$IER_{CerealsVines}$ indicates that the cultivation of one hectare of intercropping did not provide greater income than the cultivation of one hectare equally divided in cereals and vines monoculture. According to the *Cartilla*, cereals monoculture provided greater income per hectare, but also had higher costs than vines monoculture, resulting in a lower profit (taxable income) in cereals monoculture. Overall, the fact that the P-IER was favourable for intercropping over cereals monoculture, and the I-IER tended to be favourable for intercropping over vines monoculture suggests that, when cereals and vines were intercropped, cereals increased the income over vines single cultivation, while vines allowed to reduce costs over cereals single cultivation. The profit advantage of intercropping over cereals monoculture was

Table 4 Comparative analysis of the yield and economic advantage of intercropping and monocultures of vines and cereals for each soil quality

Comparative analysis—Yield and monetary advantage			Land qualities for intercropping and monocultures of vines and cereals		
			Q1/Wheat	Q2/Barley	Q3/Rye
LER			0.97	1.00	0.97
IER	Profit	$P\text{-}IER_{Vines}$	0.85	0.89	0.99
		$P\text{-}IER_{Cereals}$	1.47	1.60	1.98
		$P\text{-}IER_{CerealsVines}$	1.07	1.14	1.32
	Income	$I\text{-}IER_{Vines}$	1.04	0.94	1.13
		$I\text{-}IER_{Cereals}$	0.88	0.97	0.86
		$I\text{-}IER_{CerealsVines}$	0.95	0.96	0.97

LER land equivalent ratio; *IER* income equivalent ratio, calculated with profit -i.e., income minus expenses- (P-IER), and income (I-IER). LER compares, the relative yields of each crop in intercropping and monoculture. IER_{Vines} compares one hectare of intercropping with one hectare of vines monoculture, $IER_{Cereals}$ compares one hectare of intercropping with one hectare of cereals monoculture, $IER_{CerealsVines}$ compares one hectare of intercropping with the sum of half hectare of cereals monoculture and half hectare of vines monoculture

was the most expensive task (10 pesetas × day^{-1}) given that it required a pair of powerful draft animals and a labourer to handle them, and (ii) female work, which was the cheapest work (hired for 1 peseta × day^{-1}, half of a man's wage) as it was usually hired for tasks considered less demanding (weeding out in cereals, and grape harvest). Intercropping required relatively less ploughing and used relatively more female work than both monocultures, counterbalancing the higher requirements in days of work.

Comparing intercropping and monoculture systems: agrarian metabolism

The comparative analysis of intercropping and monoculture systems from an agrarian metabolism perspective shows, firstly, that the results for the intercropping system were generally in between those of the monocultures of vines and cereals (Table 6). The differences among cereals and vines monocultures do not stem only from the energy content and biological differences between these crops, but reflect also the different management practices traditionally used in each crop system.

Intercropping had an overall energy productivity (NPPact) in between that of monocultures, with vines monoculture having the highest NPPact, and cereals monoculture the lowest NPPact. Barley, grown in Q2, was the most productive grain both in monoculture and intercropping. However, large part of the energy produced in every crop system remained in cropland as UhP (38%–56% of NPPact), and from the energy managed by humans (TP), cereals monoculture had the lowest share of energy aimed to satisfy human needs (FP), while monoculture of vines had the highest FP. Most of the TP was reinvested as BR in all crop systems (between 67% and 84% of TP); in cereals monoculture, BR was aimed mainly to sustain animal needs (95%–96% of BR), while in vines monoculture and intercropping systems, BR was mainly aimed to replenish soil fertility (by means of buried biomass and *formiguers*). By-products from cereals monoculture (such as straw, husk and stubble, as well as the

Table 5 Labour requirements of the intercropping of vines and cereals and the corresponding monocultures

Labour		Intercropping vines and cereals			Cereals monoculture			Vines monoculture		
		Q1/Wheat	Q2/Barley	Q3/Rye	Wheat	Barley	Rye	Q1	Q2	Q3
Total days of work	Days × ha^{-1}	52	35	27	42	27	27	51	39	24
Mean labour cost	Pesetas × day^{-1}	2.6	2.8	2.9	3.7	4.0	4.0	2.6	2.8	3.2
Ploughing	Days × ha^{-1}	3	3	2	6	3	3	5	5	4
	% of total days	7%	8%	9%	14%	13%	13%	10%	12%	17%
Female	Days × ha^{-1}	14	8	5	5	2	2	12	7	2
	% of total days	27%	21%	17%	12%	6%	7%	23%	18%	10%

larger than its income advantage over vines monoculture, signalling the relevance of costs reduction in the practice of intercropping.

The greatest share of the expenses in all crop systems were labour costs[2] (corresponding to 75%–82% of total costs in monetary terms) (Table 5).

Overall, total labour requirements (days × ha^{-1}) of intercropping were similar to those of vines monoculture (a more labour-intensive crop system than cereals monoculture). The mean labour costs (pesetas × day^{-1}) of intercropping and vines monoculture were also similar, but lower than the costs of cereals monoculture. Two components of the labour costs are of special relevance in this respect: (i) ploughing, which

[2] Non-labour costs include seeds, deterioration of tools, and the wine press rental.

Table 6 Results of the agrarian metabolism biophysical analysis of the intercropping system and the respective monocultures

Agrarian metabolism analysis			Intercropping vines and cereals			Cereals monoculture			Vines monoculture		
			Q1/Wheat	Q2/Barley	Q3/Rye	Wheat	Barley	Rye	Q1	Q2	Q3
Energy flows											
NPPact		$Gj \times ha^{-1}$	76.62	77.86	58.91	53.69	65.25	49.02	101.45	87.09	67.95
UhP		% of NPPact	46%	47%	50%	55%	53%	56%	38%	40%	44%
TP		$Gj \times ha^{-1}$	41.65	41.26	29.45	23.99	30.36	21.80	62.87	52.16	37.87
FP		$Gj \times ha^{-1}$	9.88	10.98	7.68	4.02	5.76	3.49	17.67	16.13	12.38
BR	Total BR	$Gj \times ha^{-1}$	31.77	30.28	21.78	19.96	24.64	18.36	45.21	36.03	25.49
	Animal needs	% of BR	39%	44%	38%	95%	95%	96%	35%	36%	33%
	Seeds and fertilization	% of BR	61%	56%	62%	5%	5%	4%	65%	64%	67%
EI	Total EI	$Gj \times ha^{-1}$	53.31	51.96	55.79	46.50	37.61	43.34	49.32	51.60	54.66
	Labour	$Gj \times ha^{-1}$	0.43	0.29	0.23	0.57	0.39	0.38	0.42	0.32	0.20
	Woodland	$Gj \times ha^{-1}$				11.34	6.80	6.80			
	Feed	$Gj \times ha^{-1}$	52.89	51.67	56.28	34.59	30.42	36.15	48.90	51.28	54.46
EROIs											
NPPEROI			0.64	0.66	0.55	0.56	0.67	0.55	0.76	0.71	0.62
Biodiversity EROI			0.29	0.31	0.27	0.31	0.36	0.31	0.29	0.29	0.27
AFEROI			0.08	0.09	0.07	0.04	0.06	0.04	0.13	0.13	0.11
FEROI			0.12	0.13	0.10	0.06	0.09	0.06	0.19	0.18	0.15
IFEROI			0.31	0.36	0.35	0.20	0.23	0.19	0.39	0.45	0.49
EFEROI			0.19	0.21	0.14	0.09	0.15	0.08	0.36	0.31	0.23
L-FEROI			23.21	37.70	34.14	7.03	14.92	9.10	41.70	49.99	60.61
Nutrient balances											
Nitrogen (N)		$Kg\ N \times ha^{-1}$	− 18.73	− 16.84	− 10.40	2.61	1.72	4.26	− 34.12	− 26.83	− 17.52
Phosphorus (P)		$Kg\ P \times ha^{-1}$	− 2.14	− 2.10	− 1.70	2.88	2.25	1.83	− 2.95	− 2.38	− 1.53
Potassium (K)		$Kg\ K \times ha^{-1}$	− 10.31	− 11.13	− 6.78	13.56	8.41	11.55	− 17.01	− 13.95	− 9.54

pastured fallow) could satisfy 41%–50% of the yearly needs of a donkey, while by-products from intercropping and vines monoculture could only meet 7%–15% and 10%–20% of the animal needs respectively.

Looking at the energy invested as EI, cereals monoculture had the lowest energy flow from EI. This EI investment was on average 10-times larger than the FP obtained in cereals monoculture, while this relation was 3- and 6-times larger in vines monoculture and intercropping systems respectively. The management of cereals monoculture depended on access to biomass from woodland for fertilisation, in contrast with the greater use of BR in the other crop systems. However, the dependence on EI was lessened by the greater capacity of cereals produce and by-products to satisfy animal needs. Intercropping required the largest investment of EI to maintain draft force. Finally, cereals monoculture had the highest labour energy input considering the working days and the energy intensity of the tasks, leading to the lowest energy return on labour (L-FEROI). The greater energy productivity and the lower energy requirements from labour made the energy efficiency of labour in vines monoculture five times higher than in cereals monoculture, while intercropping had by mean L-FEROIs three times higher than cereals monoculture.

The results of the EROIs analysis show that all crop systems had a relatively low energy return from a human perspective (FEROI) compared to their overall performance (NPPEROI). The lower energy efficiency of cereals monoculture in all the indicators focused on the availability of energy for human purposes (FEROI, IFEROI and EFEROI) reflects the large investment of energy needed to sustain a crop system that provided a relatively low amount of energy (FP). The highest FEROIs were those of vines monoculture, indicating the lower energy investment needed per unit of energy available for human use. Additionally, all crop systems had higher IFEROI than EFEROI, due to the considerable need of EI for maintaining the resources and functioning of each crop system. Considering the flows of energy that were not directly managed by humans, the larger UhP in cereals monoculture provided a greater capacity to sustain the reproduction processes linked with farm-associated biodiversity and ecosystem services (Biodiversity EROI and AFEROI).

Finally, the different management practices of each crop system are reflected in the nutrient balances. Only cereals monoculture had positive nutrient balances. The fertilization practices applied in this crop system included fallow, *formiguers* and, according to the *Cartilla*, this was the only crop system in which manure was used. Fertilization of vines monoculture included *formiguers* and buried biomass from vines pruning, but these practices were not sufficient to replenish the nutrients extracted. Intercropping had lower nutrient deficits than vines monoculture because the management of soil fertility in this crop system combined practices from both monocultures: rests of vines pruning were used for *formiguers* and as buried biomass, stubble (which was not grazed in this crop system to avoid damage of the vines) was buried back into the soil, and fallow was alternated every other year in the strips of cereals.

Discussion

What were, then, the advantages and rationale of the intercropping of vines and cereals? Looking at who used the intercropping system, the distribution of crop systems among landowners shows that, although cereals monocultures were mainly owned by large landowners, intercropping was widespread between large and small landowners. The historical sources do not allow to distinguish to what extent intercropping in large landowners' holdings could be connected to sharecropping agreements, but the monetary analysis indicates that market incentives did not prevail in the crop system decision of farmers since the most profitable crop system in monetary terms, vines monoculture ($\text{P-IER}_{\text{Vines}}$), was not found in Les Oluges. Thus, although the spread of vine cultivation was linked to the vineyard boom experienced in the second half of the nineteenth century, the preference for intercropping over vines monoculture indicates that other criteria beyond market incentives were influencing crop system decisions.

Another reason for the widespread use of intercropping can be related with the productive limitations and edaphoclimatic conditions of Les Oluges, which affected both large and small landowners. Overall, cropland productivity in Les Oluges was low, not only because of the scarce yields, but also due to the need of biennial fallow in cereals cultivation (Díez et al. 2018). Additionally, best quality soils better suited for growing cereals were scarce, while the cultivation of vines was better adapted for the sloped, terraced, and recently deforested soils in which vineyard expansion took place. As Olarieta et al. (2008) show, intercropping was usually implemented in soils that were more suitable for vines than for cereals, which supports the idea that intercropping was a means to obtain some further grain in soils where cereals monoculture was not advantageous, following the *motto: a little bit of everything, and as much grain as possible*.

The LER results showing a similar productivity among crops both in monocultures and intercropping despite the harsh edaphoclimatic conditions, indicate that there was weak competition between vines and cereals; although this crop combination did not provide an increase in biomass productivity, as most studies on intercropping systems suggest (Himmelstein et al. 2017; Martin-Guay et al. 2018; Trenbath 1974). Despite the lack of studies analysing the intercropping of vines and cereals beyond the use of the latter as temporary cover crops, some possible mechanisms of weak competition could be related to the different cycles of water and nutrients absorption of these two crops (García-Serrano Jiménez et al. 2009; Ripoche et al. 2011), as well as to the adaptation of rooting and water and nutrient uptake when vines and cereals are intercropped (Celette et al. 2008, 2009; Cardinael et al. 2015). Other beneficial mechanisms, such as the enhancement of ecosystem services and soil biota, could be favoured by the greater crop diversity in intercropping, and further strengthened by the management practices applied in this crop system (Alcon et al. 2020; Altieri and Nicholls 2002; Nicholls and Altieri 2004; Torralba et al. 2016). On the one hand, the reduced ploughing found in intercropping management could favour the preservation of soil biota and the sustenance of soil fertility, as suggested in studies on low-till practices (Almagro et al. 2017; López-Garrido et al. 2014; Roger-Estrade et al. 2010; Tilman et al. 2011). On the other hand, while having a perennial crop could favour soil structure in terraced lands, cereals could also be helpful for avoiding the relatively high soil erosion in vineyard cultivation (Garcia et al. 2018; García-Ruiz 2010; Loumou and Giourga 2003; Ruiz-Colmenero et al. 2011).

In addition to the edaphoclimatic suitability of vines and cereals intercropping, the peasant economy perspective enables a further understanding of the possible rationale in the management and multifunctionality of this crop system. Starting with the classical balances suggested by Chayanov (1986b) and using the biophysical analysis of the crop systems as a way to approach peasant balances, the L-FEROI can be linked to the labour-consumer balance by which peasant agriculture harmonizes the productive capacity and the consumption needs of the farming unit. Although the energy efficiency of intercropping considering the labour invested and the FP obtained (L-FEROI) was lower than that of vines monoculture, intercropping had a considerably higher L-FEROI than cereals monoculture because it simultaneously reduced the energy invested in L and increased the energy obtained as FP. Additionally, intercropping provided both a cash crop (grapes) and a subsistence crop (grains), and could meet diverse consumption requirements of the farming household.

Furthermore, the detailed analysis of labour requirements unveils a specific advantage of intercropping linked to the utility-drudgery balance. The relatively lesser ploughing and higher share of female work that reduced the monetary costs of intercropping can be interpreted as a lower drudgery of intercropping compared with the corresponding monocultures. In a context of low cropland productivity, high population density, and agricultural expansion, the lower ploughing requirements found in the intercropping system are of great importance. Given the limited feed resources available in the agroecosystem and the relative scarcity of powerful draft animals, a lower requirement of more demanding tasks in terms of draft force in intercropping was a significant advantage. Additionally, according to the idea that women were traditionally employed in those agricultural tasks deemed less demanding, the relatively higher female work could indicate a reduced load of more exhausting tasks. Increased participation of women in intercropping could also enable a more efficient employment of the labour force available in the family, by means of a greater involvement of all the individuals in agricultural tasks, and a reduced need to rely on external workers.

The relevance of gender relations and inequalities in agriculture has been signalled from peasant economy (Valdivia 2001) and agrarian metabolism perspectives (Marco et al. 2020), as well as for understanding agricultural transformation processes (Addison and Schnurr 2016; Boserup 2007; Smetschka et al. 2014). However, these studies warn about considering female labour as a "reserve labour pool" (Zhang 2020). The participation of women in intercropping cultivation could entail an increased exploitation for women, whose work as part of the farming unit traditionally involved care and household tasks on top of their work in cropland. Moreover, the difference among female and male wages highlights the prevailing gender inequalities, with higher male wages although not all the agricultural tasks done by men were strenuous, and women also collaborated in burdensome agricultural tasks.

Considering the wider array of balances suggested by Van der Ploeg (2013), the FEROI, IFEROI and EFEROI can be linked with the balance between the use of external and internal resources. Intercropping required a relatively greater investment of BR than vines monoculture, and more energy from EI than both monocultures; however, this productive investment provided an energy efficiency in terms of FEROI, IFEROI and EFEROI closer to that of vines monoculture and much higher than cereals monoculture. The gain of energy efficiency on intercropping compared to cereals monoculture was higher than the loss of energy efficiency compared to vines monoculture. Furthermore, as vines monoculture, intercropping did not depend on woodland for fertilisation resources and, although it required a greater investment of EI to fulfil feed requirements, the reduced need of draft force in the management of intercropping could offset partially this burden.

In terms of the balance between productive and reproductive processes, the large reproductive effort invested in cereals monoculture, with the highest shares of UhP and BR, resulted in positive nutrient balances but also entailed the lowest energy availability and efficiency for satisfying productive purposes (AFEROI). In contrast, the low reproductive effort in vines monoculture resulted in the highest AFEROI and largest negative nutrient balances that ultimately could jeopardise the productive capacity of this crop system in the long term. The combination of productive and reproductive management of both monocultures in the intercropping system provided a better balance between the energy efficiency for human production (AFEROI) and the sustenance of the productive capacity of the crop system; although nutrient balances were still negative, nutrients deficits were lower than in vines monoculture and the satisfaction of human purposes was greater than in cereals monoculture.

Lastly, considering agriculture as a human-nature co-production process the peasant balance between human needs and living nature can be connected with the NPPEROI, AFEROI and Biodiversity EROI. Cereals monoculture had the lowest total energy efficiency (NPPEROI) and the extensive management in this crop system involved a high share of UhP that was favourable in terms of sustaining co-production processes linked with biodiversity (Biodiversity EROI), but this high co-productive effort limited the energy efficiency for human purposes (AFEROI). Contrarily, the highest NPPEROI and lower co-productive effort in terms of UhP as well as Biodiverstiy EROI of vines monoculture, enabled a higher AFEROI, entailing that co-production processes in vines monoculture were more favourable from a human perspective. Meanwhile, the intercropping system provided a better co-production balance between nature and human requirements, having a similar Biodiversity EROI to that of vines monoculture despite its lower NPPEROI, and with higher AFEROI than cereals monoculture.

Overall, understanding the biophysical analysis of the intercropping system from a peasant economy perspective provides some insights into the potential balancing rationale of combining vines and cereals. Considering the historical context of agricultural expansion and vineyard boom in which intercropping spread in Les Oluges, this crop system provided also a balance between two different productive strategies. On the one hand, cereals were a subsistence crop that required relatively high-quality soils, access to woodland biomass and powerful draft force, as well as a high reproductive effort for maintaining soil fertility. On the other hand, vines were a market-oriented crop that could be grown in lesser quality soils and whose cultural management entailed a reduced reproductive effort. In a context of low cropland productivity and limited productive resources (especially related to cropland and draft force) that affected, to a greater or lesser extent, to all the landowners in Les Oluges, intercropping allowed to take advantage of market conditions without overlooking subsistence provision. However, this multifunctionality advantage could have been found also in the productive diversification with separated monocultures of vines and cereals. In this respect, our analysis identified a specific socioeconomic advantage of intercropping: the relative reduction of ploughing and increased share of female work compared with monocultures, which potentially resulted in a reduced drudgery and monetary costs when vines and cereals were intercropped. In addition to the possibility to take advantage of less suitable soils for the production of cereals, the relatively lower drudgery entailed a wise adaptation to the productive limitations of the agroecosystem that could be useful to understand the widespread use and diversification of this traditional intercropping system. While the identified advantages of the intercropping of vines and cereals are linked to the historical context and characteristics of Les Oluges in the mid-nineteenth century, the use of this crop system in other Mediterranean agroecosystems, and the fact that it persisted until the second half of the twentieth century also with diverse crop combinations (Díez et al. 2018), suggests that the benefits of this cultivation pattern were not limited to the specific crops and context examined in this study. In addition to the contribution of traditional agriculture systems to agricultural sustainability and resilience at the landscape level (Cervera et al. 2019; Zimmerer et al. 2022), there can be further productive advantages of traditional polycultures and their management practices that need to be explored and that could be relevant to enhance the sustainability of current agricultural systems. The intercropping of vines and cereals is an example of how polycultures can be used to take advantage of soils that are less suitable for certain crops cultivation while, at the same time, they can be used to enhance the productive potential of agroecosystems offering a better balance between human needs and biodiversity protection. Additionally, crop patterns that reduce ploughing requirements can be beneficial in terms of reduced use of fossil-fuelled machinery and enhanced soil biodiversity, as well as the lower requirement of strenuous agricultural tasks can improve agricultural working conditions (Dumont and Baret 2017).

Conclusions

Our examination of the traditional intercropping of vines and cereals in the mid-nineteenth century and the management practices linked to this crop system, has identified some of the advantages of intercropping compared to the respective monocultures of vines and cereals. The intercropping system was a form of adapting to the productive limitations in terms of low soil quality and cropland productivity, allowing to obtain *as much grain as possible* and combining market and subsistence productive strategies. While market incentives drove the expansion of vine cultivation in this period, our analysis shows that this was not the main criterion determining the choice of crop system. The biophysical analysis of the functioning of the intercropping system from a peasant economy perspective showed that, beyond productivity and maximisation rationalities, intercropping was advantageous from a multifunctional balancing rationale, allowing to reduce the high reproductive effort and dependence on woodland resources of cereals monoculture, while benefitting from the productive advantages of vines monoculture with less negative nutrient balances. Furthermore, our analysis revealed a specific socioeconomic advantage of intercropping that is directly connected with the intercropped pattern: the reduced drudgery in terms of draft force and female work. This way, this paper contributes to a new acknowledgment of the agricultural rationale and advantages of an intercropping system that, even if now lost, enlarges the varied repertoire of Mediterranean traditional agricultural practices.

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Declarations

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References

Addison, L., and M. Schnurr. 2016. Introduction to symposium on labor, gender and new sources of agrarian change. *Agriculture and Human Values* 33 (4): 961–965. https://doi.org/10.1007/s10460-015-9656-1.

Agnoletti, M., and F. Emanueli. 2016. *Biocultural diversity in Europe*. Cham: Springer.

Alcon, F., C. Marín-Miñano, J.A. Zabala, M.-D. de Miguel, and J.M. Martínez-Paz. 2020. Valuing diversification benefits through intercropping in Mediterranean agroecosystems: A choice experiment approach. *Ecological Economics* 171: 106593. https://doi.org/10.1016/j.ecolecon.2020.106593.

Almagro, M., N. Garcia-Franco, and M. Martínez-Mena. 2017. The potential of reducing tillage frequency and incorporating plant residues as a strategy for climate change mitigation in semiarid Mediterranean agroecosystems. *Agriculture, Ecosystems & Environment* 246: 210–220. https://doi.org/10.1016/j.agee.2017.05.016.

Altieri, M.A. 2004. Linking ecologists and traditional farmers in the search for sustainable agriculture. *Frontiers in Ecology and the Environment* 2 (1): 35–42. https://doi.org/10.1890/1540-9295(2004)002[0035:LEATFI]2.0.CO;2.

Altieri, M.A., and C.I. Nicholls. 2002. The simplification of traditional vineyard based agroforests in Northwestern Portugal: Some ecological implications. *Agroforestry Systems* 56 (3): 185–191. https://doi.org/10.1023/A:1021366910336.

Badia-Miró, M., and E. Tello. 2014. Vine-growing in Catalonia: The main agricultural change underlying the earliest industrialization in Mediterranean Europe (1720–1939). *European Review of Economic History* 18 (2): 203–226. https://doi.org/10.1093/ereh/heu006.

Badia-Miró, M., E. Tello, F. Valls, and R. Garrabou. 2010. The grape phylloxera plague as a natural experiment: The upkeep of vineyards in Catalonia (Spain), 1858–1935. *Australian Economic History Review* 50 (1): 39–61. https://doi.org/10.1111/j.1467-8446.2009.00271.x.

Barbera, G., and S. Cullotta. 2012. An inventory approach to the assessment of main traditional landscapes in sicily (Central Mediterranean Basin). *Landscape Research* 37 (5): 539–569. https://doi.org/10.1080/01426397.2011.607925.

Barbera, G., and S. Cullotta. 2016. The traditional Mediterranean polycultural landscape as cultural heritage: Its origin and historical importance, its agro-silvo-pastoral complexity and the necessity for its identification and inventory. In *Biocultural diversity in Europe*, ed. M. Agnoletti and F. Emanueli, 21–48. Cham: Springer.

Barthel, S., C. Crumley, and U. Svedin. 2013. Bio-cultural refugia—safeguarding diversity of practices for food security and biodiversity. *Global Environmental Change* 23 (5): 1142–1152. https://doi.org/10.1016/j.gloenvcha.2013.05.001.

Bernstein, H., H. Friedmann, J.D. Van der Ploeg, T. Shanin, and B. White. 2018. Forum: Fifty years of debate on peasantries, 1966–2016. *The Journal of Peasant Studies* 45 (4): 689–714. https://doi.org/10.1080/03066150.2018.1439932.

Blondel, J. 2006. The "Design" of Mediterranean landscapes: A millennial story of humans and ecological systems during the historic period. *Human Ecology* 34 (5): 713–729. https://doi.org/10.1007/s10745-006-9030-4.

Boserup, E. 2007. *Woman's role in economic development*. New York: Earthscan.

Brooker, R.W., A.E. Bennett, W.-F. Cong, T.J. Daniell, T.S. George, P.D. Hallett, C. Hawes, P.P.M. Iannetta, H.G. Jones, and A.J. Karley. 2014. Improving intercropping: A synthesis of research in agronomy plant physiology and ecology. *New Phytologist* 206 (1): 107–117. https://doi.org/10.1111/nph.13132.

Burandt, A., and T. Mölders. 2017. Nature-gender relations within a social-ecological perspective on European multifunctional agriculture: The case of agrobiodiversity. *Agriculture and Human Values* 34 (4): 955–967. https://doi.org/10.1007/s10460-016-9763-7.

Cardinael, R., Z. Mao, I. Prieto, A. Stokes, C. Dupraz, J.H. Kim, and C. Jourdan. 2015. Competition with winter crops induces deeper rooting of walnut trees in a Mediterranean alley cropping agroforestry system. *Plant and Soil* 391 (1): 219–235. https://doi.org/10.1007/s11104-015-2422-8.

Celette, F., R. Gaudin, and C. Gary. 2008. Spatial and temporal changes to the water regime of a Mediterranean vineyard due to the adoption of cover cropping. *European Journal of Agronomy* 29 (4): 153–162. https://doi.org/10.1016/j.eja.2008.04.007.

Celette, F., A. Findeling, and C. Gary. 2009. Competition for nitrogen in an unfertilized intercropping system: The case of an association of grapevine and grass cover in a Mediterranean climate. *European Journal of Agronomy* 30 (1): 41–51. https://doi.org/10.1016/j.eja.2008.07.003.

Cervera, T., J. Pino, J. Marull, R. Padró, and E. Tello. 2019. Understanding the long-term dynamics of forest transition: From deforestation to afforestation in a Mediterranean landscape (Catalonia, 1868–2005). *Land Use Policy* 80: 318–331. https://doi.org/10.1016/j.landusepol.2016.10.006.

Chayanov, A. V. 1986a. On the theory of non-capitalist economic systems. In *The theory of peasant economy*. Wisconsin: University of Wisconsin Press.

Chayanov, A.V. 1986b. *The theory of peasant economy*. Wisconsin: University of Wisconsin Press.

Díez, L., X. Cussó, R. Padró, I. Marco, C. Cattaneo, J.R. Olarieta, R. Garrabou, and E. Tello. 2018. More than energy transformations: A historical transition from organic to industrialized farm systems in a Mediterranean Village (Les Oluges, Catalonia, 1860–1959–1999). *International Journal of Agricultural Sustainability* 16 (4–5): 399–417. https://doi.org/10.1080/14735903.2018.1520382.

Díez, L., J.R. Olarieta, and E. Tello. 2019. 'Belowground and aboveground sustainability: Historical management change in a Mediterranean agroecosystem (Les Oluges, Spain, 1860–1959-1999). *Human Ecology* 47 (5): 639–651. https://doi.org/10.1007/s10745-019-00105-8.

Dumont, A.M., and P.V. Baret. 2017. Why working conditions are a key issue of sustainability in agriculture? A comparison between agroecological, organic and conventional vegetable systems. *Journal of Rural Studies* 56: 53–64. https://doi.org/10.1016/j.jrurstud.2017.07.007.

Edelman, M. 2013. What Is a Peasant? What Are Peasantries? A Briefing Paper on Issues of Definition. *First Session of the Intergovernmental Working Group on a United Nations Declaration on the Rights of Peasants and Other People Working in Rural Areas.* Geneva

Eichhorn, M.P., P. Paris, F. Herzog, L.D. Incoll, F. Liagre, K. Mantzanas, M. Mayus, G. Moreno, V.P. Papanastasis, D.J. Pilbeam, A. Pisanelli, and C. Dupraz. 2006. Silvoarable systems in Europe—past, present and future prospects. *Agroforestry Systems* 67 (1): 29–50. https://doi.org/10.1007/s10457-005-1111-7.

Federico, G., and P. Martinelli. 2018. Italy to 1938. In *Wine globalization: A new comparative history*, ed. K. Anderson and V. Pinilla, 130–152. Cambridge: Cambridge University Press.

Federico, G., and P. Martinelli Lasheras. 2020. Risk Management in Traditional Agriculture: Intercropping in Italian Wine Production. *Working Papers in Economic History*. http://hdl.handle.net/10016/30249

Friedmann, H. 2019. The awkward class: A foundation for peasant studies. *The Journal of Peasant Studies* 46 (5): 1096–1105. https://doi.org/10.1080/03066150.2019.1608684.

Fullana Llinas, O., E. Tello Aragay, I. Murray Mas, G. Jover-Avellà, and J. Marull López. 2021. Socio-ecological transition in a Mediterranean agroecosystem: What energy flows tell us about agricultural landscapes ruled by landlords, peasants and tourism (Mallorca, 1860–1956–2012). *Ecological Economics* 190: 107206. https://doi.org/10.1016/j.ecolecon.2021.107206.

Galán, E. 2017. Feeding soils: Nutrient balance in the northeast of the Iberian Peninsula c.1920. *Historia Agraria: Revista De Agricultura e Historia Rural* 72: 107–134.

Galán, E., R. Padró, I. Marco, E. Tello, G. Cunfer, G.I. Guzmán, M. González De Molina, F. Krausmann, S. Gingrich, and V. Sacristán. 2016. Widening the analysis of energy return on investment (EROI) in agro-ecosystems: Socio-ecological transitions to industrialized farm systems (the Vallès County, Catalonia, c. 1860 and 1999). *Ecological Modelling* 336: 13–25. https://doi.org/10.1016/j.ecolmodel.2016.05.012.

Garcia, L., F. Celette, C. Gary, A. Ripoche, H. Valdés-Gómez, and A. Metay. 2018. Management of service crops for the provision of ecosystem services in vineyards: A review. *Agriculture, Ecosystems & Environment* 251: 158–170. https://doi.org/10.1016/j.agee.2017.09.030.

García-Ruiz, J.M. 2010. The effects of land uses on soil erosion in Spain: A review. *CATENA* 81 (1): 1–11. https://doi.org/10.1016/j.catena.2010.01.001.

García-Ruiz, R., M. González de Molina, G. Guzmán, D. Soto, and J. Infante-Amate. 2012. Guidelines for constructing nitrogen, phosphorus, and potassium balances in historical agricultural systems. *Journal of Sustainable Agriculture* 36 (6): 650–682. https://doi.org/10.1080/10440046.2011.648309.

García-Serrano Jiménez, P., Y. Delgado de Robles, S. Ruano Criado, J. Lloveras Vilamanya, P. Urbano Terrón, M. Pérez Minguijón, J. Ortiz de Frutos, and B. María Rodríguez Sendón. 2009. *Guía práctica de la fertilización racional de los cultivos en España*. Ministerio de Medio Ambiente y Medio Rural y Marino.

Gardeñes i Rosell, D., and E. Vicedo i Rius. 1993. *La vinya i el vi a les terres de Lleida: Història i cultura*. Lleida: Pagès.

Garrabou, R., and J.M. Naredo, eds. 1999. *El agua en los sistemas agrarios. Una perspectiva histórica*. Madrid: Visor.

Garrabou, R., and J. Pujol. 1987. El Canvi Agrari a La Catalunya Del Segle XIX. *Recerques Història, Economia, Cultura* 19: 35–83.

Garrabou, R., J. Planas Maresma, E. Saguer, and E. Vicedo Rius. 2014. Propiedad de La Tierra y Desigualdad Social En El Mundo Rural Catalán de Mediados Del Siglo XIX. *Historia Agraria: Revista De Agricultura e Historia Rural* 63: 115–150.

Giraldo, O.F., and P.M. Rosset. 2018. Agroecology as a territory in dispute: Between institutionality and social movements. *The Journal of Peasant Studies* 45 (3): 545–564. https://doi.org/10.1080/03066150.2017.1353496.

Gliessman, S. R. 1985. Multiple Cropping Systems: A Basis for Developing an Alternative Agriculture. In *US Congress Office of Technology Assessment. Innovative biological technologies for lesser developed countries: workshop proceedings*. 67–83. Washington, DC

González de Molina, M., and G.I. Guzmán. 2017. On the Andalusian origins of agroecology in Spain and Its contribution to shaping agroecological thought. *Agroecology and Sustainable Food Systems* 41 (3–4): 256–275. https://doi.org/10.1080/21683565.2017.1280111.

González de Molina, M., D. Soto Fernández, G. Guzmán Casado, J. Infante-Amate, E. Aguilera Fernández, J.Vila Traver, and R. García Ruiz. 2020. *The social metabolism of Spanish agriculture, 1900–2008: The Mediterranean way towards industrialization*. Cham: Springer Nature. https://doi.org/10.1007/978-3-030-20900-1.

Guzmán, G.I., and M. González de Molina. 2015. Energy efficiency in agrarian systems from an agroecological perspective. *Agroecology and Sustainable Food Systems* 39 (8): 924–952. https://doi.org/10.1080/21683565.2015.1053587.

Guzmán, G.I., E. Aguilera, R. García-Ruiz, E. Torremocha, D. Soto-Fernández, J. Infante-Amate, and M. González de Molina. 2018. The agrarian metabolism as a tool for assessing agrarian sustainability, and its application to Spanish agriculture (1960–2008). *Ecology and Society*. https://doi.org/10.5751/ES-09773-230102.

Himmelstein, J., A. Ares, D. Gallagher, and J. Myers. 2017. A meta-analysis of intercropping in Africa: Impacts on crop yield, farmer income, and integrated pest management effects. *International Journal of Agricultural Sustainability* 15 (1): 1–10. https://doi.org/10.1080/14735903.2016.1242332.

Infante-Amate, J., I. Villa, E. Aguilera, E. Torremocha, G. Guzmán, A. Cid, and M. González de Molina. 2016. The Making of Olive Landscapes in the South of Spain. A History of Continuous Expansion and Intensification. In *Biocultural diversity in Europe*, eds. M. Agnoletti and F. Emanueli. 157–179. Cham: Springer.

Innis, D.Q. 1997. *Intercropping and the scientific basis of traditional agriculture*. London: Intermediate Technology.

Jodha, N.S. 1980. Intercropping in traditional farming systems. *The Journal of Development Studies* 16 (4): 427–442. https://doi.org/10.1080/00220388008421770.

Joffre, R., S. Rambal, and J.-P. Ratte. 1999. The Dehesa system of Southern Spain and Portugal as a natural ecosystem mimic. *Agroforestry Systems* 45 (1): 57–79. https://doi.org/10.1023/A:1006259402496.

Junta Consultiva Autonómica. 1889. *Avance estadístico sobre el cultivo y producción de vid en España*. Madrid.

Junta Municipal de Amillaramientos. 1883. *Cartilla de rectificación de Amillaramiento del distrito municipal del pueblo de Las Olujas*. Les Oluges.

Koohafkan, P., and M.A. Altieri. 2011. *Globally important agricultural heritage systems: A legacy for the future*. Food and Agriculture Organization of the United Nations Rome.

Krausmann, F., K.H. Erb, S. Gingrich, H. Haberl, A. Bondeau, V. Gaube, C. Lauk, C. Plutzar, and T.D. Searchinger. 2013. Global human appropriation of net primary production doubled in the 20th century. *Proceedings of the National Academy of Sciences* 110 (25): 10324–10329. https://doi.org/10.1073/pnas.1211349110.

Krčmářová, J., and M. Arnold. 2016. Traditional Agriculture as Cultural Heritage. Forgotten Agroforestry Practices Recorded in Textual Part of Nineteenth Century Tax Records. In *Biocultural diversity in Europe*, eds. M. Agnoletti and F. Emanueli. 211–231. Cham: Springer.

Kremen, C., A. Iles, and C. Bacon. 2012. Diversified farming systems: An agroecological, systems-based alternative to modern industrial agriculture. *Ecology and Society* 17 (4): 44. https://doi.org/10.5751/ES-05103-170444.

Liebman, M. 2018. Polyculture Cropping Systems. In *Agroecology: The science of sustainable agriculture*, M. Altieri, 205–218. Boca Raton: CRC Press.

López-Garrido, R., E. Madejón, M. León-Camacho, I. Girón, F. Moreno, and J.M. Murillo. 2014. Reduced tillage as an alternative to no-tillage under Mediterranean conditions: A case study. *Soil and Tillage Research* 140: 40–47. https://doi.org/10.1023/A:1022444005336.

Loumou, A., and C. Giourga. 2003. Olive groves: "The Life and Identity of the Mediterranean." *Agriculture and Human Values* 20 (1): 87–95. https://doi.org/10.1023/A:1022444005336.

Malézieux, E., Y. Crozat, C. Dupraz, M. Laurans, D. Makowski, H. Ozier-Lafontaine, B. Rapidel, S. De Tourdonnet, and M. Valantin-Morison. 2009. Mixing plant species in cropping systems: Concepts, tools and models: A review. In *Sustainable agriculture*, ed. E. Lichtfouse, M. Navarrete, P. Debaeke, V. Souchere, and C. Alberola, 329–353. Cham: Springer.

Marco, I., R. Padró, C. Cattaneo, J. Caravaca, and E. Tello. 2018. From vineyards to feedlots: A Fund-flow scanning of sociometabolic transition in the Vallès County (Catalonia) 1860–1956–1999. *Regional Environmental Change* 18 (4): 981–993. https://doi.org/10.1007/s10113-017-1172-y.

Marco, I., R. Padró, and E. Tello. 2020. Dialogues on nature, class and gender: Revisiting socio-ecological reproduction in past organic advanced agriculture (Sentmenat, Catalonia, 1850). *Ecological Economics* 169: 106395. https://doi.org/10.1016/j.ecolecon.2019.106395.

Martin-Guay, M.-O., A. Paquette, J. Dupras, and D. Rivest. 2018. The new green revolution: Sustainable intensification of agriculture by intercropping. *Science of the Total Environment* 615: 767–772. https://doi.org/10.1016/j.scitotenv.2017.10.024.

Marull, J., E. Tello, N. Fullana, I. Murray, G. Jover, C. Font, F. Coll, E. Domene, V. Leoni, and T. Decolli. 2015. Long-term bio-cultural heritage: Exploring the intermediate disturbance hypothesis in agro-ecological landscapes (Mallorca, c. 1850–2012). *Biodiversity and Conservation* 24 (13): 3217–3251. https://doi.org/10.1007/s10531-015-0955-z.

Marull, J., C. Font, R. Padró, E. Tello, and A. Panazzolo. 2016. Energy-landscape integrated analysis: A proposal for measuring complexity in internal agroecosystem processes (Barcelona Metropolitan Region, 1860–2000). *Ecological Indicators* 66: 30–46. https://doi.org/10.1016/j.ecolind.2016.01.015.

McCune, N., I. Perfecto, K. Avilés-Vázquez, J. Vázquez-Negrón, and J. Vandermeer. 2019. Peasant balances and agroecological scaling in Puerto Rican coffee farming. *Agroecology and Sustainable Food Systems* 43 (7–8): 810–826. https://doi.org/10.1080/21683565.2019.1608348.

Migliorini, P., F. Galioto, M. Chiorri, and C. Vazzana. 2018. An integrated sustainability score based on agro-ecological and socioeconomic indicators. A case study of stockless organic farming in Italy. *Agroecology and Sustainable Food Systems* 42 (8): 859–884. https://doi.org/10.1080/21683565.2018.1432516.

Moreno, G., S. Aviron, S. Berg, J. Crous-Duran, A. Franca, S. García de Jalón, T. Hartel, J. Mirck, A. Pantera, and J.H.N. Palma. 2018. Agroforestry systems of high nature and cultural value in Europe: Provision of commercial goods and other ecosystem services. *Agroforestry Systems* 92 (4): 877–891. https://doi.org/10.1007/s10457-017-0126-1.

Nerlich, K., S. Graeff-Hönninger, and W. Claupein. 2013. Agroforestry in Europe: A review of the disappearance of traditional systems and development of modern agroforestry practices, with emphasis on experiences in Germany. *Agroforestry Systems* 87: 475–492. https://doi.org/10.1007/s10457-012-9560-2.

Nicholls, C.I., and M.A. Altieri. 2004. Designing species-rich, pest-suppressive agroecosystems through habitat management. *Agroecosystems Analysis* 43: 49–61. https://doi.org/10.2134/agronmonogr43.c4.

Olarieta, J.R., F.L. Rodríguez-Valle, and E. Tello. 2008. Preserving and destroying soils, transforming landscapes: Soils and land-use changes in the Vallès County (Catalunya, Spain) 1853–2004. *Land Use Policy* 25 (4): 474–484. https://doi.org/10.1016/j.landusepol.2007.10.005.

Olarieta, J.R., R. Padrò, G. Masip, R. Rodríguez-Ochoa, and E. Tello. 2011. "Formiguers", a Historical System of Soil Fertilization (and Biochar Production?). *Agriculture, Ecosystems & Environment* 140 (1–2): 27–33. https://doi.org/10.1016/j.agee.2010.11.008.

Olea, L., and A. San Miguel-Ayanz. 2006. The Spanish Dehesa. A Traditional Mediterranean Silvopastoral System Linking Production and Nature Conservation. *Proceedings of the 21st general meeting of the European Grassland Federation*, Badajoz

Paffarini, C., F. Galioto, M. Chiorri, and P. Migliorini. 2012. Energy analysis of organic horticultural farms in Italy. *New Medit: Mediterranean Journal of Economics, Agriculture and Environment Revue Méditerranéenne D'economie Agriculture Et Environment* 11 (4): 49–52.

Paris, P., F. Camilli, A. Rosati, A. Mantino, G. Mezzalira, C. Dalla Valle, A. Franca, G. Seddaiu, A. Pisanelli, and M. Lauteri. 2019. What Is the future for agroforestry in Italy? *Agroforestry Systems* 93: 2243–2256. https://doi.org/10.1007/s10457-019-00346-y.

Pastor, L. V. E. 2016. *Atlas del cultivo tradicional del viñedo y de sus paisajes singulares*. Ministerio de Educación Cultura y Deporte.

Perfecto, I., and J. Vandermeer. 2010. The Agroecological matrix as alternative to the land-sparing/agriculture intensification model. *Proceedings of the National Academy of Sciences* 107 (13): 5786. https://doi.org/10.1073/pnas.0905455107.

Pinto-Correia, T., and W. Vos. 2004. Multifunctionality in Mediterranean landscapes-past and future. In *The new dimensions of the European landscape, wageningen UR frontis series*, ed. R.H.G. Jongman, 135–164. Cham: Springer.

Pleasant, J.. Mt.., and R.F. Burt. 2010. Estimating productivity of traditional iroquoian cropping systems from field experiments and historical literature. *Journal of Ethnobiology* 30 (1): 52–79. https://doi.org/10.2993/0278-0771-30.1.52.

Plieninger, T., F. Höchtl, and T. Spek. 2006. Traditional land-use and nature conservation in European rural landscapes. *Environmental Science & Policy* 9 (4): 317–321. https://doi.org/10.1016/j.envsci.2006.03.001.

Pro Ruiz, J. 1995. Ocultación de La Riqueza Rústica En España (1870–1936): Acerca de La Fiabilidad de Las Estadísticas Sobre La Propiedad y Uso de La Tierra. *Revista De Historia Económica-Journal of Iberian and Latin American Economic History* 13 (1): 89–114. https://doi.org/10.1017/S0212610900004894.

Rigueiro-Rodríguez, A., J. McAdam, and M.R. Mosquera-Losada. 2008. *Agroforestry in Europe: Current status and future prospects*. Dordrecht: Springer.

Ripoche, A., A. Metay, F. Celette, and C. Gary. 2011. Changing the soil surface management in vineyards: Immediate and delayed effects on the growth and yield of grapevine. *Plant and Soil* 339 (1): 259–271. https://doi.org/10.1007/s11104-010-0573-1.

Roger-Estrade, J., C. Anger, M. Bertrand, and G. Richard. 2010. Tillage and soil ecology: Partners for sustainable agriculture. *Soil and Tillage Research* 111 (1): 33–40. https://doi.org/10.1016/j.still.2010.08.010.

Ruiz-Colmenero, M., R. Bienes, and M.J. Marques. 2011. Soil and water conservation dilemmas associated with the use of green cover in steep vineyards. *Soil and Tillage Research* 117: 211–223. https://doi.org/10.1016/j.still.2011.10.004.

Segura i Mas, A. 1990. Els Amillaraments: Una Font per a l'anàlisi de La Propietat de La Terra a La Segona Meitat Del Segle XIX. *Estudis D'història Agrària* 8: 235–265.

Sereni, E. 1997. *History of the Italian agricultural landscape*. New Jersey: Princeton University Press.

Sevilla Guzmán, E., and G. Woodgate. 2013. Agroecology: Foundations in Agrarian social thought and sociological theory. *Agroecology and Sustainable Food Systems* 37 (1): 32–44. https://doi.org/10.1080/10440046.2012.695763.

Shanin, T. 1972. *The awkward class*. Oxford: Clarendon Press.

Shanin, T. 1973. The nature and logic of the peasant economy 1: A generalisation. *The Journal of Peasant Studies* 1 (1): 63–80. https://doi.org/10.1080/03066157308437872.

Smetschka, B., V. Gaube, and J. Lutz. 2014. Working time of farm women and small-scale sustainable farming in Austria. In *Ester Boserup's legacy on sustainability*, ed. M. Fischer-Kowalski, A. Reenberg, A. Schaffartzik, and A. Mayer, 221–238. Dordrecht: Springer.

Soto, D., J. Infante-Amate, G.I. Guzmán, A. Cid, E. Aguilera, R. García, and M. González de Molina. 2016. The social metabolism of biomass in Spain, 1900–2008: From food to feed-oriented changes in the agro-ecosystems. *Ecological Economics* 128: 130–138. https://doi.org/10.1016/j.ecolecon.2016.04.017.

Tamburini, G., R. Bommarco, T.C. Wanger, C. Kremen, M.G.A. van der Heijden, M. Liebman, and S. Hallin. 2020. Agricultural diversification promotes multiple ecosystem services without compromising yield. *Science Advances* 6 (45): eaba1715. https://doi.org/10.1126/sciadv.aba1715.

Tello, E., E. Galán, V. Sacristán, G. Cunfer, G.I. Guzmán, M. González de Molina, F. Krausmann, S. Gingrich, R. Padró, and I. Marco. 2016. Opening the black box of energy throughputs in farm systems: A decomposition analysis between the energy returns to external inputs, internal biomass reuses and total inputs consumed (the Vallès County, Catalonia, c. 1860 and 1999). *Ecological Economics* 121: 160–174. https://doi.org/10.1016/j.ecolecon.2015.11.012.

Tello, E., M. González de Molina. 2023. Agrarian Metabolism and Socio-Ecological Transitions to Agroecology Landscapes. In *The Barcelona School of Ecological Economics and Political Ecology: A companion in honour of Joan Martinez-Alier,* eds. S. Villamayor and T. Roldan Muradian, 93–107. Cham: Springer.

Tello, E., E. Galán, G. Cunfer, G. Guzmán, M. González de Molina, F. Krausmann, S. Gingrich, V. Sacristán Adinolfi, I. Marco, and R. Padró. 2015. A Proposal for a Workable Analysis of Energy Return On Investment (EROI) in Agroecosystems. Part I: Analytical Approach. *IFF Social Ecology Working Papers* 156:1–110

Tello, E. 1995. *Cervera i La Segarra al segle XVIII: En els orígens d'una Catalunya pobra, 1700–1860*. Lleida: Pagès Editors.

Tilman, D., C. Balzer, J. Hill, and B.L. Befort. 2011. Global Food demand and the sustainable intensification of agriculture. *Proceedings of the National Academy of Sciences* 108 (50): 20260–20264. https://doi.org/10.1073/pnas.1116437108.

Toledo, Víctor Manuel. 1995. Campesinidad, Agroindustrialidad, Sostenibilidad: Los Fundamentos Ecológicos e Históricos Del Desarrollo Rural. *Revista de Geografía Agrícola* (28).

Torralba, M., N. Fagerholm, P.J. Burgess, G. Moreno, and T. Plieninger. 2016. Do European agroforestry systems enhance biodiversity and ecosystem services? A meta-analysis. *Agriculture, Ecosystems & Environment* 230: 150–161. https://doi.org/10.1016/j.agee.2016.06.002.

Trenbath, B.R. 1974. Biomass productivity of mixtures. *Advances in Agronomy* 26: 177–210. https://doi.org/10.1016/S0065-2113(08)60871-8.

Valdivia, C. 2001. Gender, livestock assets, resource management, and food security: lessons from the SR-CRSP. *Agriculture and Human Values* 18 (1): 27–39. https://doi.org/10.1023/A:1007613031102.

Van der Ploeg, J. D. 2013. *Peasants and the art of farming: A Chayanovian manifesto*. Black Point, Nova Scotia: Fernwood.

Van der Ploeg, J.D. 2009. *The new peasantries: Struggles for autonomy and sustainability in an era of empire and globalization*. London: Earthscan.

Vandermeer, J. 1992. *The ecology of intercropping*. Cambridge: Cambridge University Press.

Vandermeer, J. 2009. *The ecology of agroecosystems*. London: Jones & Bartlett Publishers.

Vicedo i Rius, E. 1993. Las Condiciones de Reproducción de La Unidad Familiar Campesina En La Catalunya Nova: Las" Terres de Lleida". *Noticiario De Historia Agraria* 5: 43–66.

Vicedo i Rius, E. 2002. Estacionalidad y Productividad Del Trabajo En Un Marco Tecnológico Tradicional: Cataluña Occidental, 1750–1890. *Historia Agraria* 27: 101–131.

Vilá, V.J., and J. Vernet. 1971. *L'altra cara de Catalunya: Un país d'agricultors*. Barcelona: Real Academia de Buenas Letras.

Vilar, Pierre. 1987. *Catalunya dins l'Espanya moderna: Les transformacions agràries del segle XVIII català*. Barcelona: Edicions 62,

Vitousek, P.M., P.R. Ehrlich, A.H. Ehrlich, and P.A. Matson. 1986. Human appropriation of the products of photosynthesis. *BioScience* 36 (6): 368–373. https://doi.org/10.2307/1310258.

Vos, W., and H. Meekes. 1999. Trends in European cultural landscape development: Perspectives for a sustainable future. *Landscape and Urban Planning* 46 (1–3): 3–14. https://doi.org/10.1016/S0169-2046(99)00043-2.

Weigelt, A., and P. Jolliffe. 2003. Indices of plant competition. *Journal of Ecology* 91 (5): 707–720.

Winkel, T., L. Núñez-Carrasco, P. José Cruz, N. Egan, L. Sáez-Tonacca, P. Cubillos-Celis, C. Poblete-Olivera, N. Zavalla-Nanco, B. Miño-Baes, and M.-P. Viedma-Araya. 2020. Mobilising common biocultural heritage for the socioeconomic inclusion of small farmers: Panarchy of two case studies on Quinoa in Chile and Bolivia. *Agriculture and Human Values* 37 (2): 433–447. https://doi.org/10.1007/s10460-019-09996-1.

Wolf, E.R. 1966. *Peasants*. Englewood Cliffs: Prentice Hall.

Zhang, L. 2020. From left behind to leader: Gender, agency, and food sovereignty in China. *Agriculture and Human Values* 37 (4): 1111–1123. https://doi.org/10.1007/s10460-020-10114-9.

Zimmerer, K.S., Y. Jiménez Olivencia, L. Porcel Rodríguez, N. López-Estébanez, F. Allende Álvarez, R. Mata Olmo, C. Yacamán Ochoa, Á. Raúl Ruiz Pulpón, and Ó. Jerez García. 2022. Assessing social-ecological connectivity of agricultural landscapes in Spain: Resilience implications amid agricultural intensification trends and urbanization. *Agricultural Systems* 203: 103525. https://doi.org/10.1016/j.agsy.2022.103525.

Zuazo, V., H. Durán, and C.R. Rodríguez Pleguezuelo. 2009. Soil-erosion and runoff prevention by plant covers: A review. In *Sustainable agriculture*, ed. E. Lichtfouse, M. Navarrete, P. Debaeke, V. Souchere, and C. Alberola, 785–811. Cham: Springer.

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