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RABASSAIRES, FORMIGUERS AND CAGANERS: COMPARING TWO NUTRIENT BALANCES c.1860 AND c.1920 IN THE NORTHEAST OF THE IBERIAN PENINSULA

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Resumen

Entender la reposición de nutrientes extraídos por las cosechas nos ayuda a entender la influencia de los seres humanos sobre la fertilidad. En este trabajo comparamos dos estudios anteriores sobre el balance de nutrientes de la superficie agraria del noreste peninsular, que transcurren alrededor de 1860 y de 1920. Pese a que en esta zona las densidades ganaderas por superficie agraria eran insuficientes para equilibrar la extracción de tres macronutrientes— N, P y K—, todo un abanico estrategias de fertilización distintas conseguía llegar al equilibrio a nivel regional. El viñedo jugaba un papel clave, no sólo por la gran extensión que ocupaba, sino por sus relativamente bajas necesidades de nutrientes. Aunque debido a la disponibilidad de fuentes históricas la escala de análisis no puede ser la misma, la comparación de ambos casos muestra dos momentos distintos de la Transición Socioecológica del metabolismo agrario. Por último, los resultados de un caso y otro nos llevarán a plantearnos la relación entre la fertilidad y la desigualdad en un mundo rural ya muy polarizado de finales del siglo diecinueve.

Palabras clave: Metabolismo Social; Transición Socioecológica; Balance regional de nutrientes; Agricultura Industrial; Cambio Agrario.

Abstract

Understanding the replacement of the nutrients removed by harvests helps us understand the influence of humans on fertility. In this paper we compare two previous studies on the nutrient balance of the cropland area in the northeast of the Iberian Peninsula, which run circa 1860 and 1920. Although in this region livestock densities per cropland area were insufficient to balance the extraction of three macronutrients—N, P and K—, a diverse range of fertilising sources managed to reach equilibrium at regional level. The vineyard played a key role, not because of the great area occupied, but by its relatively low nutrient requirements. Albeit due to the availability of historical sources the scale of analysis differs, the comparison of the two cases shows two different steps of the Socio-Ecological Transition of agricultural metabolism. Finally, the results take us to consider the relationship between fertility and inequality in the highly polarized Catalan rural world at the late nineteenth century.

Key words: Social Metabolism; Socio-Ecological Transition; Regional Nutrients Balance; Industrial Agriculture; Agricultural Change.

JELCodes: N53, N93, Q10, Q19, Q59

Rabassaires, *formiguers* and *caganers*[1]: comparing two nutrient balances c.1860 and c.1920 in the northeast of the Iberian Peninsula

1. Introduction

1.1. Aims and scope

The dominant socio-economic and socio-technical view on industrialization as a gradual process of continuous growth and technological change can be complemented by focusing on changes in society-nature relations (Krausmann et al., 2008). Sieferle (2001) related them with material and energy use in History. In doing so, he described three socio-ecological regimes depending on the mode of appropriation of energy: uncontrolled solar energy use (hunter-gatherers societies), controlled solar energy use (agrarian societies) and fossil energy use (industrial societies). The periods of change between them are usually referred to as revolutions, although thinking of them in terms of Socio-Ecological Transitions provides more analysis potential (González de Molina, 2010a; Infante-Amate and González de Molina, 2013; Krausmann and Fischer-Kowalski, 2013; Krausmann et al., 2008). The transition to an industrial regime entailed the progressive adoption of a new pattern of society-nature interaction along with its material and energy use, that could be understood as "a stepwise process of decoupling the supply of energy from land related biomass and from human labour on the land."(Krausmann et al., 2008, p. 188). Indeed, the exploitation of finite stocks of fossil energy allowed societies to overcome the growth ceilings of agrarian societies. In turn, it created new environmental problems derived from the use of fossil energy and excess of synthetic fertilizers.

Our hypothesis is that, in the context of the late nineteenth-century Iberian Peninsula, a number of factors including the liberal reforms of the Spanish State, population growth, market integration (which in an extended area of Catalonia crystallised in vineyard specialisation) and urbanization, made the soil fertility a critical issue. Moreover, replenishing soil nutrients was further hindered by the social inequality that already existed in rural societies, which deepened from the end of the nineteenth century onwards. Nevertheless, if so, to what extent was the growing amount of nutrients extracted by crops replenished into the soil? The aim of this article is to search for historical answers to this general question by comparing two agrarian systems in the northeast corner of the Iberian Peninsula c.1860 and c.1920.

1.2. The Socio-Ecological Transition of the agrarian metabolism

The transition from controlled solar energy to fossil energy modes of appropriation occurred typically in two steps. First, a coal era coexisted with agricultural activities

[1] Traditional Catalan figurine appearing in nativity scenes depicted as a peasant defecating.

that remained still organic; and second, an oil and electricity era pulled agriculture into the industrial mode. The first coal era[2]started in the United Kingdom around 1800, where 900 kg·cap^{-1}were used. A century later, the use of coal expanded to other places. However, while most urban-industrial centres in other world regions had already begun the transition, over 70% of coal extracted globally was used by only four countries: UK, France, Germany and USA (Krausmann and Fischer-Kowalski, 2013).

Paradoxically, the use of coal did not replace the need for human physical work, but increased the demand for non-agricultural production. The same happened with the expansion of the railway and the need for draught animals as they covered in combination the increasing needs for transport of goods and people. Hence, the number of draught livestock increased at the beginning of the twentieth century (Krausmann and Fischer-Kowalski, 2013). Consequently, the need for biomass (either as infrastructures, paper or food) increased (Iriarte-Goñi and Ayuda, 2012), while the cultivable area and yields per area stagnated at the end of the nineteenth century in Western Europe. Most of the cultivated land relied mainly on organic fertilizing methods, e.g. manure, green manure, deposition, etc., and the applications of guano, Chilean nitrates or superphosphates at that time were barely enough to supply all the required nutrients.

In the meantime, on the other side of the Atlantic ocean, USA's farms managed to export to Western Europe four million tonnes of cereal, enough to feed over 20 million people (Krausmann and Fischer-Kowalski, 2013). Unlike European soils, the newly ploughed fertile soils of the American prairies produced, during the initial decades, high yields per hectare with low rural population densities,hence allowingfood exports to densely populated coastal urban centres and to Europe (Cronon, 1991). This system functioned as long as it was possible to expand the frontier and abandon lands with declining fertility. In some areas of the Great Plains the soils lost around 45% of their N content, and by 1870, as the frontier was closing, this led to fertility losses and subsequent declining yields in the first decades of the twentieth century (Cunfer, 2004, 2005).

Nevertheless, this situation changed in the second step of the transition. Since 1940,the use of cheap oil in the energy-consuming Haber-Bosch process allowed N fertilizer to be easily obtainable (Smil, 2001), the number of tractors started to increase, and the availability of electricity permitted the use of groundwater to expand the irrigated land (Cunfer, 2004, 2005). Besides closing the main nutrients gap through the industrial production of N, P and K[3], all these techniques and technologies allowed economies of scale in agriculture. These technologies, were exported to Europe after the end of World War II, and then to the rest of the world. This mode of agriculture was intensive in energy use as it was developed when oil prices were cheap. This created a new relationship between industrial centres and the global periphery, introducing new ecological problems (Krausmann and Fischer-Kowalski, 2013).

[2] That of the subterranean forests of Sieferle (2001) or the *Coketowns* of McNeill (2001).

[3]Calcium was restored through liming practices, which had been done in Europe previously.

To complement this vision, González de Molina (2010a) argued that, in Europe, the transition towards an industrial agriculture did not start after World War II but before, during the nineteenth century, and suggested that it occurred in a series of waves.

The first wave, entailed increasing the biomass production of the agroecosystems by three means: increasing the extension of cropland for the provision of food, increasing yield per land unit (substituting human labour force by draught animals, eliminating fallow, introducing rotations, etc.), and specializing the production instead of maintaining a heterogeneous landscape[4]. The enforcement of one or more of these strategies depended on land availability, climate and soil conditions; hence, the role played by humans to maintain or increase fertility was a key point. When by 1870s American grains invaded the European markets (O'Rourke, 2009),the strategy of importing the biomass that European agroecosystems were unable to produce prevailed over the other three (González de Molina, 2010a).

This had different effects in different European areas. In Britain, the most well-known case, the system of combining convertible husbandry with the Norfolk rotation (mainly the second of the above strategies) started its end and animal breeding using American grains as feed expanded (González de Molina, 2010a; van der Ploeg, 2014). In any case, when humans were not able to replace the organic matter and nutrients, the increase in agrarian productivity was at the expense of the reserves in the soil. This led to an earlier European loss of soil fertility, as would later happen in North America in the first decades of the twentieth century. To escape from this situation, it was necessary to find external sources of fertility. Therefore, between the end of the nineteenth century and World War II, when coal was replaced by oil and natural gas and manual labour was replaced by machines, González de Molina(2010a) suggested a second wave starting from the initiation of the use of synthetic fertilizers. Albeit not yet by the hand of the Haber-Bosch process for N. Although the weight of synthetic fertilizers was not as big as after World War II, its use along with guanos meant that the lack of nutrients started to be overcome by reducing the land cost of fertilization (González de Molina, 2010a), which was the main constraint in solar-energy based agriculture.

From the seminal works of Liebig and his discussions with the British agronomists Lawes and Gilbert during the nineteenth century, one can distil the following idea: it was not enough to apply a random quantity of manure in fields; to preserve or increase their fertility, it was necessary to refill the nutrients extracted by crops (Smil, 2001). This idea was in the mind of the Spanish agronomists at the beginning of the twentieth century, who, in addition to pointing out insistently the low livestock densities and the ensuing chronic insufficiency of manure, recommended the use of other fertilizers (synthetic and organic) as an obligatory complement to manure (Cascón, 1918; García-Luzón, 1922; Llorente and Galán, 1910; Rueda-y-Marín, 1934). Along with the sellers of P fertilizers (Medem, 1897), they argued that, although N was the main concern in

[4] At the crop scale, this implied the loss of multifunctionality of some crops, as was the case of olive groves in Spain (Infante-Amate and González de Molina, 2013).

agriculture,it was the main nutrient returned by organic fertilizing methods, so there was a need to complement them with fertilizers rich in other nutrients. In addition, others insisted in abandoning the extended belief that permanent wooden crops, such as olive groves or vineyards, did not need fertilization. Besides, they provided other complementary sources of nutrients, cheap and available for farmers, such as human faeces, dry blood, shearing residues, or even the dead and dried bodies of locusts hunted when there was a plague (López-Mateo, 1922; Soroa, 1929).

The elimination of fallows was a matter of concern of the time and the use of rotations was highly recommended. Needless to say, the Norfolk rotation could not be reproduced everywhere as clover, which played a more important role as a N fixing crop than other leguminous crops (Allen, 2008), is more susceptible to aridity (the climate of Mediterranean Spain)than the more drought-resistant forage legumes, such as sainfoin (FAO, 2012). Another purpose for leaving lands in fallow was to eliminate predators and competitors, i.e. weeds, and so enhance fertility. This is why other agronomists recommended the chemical disinfection of soils (Casado de la Fuente, 1923) when fallows were eliminated. Although the reduction of fallow could be seen as further evidence to an earlier starting point for the transition of the agrarian metabolism, for this study we left it aside, as well as other technical innovations not concerning the direct applications of nutrients.

Beyond agronomists considerations, tenants and sharecroppers had to accomplish the contractual obligations of landowners concerning fertility, which started to be common in the second half of the nineteenth century. They could be, for example, the prohibition to sell the straw and the obligation to use it as bedding material for the manure of the farm, or the obligation to burn the pruning from vineyards in soil covered piles called «*hormigueros*» and use them as fertilizer (Saguer and Garrabou, 1995).

1.3. Nutrient flows, history and agricultural systems

Accounting for the flows of nutrients within a system allows analysing the impact of human activities in compartments of ecosystems throughout time. As an example, Kimura and Hatano, (2007) and Kimura et al., (2004) assessed the increasing N pollution in the agricultural system of the city of Hokkaido (Japan) due to the separation of consumption and production food sectors during the twentieth century; Lassaletta et al.(2013) analysed the increase of N emissions within Spanish river basins due to the change in diet pattern from 1960 to 1990; and Billen et al. (2007) explored the changing relationship between the population of Paris and the Seine river over 500 years through the quantification of N, P and Si flows. When applied to prior periods, the analysis of nutrients flows gave information about the relation between fertility, rotations including legumes (specially the Norfolk rotation) and convertible husbandry in England and Northern Europe until they reached productivity ceilings (Allen, 2008; Chorley, 1981).

The first wave of the Socio-Ecological Transition, however, happened earlier in Mediterranean Europe due to water availability constraints, whose main effects were the lower livestock densities that could be maintained and the reduced capacity to grow leguminous crops (González de Molina 2002). The increase of monogastric animals (mostly mules) for transport and the trend to cultivate more cereal land pressured Mediterranean agroecosystems even more, hence only the more productive (often irrigated) land types were properly fertilized (González de Molina, 2002). On the other side of the Atlantic, once the frontier was closed, the first wave gave way to the second only in few decades (Cunfer, 2004, 2005).

In the South of the Mediterranean Iberian Peninsula it was argued that fertilizing efforts were concentrated in some rotations such as *ruedo* and thus mined the soils of others e.g. the extreme case of olive groves (González de Molina and Guzmán, 2006; González de Molina, 2002). In the Northeast of the Mediterranean Iberian Peninsula, Tello et al. (2012) assessed the importance of cultural peasant practices when restoring nutrients in the municipality of Sentmenat circa 1860. By contrast, due to lack of data, they did not follow the nutrient flows in other (more arid) municipalities, crop type or rotation; but they concluded that, probably, to balance the soil nutrients some crop types, others such as vineyards had to be short of nutrients. We aim to lengthen in time that study by doing another case circa 1920 to figure out to what extent were organic and synthetic fertilizers important for the maintenance of fertility, as by this time the system should be situated in between the first and the second wave according to González de Molina(2010a). Some concerns about the scale and methodological differences are described in the following section.

2. Material and methods

2.1. Sources and scale justification

As said above, the aim of this paper is to compare two exercises of nutrient flow accountings within the framework of Socio-Ecological Transitions (González de Molina, 2010a; Krausmann and Fischer-Kowalski, 2013; Krausmann et al., 2008). They represent a fixed picture of the first two waves of the Socio-Ecological Transition of agriculture in the Northeast of the Iberian Peninsula. Circa 1860 represent the first wave, with the agro-ecosystem approaching its limits, whereas circa 1920 represents a system with one foot in the first wave and the other in the second. Previously to the comparison, however, we should specify some differences concerning scale and method, which are the result of the historical processes that created the available sources.

During the nineteenth century, the configuration of the Spanish liberal State and a centralized tax office gave rise to the consolidation of a new and unified Spanish fiscal system. From then, not only a number of cadastral surveys and statistical information of the mid-nineteenth century are available as historical sources. Additionally, as a reaction to the new taxes on land, some towns and villages all over the Spanish State declared land by providing detailed information about land properties, in the form of reports, maps, etc. However, opposite as the consolidation of other liberal states such as

France or the Austro-Hungarian Empire, this process was done in a chaotic way and the information that remains today is far from centralized, complete and homogeneous. From 1860s onwards the main source for calculation of the State agricultural taxes were the «*amillaramientos*» surveys about rural properties and its monetary value, which is the main source that we used for these years (Muro et al., 1996).

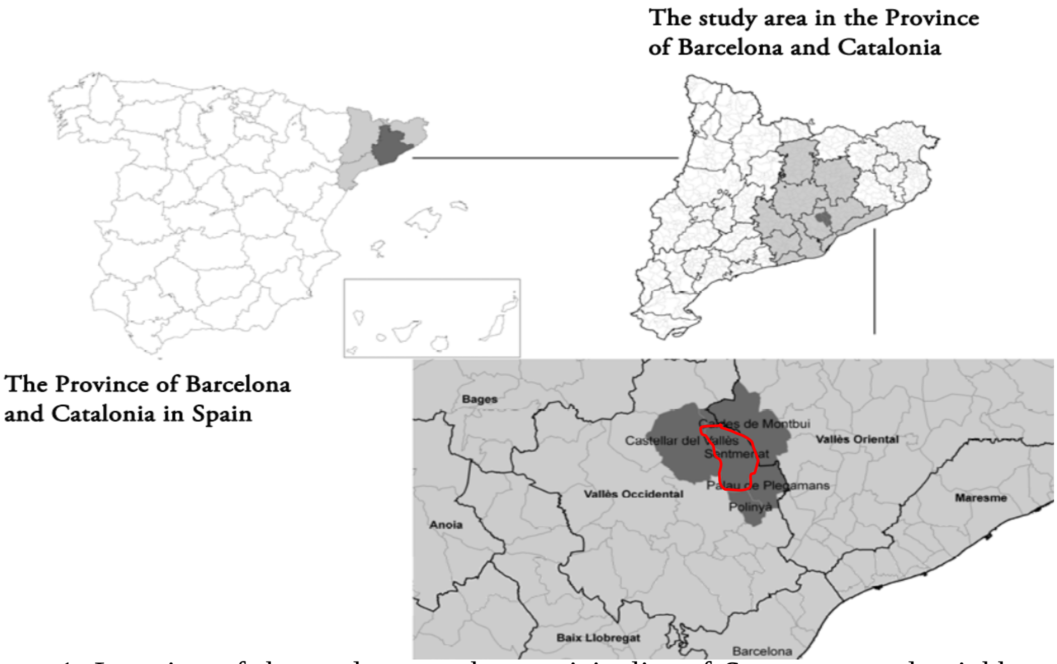

Figure 1. Location of the study area: the municipality of Sentmenat and neighbouring townships in the province of Barcelona and Catalonia (Spain). Source: from Marull et al. (2008a)

At first, these *amillaramientos* were conceived as a temporary expedient until the Spanish cadastre ended, but as this eventually did not happen in the nineteenth century, they remained in a fossilized state. From the beginning of the twentieth century and until the end of that monarchal regime with the Second Spanish Republic, they became increasingly out of date. As a result, the tax system deteriorated and became more and more conflictive, which also entailed the deterioration of the *amillaramientos* as a reliable historical source.

Hence, the *amillaramientos* have some disadvantages as a statistical source. First, as they were a fiscal instrument, some information could have been omitted or distorted to avoid the payment of higher taxes. Second, the information is rather general, they offer mainly total areas of irrigated and rainfed land classified by the main agricultural uses (grains, vines, olive orchards and other arboriculture crops, pastureland and woodland) without specifying rotations and fallow land. To turn this basic information onland uses into taxable incomes some converters such as; average yields, current prices of products and usual cost of the main inputs (labour, draught power, seeds, manure, etc.) were required. This information was provided by the «*cartillas evaluatorias*», a crucial document only rarely kept in local archives—thus obliging us to resort on the few that are available which do not always correspond to the particular local conditions of the area studied. Third, once the land of a municipal territory had been classified in the first *amillaramiento* only the final distribution of the tax burden according to the taxable incomes assigned were updated over time, this does not provide enough periodicity to make a real series (GEHR, 1991). Last, but not least, the information on land uses was only kept at municipal level and no aggregated statistics was compiled at district, provincial or national level throughout this period.

In 1879, *Ministerio de Fomento* established the *Servicio Agronómico de España* to centralize the surveys dealing with the agricultural sector. It was organized by the chief agronomist engineers of each province and a higher level of nine engineers located in the capital, which were known as the *Junta Consultiva Agronómica,* which published some reports until the reform of 1927, when a series of agricultural yearbooks started (GEHR, 1991). Notwithstanding, the information that they generated in the first decades of its existence was incomplete and poorly detailed, and the local surveys that the engineers of each province used to compile in the provincial reports during all the lifespan of the *Junta Consultiva Agronómica* have never been found(GEHR, 1991).

Summing up, for the years 1845-1865 we have a number of local sources, but it is almost impossible to find and group them to allow the aggregation at provincial scale or even other smaller administrative units such as the *comarcas* (similar to English counties). Then, from the 1860s to the 1890s there is an authentic statistical blackout, created not only by what has been explained above but due to the tumultuous period of the *Sexenio Revolucionario* (1868-73) and the Third *Carlista* War (1872-76),followed by a lack of interest in the first decades of the *Restauración Borbónica* (1974-1931) to renew the fiscal system. It was only after 1890, when the idea that the State had to become an active stakeholder in the economic improvement of the country, that we start to have a proliferation of aggregated statistical sources, by Province and sometimes by *Partido Judicial* (similar to English districts), but not local districts. As a result, from 1845 to 1865 we can carry out many local case studies but there are not historical series at provincial and national level. Ironically, after the statistical blackout from 1860 to 1890, we can start relying on the series and surveys compiled by the *Junta Consultiva Agronómica*(JCA) at provincial or national level, but no local information is available.

As a local case study we selected Sentmenat, a municipality located in Vallès *comarca* in the province of Barcelona (Figure 1) c.1860 for the analysis. For two main reasons, the availability of sources and the long trajectory of research on these sources. The aristocrat lineage of the Marquises of Sentmenat had carefully preserved their patrimonial documents over the centuries, and they finally donated it to the main archive of Catalonia, the *Arxiu de la Corona d'Aragó*. The richness and detail of these records allowed a number of studies. As the feudal and landlord bookkeeping together with copies of probate inventories and wills contained a great deal of information about land uses, crop yields, water conflicts, rents, tithes, wages, litigations, etc. (Badia-Miró and Tello, 2014; Cussó et al., 2006; Garrabou et al., 2010; Garrabou Segura et al., 2001; Millán et al., 2006; Serra, 1988; Soto and Batet, 1997).

Details of the nutrient balance c.1860 are published elsewhere (Tello et al., 2012). On the other hand, for the analysis c.1920, we used the data at the only available scale, which was mostly at province level. Hence for crop production we used JCA (1923), for livestock numbers we used data from two livestock census (JCA, 1920; MF,1924), for the main fertilizing materials we used JCA (1921) and we inferred irrigation doses using JCA (1916). Criticisms and corrections of these specific sources are too long for this article and are detailed in Galán (2014).

2.2. Methodological aspects

Both studies were made following the "Guidelines for Constructing Nitrogen, Phosphorus, and Potassium Balances in Historical Agricultural Systems"(Garcia-Ruiz et al., 2012; González de Molina, 2010b). Nevertheless, the are some differences in the methodology of calculating some of the nutrient flows between both cases. Especially regarding manure and humanure[5] as a result of improvements on the methodology and correction of sources.

We augmented the number of sources of production and composition of manure and humanure. Two main concerns motivated this change: the huge potential variability of data—as production and composition of manure relies on a number of factors such as diet, age, activity, etc—and the lack of dry weight data. Moreover, concerning humanure we adopted a new method to estimate the potential collection taking into account the main disposal systems conditioned by the type of human settlements instead of only considering sewage systems as we did c.1860.

Hence we discriminated among scattered rural houses or group of houses (population that inhabits in 10 buildings or less is accounted as *diseminados* or scattered by Nomenclator), concentrated rural villages and urban areas (Esteve-Palós, 2003). While in our first analysis we omitted the variability, in the second analysis we decided to include the Standard Deviations to leave some space for variability and thus increasing the robustness of the analysis. The specification for these calculations, as well as the compilation of historical sources and the values considered, lengthen the list that appears in Lana-Berasain (2010), these are specified in Galán (2014).

The next important difference concerned the emission of nutrients to the atmosphere or water bodies. We could not find historical sources for the losses of N, P and K although for the analysis c. 1860 they were presumably found in Cascón (1918). However, this engineer only mentioned some experiments of N losses in manure in other countries and did not quantify nutrient losses on his farm, at least in the work cited, so we found an alternative way to quantify nutrient losses.

For the analysis c.1920 we used the "Guidelines of the Intergovernmental Panel on Climate Change"(IPCC, 2006). They quantify the losses of N following two processes:

[5]We preferred to use this elegant way when referring to human fecal material and urine and its potential as fertilizer (Jenkins, 2005) as started to be used in scientific journals e.g. Schneider and McMichael (2010) instead of a large and confusing list of euphemisms.

through storage, which involved almost the 50% of the N in manure; and through land management, which involved other fertilizers, tillage and irrigation. The weak point of our estimation is that we needed to separate dung from straw (as the main losses occur in dung) and the production together with the composition data that we have is for manure i.e. dung and straw together. However, it can be done as long as we estimated the amount of straw used and its composition. These former considerations apply to humanure as well.

In any case, Tello et al., (2012) did not explicitly account for manure losses in the balance c.1860, although they were subtracted from the potential N inputs of manure. Simultaneously, we overestimated the losses from lixiviation, which in this case was close to the total of N losses on balance. Considering a Mediterranean climate, to be compatible with the methodology we should multiply the lixiviation factor only by irrigated land and not by all the cropland area, and hence the value would drop from 5.5 to 0.23 kg of $N \cdot ha^{-1}$ (Figure 3). Yet, the overall result for N would not have changed that much as it would be compensated by the increase of N denitrification of managed land, which according to the IPCC (2006) methodology would have rose from 1.5 to 6.5 kg of $N \cdot ha^{-1}$ approximately. Something similar would have happened with K losses, however as given that would be negligible (Garcia-Ruiz et al., 2012), the amount considered c.1860 is so low that they could have been compensated by other minor differences without affectingthe overall balance significantly.

We reviewed a number of historical sources written by Spanish agronomists at the end of the nineteenth century and the beginning of the twentieth for the analysis c.1920. Among the recommended manure applications, we only found the already mentioned amount of 6-7.2 $t \cdot ha^{-1}$ of fresh manure (Llorente and Galán, 1910), but we could not confirm the 10 $t \cdot ha^{-1}$ wrongly attributed to Cascón (1918) in the analysis c.1860, as he only stated that he used 20 $t \cdot ha^{-1}$ to fertilize his own farm (Cascón, 1918, p. 60). In any case, all the agronomists of the time were concerned about the low availability of nutrients, and their advice was not limited to a fixed amount of manure as they recommended quantifying the extractions of nutrients in order to return them to the soils using all possible combinations.

In addition of the sources already mentioned for the analysis c.1920, we used nutrient composition data from Soroa (1953) for crops and seeds, ACA (2000-2014) for nutrients in irrigation water, Rodrigo (1998) for deposition, Goulding (1990) for free fixation and Gallego (1986) for synthetic fertilizers.

3. Discussion

3.1. Socioeconomic features

Low livestock densities, low share of forest and pasturelands, and vineyard specialisation of Sentmenat c.1860 were argued to be typical of a Mediterranean-type of «intensive organic agriculture» (Tello et al., 2012). Vineyard specialisation played a key role by complementing forest produce, such as prunings burnt as fuel or as fertilizer in *hormigueros*, leaves, shoots and pomaces as animal feed or fertilizer (Cussó et al., 2006), as was done for centuries in the great diversity of silvoarable landscapes of Europe (Eichhorn et al., 2006). Indeed, the low forest, scrubland and pastures ratio per unit of cropland was a matter of concern at the end of the nineteenth and the beginning of the twentieth centuries. As claimed by Huguet del Villar in 1921, when he stated that in Spain forest land was only between 10 and 15% of total area (Tello and Sudrià, 2011). This number is similar to that found in the plains of the province of Lleida (Galán, 2014) and was probably shared with other cereal regions of the Castilian plains, but is lower compared to our case study (Table 1). The general trend in comparing Sentmenat and the province of Barcelona was an increase in the share of forest, scrubland and pastures[6].At the same time, the complementary function of the vineyards lost importance, as the multifunctionality of arboricultural crops lost importance in other places of the Iberian Peninsula (Cervera et al., 2014; Infante-Amate and González de Molina, 2013).

Other indicators are difficult to compare as the province of Barcelona was strongly influenced by Barcelona city. However the census of population (INE, 1920) and livestock (JCA, 1920) allowed to separate the *Partido Judicial* of Barcelona from the rest of the province, showing that while the population density in the later increased up to 84 inhab·km^{-2}, the increase in livestock density per cropland area was not so dramatic(14 LU 500 kg·km^{-2}). The high concentration of people and manure involved high concentration of manure, therefore, the cropland areas surrounding the city of Barcelona took advantage of its dumping as happened with other cities such as Paris (Barles, 2007; Billen et al., 2007). Notwithstanding, lacking other data sources, we cannot refine this supposition.

The range of population densities between 16-64inhab·km^{-2} was considered by Boserup (1981)typical of those agricultural systems that combined short rainfed fallow with domestic animals. At the same time, Badia-Miró et al. (2010) found that the optimal population density in vineyard areas in Catalonia during the 1860s-1880s would have been between 25 and 40 inhab·km^{-2}. In contrast with the low population densities of Lleida province, which had to match those of Castilian grain areas. Barcelona province c.1920overcome that threshold, regardless of taking into account the city of Barcelona or not, thus indicating that the agri-food system had started to change profoundly. Gini index c.1860—not available for the province c.1920—showed lower levels of inequality in land distribution compared with the previous local situation in the eighteenth century. These lower levels of inequality were linked to access to land. Which he were due to the spread of *rabassa morta* sharecropper leases, these were strongly linked with the vineyard specialisation in Catalonia before the twentieth century (Badia-Miró and Tello, 2014).

[6]We could not disaggregate between forest, scrubland or pastures as in JCA (1923) forest and scrubland are considered adjoined to pastures.

	c.1860 Sentmenat	c.1920 Barcelona
Rainfall (mm)	643	640
Population density (inhab/km2)	59	176
% forest, scrubland and pastures over total area	37.8	56.9
Ratio forest, scrubland and pastures over annual crops[7]	2.4	3.5
Ratio permanent land covers over annual crops	5.1	4.9
Livestock density per cropland area(LU 500 kg/km2)	12	40

Table 1. Main characteristics of the municipality of Sentmenat and the province of Barcelona. Source: the sources and the steps to calculate them are detailed in Galán (2014).

Vineyards had occupied and occupy important cropland extensions in Catalonia and their changes between c.1860 and c.1920 (Figure 2) had important effects at all levels: "Catalan vineyard specialisation cannot be seen as a simple market-driven resource reallocation, undertaken only according to a given set of agro-climatic features. The active development of second-nature factors was very important, thus confirming the role played by socio-institutional settings and socio-political conflicts related with income inequality. While in the mid-nineteenth century vineyard spread had led to a less unequal rural society, it was also growing faster there than anywhere *else*. This explains why the *rabassa morta* sharecroppers fought so fiercely during the second half of nineteenth century and up to the Spanish Civil War (1936–39)."(Badia-Miró and Tello, 2014, p. 222).

Before becoming a cash crop grape vines used to be planted as a temporary crop, slashing and burning forest or scrublands (Miret, 2004). When planted in rows of vines it was common to leave land between them to be sown alternatively with grains or left to fallow (Badia-Miró and Tello, 2014). Unlike other winegrower areas of the Iberian Peninsula specialized in luxury wines such as Porto, Malaga or Sherry, the Catalan vines produced cheap table wines. Exportation, oriented to an elastic demand, started to grow at the end of the seventeenth century.

The majority of the expansion of the vineyard area was at the expense of woodland or scrubland, and under the sharecropping contract called *rabassa morta,* which ended when two-thirds of the vines had died. Since the consolidation of the Spanish Liberal State, the aristocratic landlords lost the right to ask for tithes and some of the wealthiest sharecroppers got access to land. Both found in the *rabassa morta*a way to receive rents and expand cultivated land without assuming the labour costs (Colomé, 2014; Valls-Junyent, 1997). The end of these contracts was undefined and it could be sold or even inherited due to layering practices, which extended the lifespan of the plantation, not without controversy (Congost, 2004). This system allowed landless peasants to have a

[7]Although questionable, we refer to *herbaceous crops* and *annual crops* indistinctly when we want to group all the crops that are not wooden and perennial.

kind of long-term access to land up to the second half of the nineteenth century, hence creating the effect of land distribution as forests used to belong to big landowners. Besides wine, vines were an extra source of fuel (pruning) and feed for livestock (vine shoots, leaves and grape pomaces) (Garrabou et al., 2010) akin to forests. Wine prices were highly fluctuating and these indefinite contracts based on a fixed rent started to create problems when inputs required (such as pesticides) increased(Carmona and Simpson, 2009). This happened during the nineteenth century, when the demand of wines peaked due to the spread of two plagues unknown to European winegrowers but common on the other side of the Atlantic.

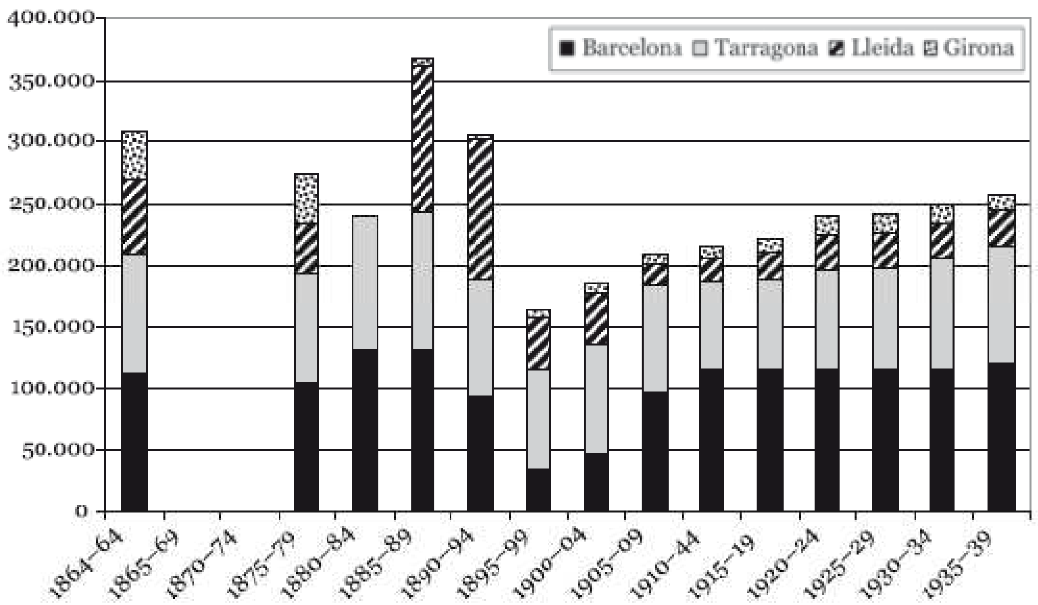

Figure 2. Vineyard land in the four provinces of Catalonia, 1860-1935 (ha). Note: 1880-84 data are only available for the provinces of Barcelona and Tarragona. Source: from Badia-Miró et al., (2010, p. 42).

The *oïdi, oidium* or powdery mildew (*Uncinula necator/ Oidium tuckeri*) was detected for the first time in 1845 in the United Kingdom and spread through France between 1852 and 1861. This produced a dramatic decrease in French wine production, which could not supply the American and English markets, nor the French itself (Piqueras-Haba, 2010). While the plague spread across the Iberian Peninsula as well, its virulence was lower in those areas with arid and drier climates like the inner *comarques* of Bages, Conca de Barberà, Garrigues and Priorat. There new land was ploughed, taking advantage of the international situation of prices, thus increasing massively vineyard acreage. On the contrary, on the coastal and humid areas of the provinces of Barcelona and north of Girona, the effects of the plague were exacerbated and together with the abridgment of fungicide availability (sulphur in this case) and other factors, some winegrowers decided to uproot their vines. The recovery of the vineyards from these areas started in 1858 (Piqueras-Haba, 2010) and so did the relative prices of wine/wheat. Which rose again at the end of the 1870s until the beginning of the 1890s due to the spread of the *phylloxera* (Carmona and Simpson, 2009).

During the late 1850s, *fil·loxera, filoxera* or phylloxera (*Dactylosphaera vitifolia or Phylloxera vastatrix*) was introduced accidentally in Europe through the imports of American varieties of vines resistant to powdery mildew, and by mid-1890s, there was not a corner in France free from the insect (Piqueras-Haba, 2005). In order to supply the French internal demand, not only did imports from their Mediterranean neighbours increase, but vineyards started to be planted in Algeria. The phylloxera has a complex reproduction cycle and attacks the root system of the European varieties until death, whereas the root system of the American varieties resists. The only solution was (and still is) to graft the European varieties with American rootstocks or use hybrids resulting from crossing varieties from the two continents. The spread of the phylloxera across the Iberian Peninsula had two main outbreaks in Porto (1871) and Malaga (1878). However, the expected arrival from France was detected for the first time in Girona (1879) and took more than 25 years for it to reach the last vineyards in Tarragona and Lleida (Piqueras-Haba, 2005). Hence, Catalan winegrowers could still take advantage of the favourable prices, either by replanting the first destroyed vines or by planting new ones in the last affected areas. Such was the case of Lleida, where during this period the area of vineyards almost doubled. As they were using pre-phylloxeric varieties however, at the end all of them were destroyed.

The former was the case for Barcelona and Tarragona, where the vineyard area increased only 15% during the phylloxera’s bubble and the winegrowers were able to replant the dead vines with other ones resistant to plague, so they recovered the vineyard area of the previous years according to Badia-Miró et al. (2010). These authors argue that a key component for the recovery of these two provinces was that of path dependence. In other words, as they started their vineyard specialisation in the seventeenth century, the culture and social fabric co-evolved with vines, thus creating a sort of comparative advantage when the vines were exterminated and it was time to leave agriculture, move to another crop or replant vines.

After the phylloxera plague, viticulture became something totally different. Many investments had to be done for replanting the dead vines: buying them from nurseries and grafting them (and learning to do it); protecting them from the diseases that accompanied the American rootstocks such as the *mildiu* or downey mildew (*Plasmopara viticola*) and to fertilize them (recall that the pre-phylloxera vines were not fertilized). As a result this new viticulture needed more labour than before, up to 94 man-equivalent working days per year per hectare, vis-à-vis the 25 needed in extensive cultivation of cereals with fallow that was practiced in inland Spain and the province of Lleida, were population densities matched those in Castile during 1860–1920 (Badia-Miró et al., 2010). Moreover between 1890 and 1930 wine prices decreased and winegrowers had to face several *crises de mévente*, when prices of wine were lower than production costs, something unknown for Catalan winegrowers since 1850 (Planas, 2014). The decrease of wine prices in respect to bread prices, and particularly with respect to wage labour, created an opportunity cost for sharecroppers with respect to off-vineyard land and off-farm activities (Carmona and Simpson, 2009). Needless to say, with all the vines wiped out and the impossibility of layering or transplanting cuttings, all the *rabassa morta* contracts ended.

Under these conditions, in the succeeding years of the phylloxera, a bulk of rural population migrated towards urban and industrial poles, hence boosting the growth of large cities like Barcelona, as was happening in other European countries during this *fin-de-siècle* agrarian crisis (Colomé and Valls-Junyent, 2012). Some rural areas began a process of demographic transition towards the current pattern of low birth rates (Colomé and Valls-Junyent, 2012). This was not the end of the existence of the *rabassa morta* contracts, which still were the contracts dominating the relationship between sharecroppers and landowners at the beginning of the twentieth century, although they were modified. Indeed, the undefined lasting terms of the contract were changed during the nineteenth century, as the landowners wanted to facilitate the eviction conditions. For example in the Penedès *comarca*, one of the most specialised vineyard areas in the province of Barcelona, more than half of the contracts already specified a fixed duration in the decade of 1850s and 100% was attained after the phylloxera plague (Colomé, 2014). However Carmona and Simpson (1999) argued that although the contracts changed its name and conditions, the path dependence and social pressure in the areas where vines were replanted were so strong that in practice everything remained the same. So, while for some authors this was the starting point of the tightening of the conditions imposed by landowners (because sharecroppers were losing the property of the vines); for others it is the demonstration of the high transaction costs for both sides to change to another alternative such as renting.

Going in depth into this debate Badia-Miró and Tello (2014) tried to explain the apparent contradiction in the expansion of vineyard land (and so *rabassa morta* contracts) before the decade of 1850, when the relative prices of wine were fluctuating vastly (Badia-Miró and Tello, 2014). These authors explain that the vineyard specialisation in Catalonia enhanced the capacity of rural areas to sustain population. As this expansion was done through the use of *rabassa morta* contracts, which previous to the phylloxera attack allowed access to land for small growers with little or no land of their own. Hence retaining them from migrating to urban environments or the New World. This, as expressed by the lower rental-wage ratios of this period, resulted in lower inequality levels for those municipalities whose major cropland area were vineyards compared to municipalities devoted to grain.

This trend ended circa 1840, when vineyard areas reached a critical threshold in population densities and the rental-wage ratios increased in winegrowing areas and decreased in grain areas. Thus, from circa 1840 inequality between landowners, and tenants and sharecroppers started to rise again whereas it diminished in grain-growing areas. This explains the social unrest found in winegrowing areas at the end of the nineteenth century and the beginning of the twentieth century (Badia-Miró and Tello, 2014).

Responses to face the conditions after the phylloxera plague were not only centred in rents and land contracts. The new situation fostered the creation of wine cooperatives in Catalonia, which unlike the French ones, were platforms to buy inputs for agriculture, find credit and have access to affordable wine processing facilities. However, by no means the main objective was improving the quality of wine (Planas, 2013). In addition, the conflict between big landowners and small winegrowers was transferred to this institutional ambit, and it was possible to find two cooperatives grouping members of each side fighting in the same village (Hansen, 1969; Planas, 2013). Again, contrasting the French case, the Spanish cooperatives suffered a lack of support from the state.

Still, the local government of Catalonia helped in the creation of cooperatives: in 1919, the *Mancomunitat* launched a service to encourage the formation of new wine cooperatives and assist them (*Servei d'Acció Social Agrària*). These services were closed down after the Primo de Rivera coup d'état (1923) and reopened again during the Second Republic by the *Generalitat* in 1931 (Garrabou, 2006). In 1934 only 16% of all the wine produced in Catalonia came from cooperatives, so although it was by far the region of Spain with more cooperatives(3/4 of the over 100 Spanish wine cooperatives were from Catalonia), the success of its spread was modest (Planas, 2013).

Winegrowers, being aware of the French opposition to Spanish wines, tried to pressure for favour of regulation of the domestic market to use the distillates sector as a destination for the overproduction of wine. Nevertheless, they had strong internal conflicts and were not such strong a lobby as the producers of "artificial" wines and the alcohol industry (alcohol from sugar or starch was used to strengthen wines to export them during the plague) (Planas, 2014). At the same time, the main demand from sharecroppers was towards land ownership recognition, while landowners were more worried about wine taxes. In fact, the main landowners associations, the *Institut Agrícola Català de Sant Isidre (IACSI)* and the *Federació Agrícola Catalano-Balear*, were more concentrated in the technical aspects of vine cultivation than in establishing measures to control fraud or wine quality. Contrary to what happened in the French Midi with the *Confederation Générale des Vignerons*, which allowed the improvement the quality of wines and so the price (Carmona and Simpson, 2009; Planas, 2014). Nevertheless, the weakness of the winegrower groups was not the only factor that contributed to the failure of the creation of an institutional framework favourable to the Spanish winegrowing sector. Also, their lack or bad relationship with political parties and the State's inability to respond to their demands, as opposed as to what happened in the French Midi (Planas, 2014).

3.2. The Socio Ecological Transition of Farm Systems from c.1860 to c.1920

The weakest point of the balance in Sentmenat was N, while K and P were almost in equilibrium; conversely, the most unbalanced nutrient c.1920 was K, whereas the extraction of the other two nutrients analysed were compensated by the inputs (Figure 3). Note that the main difference between the two balances in this figure is the *scale* of the flows, i.e. the magnitude of both positive and negative vertical bars. Two main reasons explain this difference: the spatial scale and the Socio-Ecological Transition.

Regarding the spatial scale, despite more than half of the cropland area being vineyards in both cases (66% and 55% c.1860 and c.1920 respectively), the province of Barcelona was not as homogeneous as the municipality of Sentmenat. Some geographic factors, the mountains, sea, etc., or the existence of urban centres as the city of Barcelona and its port, would have structured local possibilities and demands for some crops. To serve as an example, adjacent areas to the city would have benefited from the marketed humanure (JCA, 1921) and manure dumped by the high livestock densities c.1920, but not more distant areas. In addition, the yields of cereals in the Vallès area could have been lower than in other places of the province of Barcelona such as Osona (Garrabou et al., 1995). These effects however cannot be discriminated in the provincial balance, as we cannot decrease the scale of yields.

As for the latter, to what extent the different moments of the Socio-Ecological Transition explain lower fertilizer flows and lower yields? Although the balance of Sentmenat c.1860 is not in equilibrium, the negative trend is not so strong as the one found in the more arid regions of Catalonia c.1920 (Galán, 2014). Thus, we could say that, from this point of view, the system was not so close to its limits mainly because the extractions kept up with the availability of fertilizers. Considering the fact that a global abundance of fertilizer would masking local scarcity of fertilizer, there was more manureavailablec.1920 than c.1860 (4.57 ± 0.68 $t\cdot ha^{-1}$vis-à-vis 1.4 $t\cdot ha^{-1}$ respectively). Theoretically, two main reasons could explain the lower extractions c.1860: lower intensity in the use of nutrients and lower yields. Unfortunately, we cannot specify nutrient variations in the composition of ancient crop types and cultivars due to lack of reliable information (we had to use the same sources in both years for nutrient content). Concerning yields, although presumably these were lower c.1860, we considered that it was not worth comparing quantitatively two moments of time because the annual variability could lead us towards uncertain conclusions—*cartillas evaluatorias* used to be five-year compilations and the report from *Junta Consultiva Agronómica* only related to one year.

Still, as in both cases more than half of cropland area were vineyards, we can make an important observation. Recall that they were not the same type of vines due to the phylloxera plague at the end of nineteenth century. On one hand, the extractions were of a different kind, as pre-phylloxeric vines produced much less fruit (Marco et al., forthcoming).On the other hand, vineyards allowed cultivating poor land without great fertilizing efforts, due to the lower relative needs of N and P compared to other crops. Hence, this first wave strategy to increase marketable agrarian produce—but also access to land and availability of forest-like produce—concentrated high levels of soil mining c.1860, as vines were not fertilized at all.

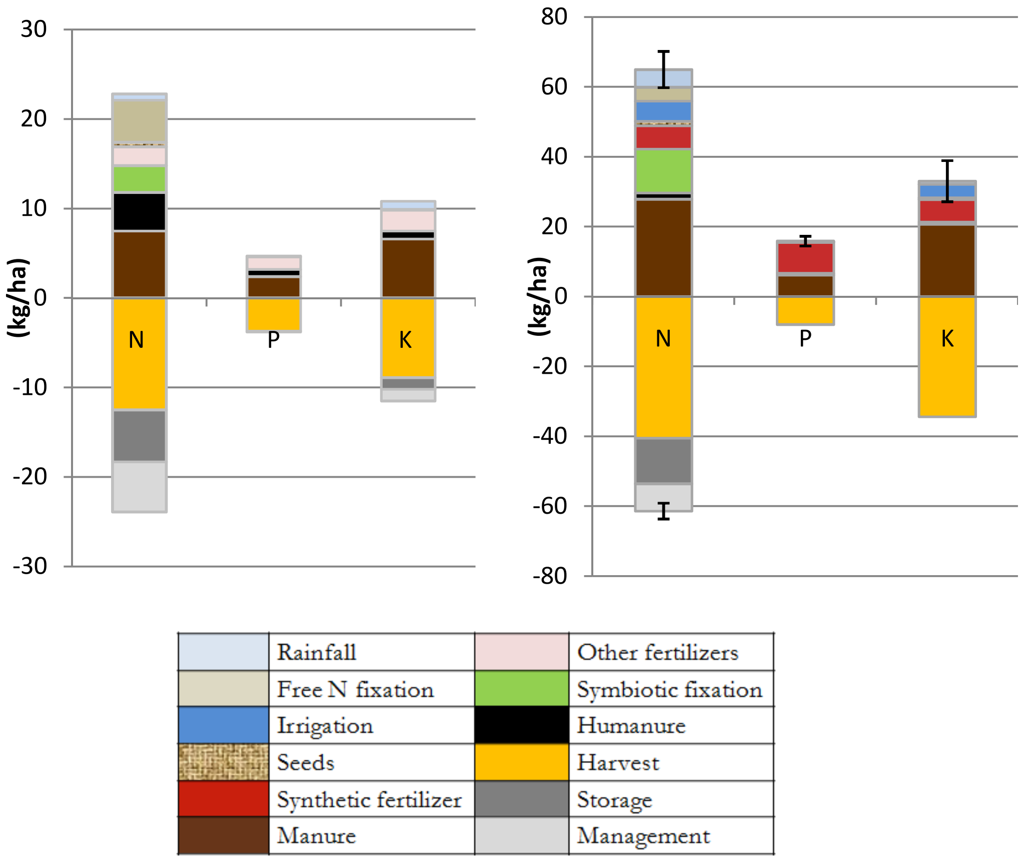

Figure 3. Nutrient balance of the cropland area of Sentmenat c.1860 adapted to the legend of c.1920 in the Barcelona province; note that they are not at the same scale. Negative values represent extractions and losses, positive values are additions of nutrients. Error bars are the accumulation of Standard Deviations in each extraction or addition bar and are due to the estimation of manure, humanure and the N emissions associated. Source: Tello et al. (2012) and our own as described in text.

The origin of fertilizers strongly differed in both cases. The non-manure organic fertilizers had more weight c.1860 than c.1920 in the replenishment of all nutrients. Among them, free fixation is the main source of N c.1860, while c.1920 has nearly the same amount; it has not the same relative importance. Rainfall deposition of N is not the same due to calculation differences. N fixed by leguminous crops is higher c.1920 because a greater area of cropland was devoted to them. The use of humanure is higher c.1860 despite lower population densities as less was lost due to the disposal system type, opposite of what happened in the city of Barcelona, where the proximity of the sea and the bad conditions of the sewage systems (García-Faria, 1893)allowed less recovering of humanure. The rest of fertilizers that we grouped as «other» (*homigueros*, ashes and other materials buried) were higher c.1860 than c.1920. The reason is that we could not quantify them c.1920 as, in contrast to neighbouring provinces, they were neglected by the agronomist in charge of Barcelona (JCA 1921). These other fertilizers could respond to practices relevant at local level but were diluted at a more aggregated scale. This could explain why the engineers of the *Junta Consultiva Agronómica* did not consider them—although it is rather likely that the significant rise in agricultural wages experienced between the two dates (Garrabou and Tello, 2002), together with the peak of deforestation attained during the First World War (Cervera et al., 2014), would have reduced these fertilizing practices (*hormigueros*). Two new categories of fertilizer applications appear c.1920: one due to nutrients carried by irrigation water, applied mainly in horticultural land, and the other due to synthetic fertilizers.

The flows of nutrients out from cropland area in the province of Barcelona could be balanced due to the incorporation of synthetic fertilizers to the mix of fertilizing methods (Figure 3). Nevertheless, were there other alternatives to increase nutrient flows towards croplands? In past organic agricultures, there were mainly three ways to do it. First, increasing the recycling of nutrients: seeds contain nutrients that the plant needs to grow, so the lower the yield of the seed the higher the nutrients recycled (Chorley, 1981); the use of by-products from crops as fertilizer being buried, as a component of manure heaps or as feed for the animals, and the use of humanure. Second, transferring nutrients from nearby uncultivated lands as biomass to be buried and as feed for livestock—yet, to what extent could biomass be extracted from Mediterranean forest or scrubland (whenever it was allowed by the owner) without damaging the capability of providing ecosystem services or its regenerative structures? Third, the availability of stocks from the atmosphere and soils could be increased (through atmospheric N fixation or mineralization from soil). Leguminous crops in Sentmenat c.1860 were 9.6% of cropland but 35.7% of annual crops, whereas in Barcelona province c.1920 they represented 10.8% of total cropland area and 25.1% of annual crops. Could it have been possible to increase even further the area of leguminous crops? Also, not all leguminous crops behave in the same way: wheat yields more if planted after clover than after beans (Allen, 2008). Was it possible to increase further the area sown with clover or other leguminous forages more drought resistant as sainfoin? I deem that, from all the fertilizing methods described so far for the system c.1860, the only way to increase the nutrient flows escaping from the zero sum game of land dependence was the reduction of nutrients losses throughout the fertilizing processes.

Then there were all the socio-economic factors, e.g. human labour, market profitability, inequality. The well-known case of the English high farming system prior to the 1870s becomes a useful reference. In spite of the contemporary observations of Liebig and Marx (Foster, 2004), other authors recently argue that it was more ecologically sustainable than it could have seemed, as with convertible husbandry and rotations with leguminous plants, they were increasing production by enhancing internal ecological processes. What was unsustainable were inequality and exploitative social conditions by landowners and capitalist tenants (Schneider and McMichael, 2010). "Yet High Farming succumbed not to social inequality or popular resistance (the Luddist uprising) but to exposure to world commerce" (Friedmann, 2000, p. 491)—that is, by the 'grain invasion' (O’Rourke, 2009) from the American Great Plains which still did not have fertility concerns.

4. Final remarks

Recalling our main hypothesis, the repositioning of nutrients—that was strongly related with other physical factors such as water availability—was a weak point of the past organic agricultures stressed by market forces, increasing inequality, urbanization and a growing population. Hence, we end with a big open question: which were the social and economic factors affecting soil fertility? I guess answering this question requires a complex combination of geographic, demographic, socioeconomic or political and cultural factors. Examples of these could be population densities and livestock densities, settlement patterns, social inequality in land ownership and income distribution, the advance of a market-oriented agricultural specialisation of a former crop diversification with multiplicity of land uses, or the ways of transmitting a peasant traditional knowledge versus the new technologies provided by scientifically based agronomics. Further research is needed before trying to construct such an ambitious historical synthesis that would require combining different approaches taken from cultural, political, socioeconomic and demographic history, as well as from environmental history. This becomes an unattainable aim for this historical study based on the Material Flow Analysis methods applied from an environmental history viewpoint, which is more focused on contributing to the pending historical narrative of Socio-Ecological Transitions in Mediterranean agriculture.

The comparison with the adjacent regions could be interesting due to the strong differences among them. In the province of Girona medium-sized farms (*masies*) with a rather complex and equilibrated policultural endowment of arable land, woodland, pastures and livestock were common. In addition to being located in the more rainy area of Catalonia, this agrarian class structure was arranged in a habitat of scattered farms, which mainly explains how they could still enjoy enough manure to replenish the soil nutrients without having to resort to chemical fertilizers c.1920 (Galán, 2014; Pujol, 1998). This was also probably true in the mainly forestry and livestock breeding rural communities located along the Pyrenees. Both were unequal rural societies, where a stratum of peasant families lacking enough land of their own had to work for the wealthier owners as sharecroppers, farmhands or daily workers (Congost and To, 1999; Congost, 1989). These regions, however, neither generated a great surplus of landless people lacking a contractual link with the well-established families, nor forced them to emigrate to other Catalan places (like the ones who migrated over centuries from the mountains towards the lowlands in the provinces of Barcelona and Tarragona).

Conversely, the littoral and pre-littoral fringes of the Barcelona and Tarragona provinces experienced an increase of population densities because of the growing number of landless people seeking an opportunity to make a living. For a while, the owners of the land saw them as a trickle of foreign tramps who could become potential thieves of their own wellbeing. They were becoming a new frightening class of people without a place in traditional Catalan rural society (Garrabou et al., 2010; Tello et al., 2008). A response to this challenge was the opening of the vine-planting frontier (Badia-Miró and Tello, 2014) in former scrubs and woodland areas that we described above which, together with the spread of industrious activities and the increase in industrial activities near the network of cities and towns with close access to seaports (Espuche, 1998; Marfany, 2012). The advance of this vineyard frontier turned viticulture into a cash crop exported to the emerging Atlantic economy, and entailed a cropland expansion as well as a land-use intensification that put additional pressure on the replenishment of nutrients extracted from soil.

We have seen that c.1920, the increasingly polarized and evolving agrarian world in Barcelona province could no longer equilibrate their nutrient balances without resorting to chemical fertilizers. We deem that before the arrival of these industrial fertilizers a soil mining process had been in place, mainly in vineyards and perhaps other perennial crops like olive, almond and nut orchards. A pending issue that needs further research is to what extent this imbalance existed simply because there were too many people demanding too many crops being grown on the land, or rather most of this soil mining process had been driven by social inequality in a rural society increasingly polarized. From the data collected c.1860 in Sentmenat, it was concluded that vineyards were under-fertilized not because there were insufficient organic fertilizers but mainly due to the lack of access of many small winegrowers to livestock, pastureland and woodland (Tello et al., 2012), as it can be understood by considering land distribution (Figure 4).

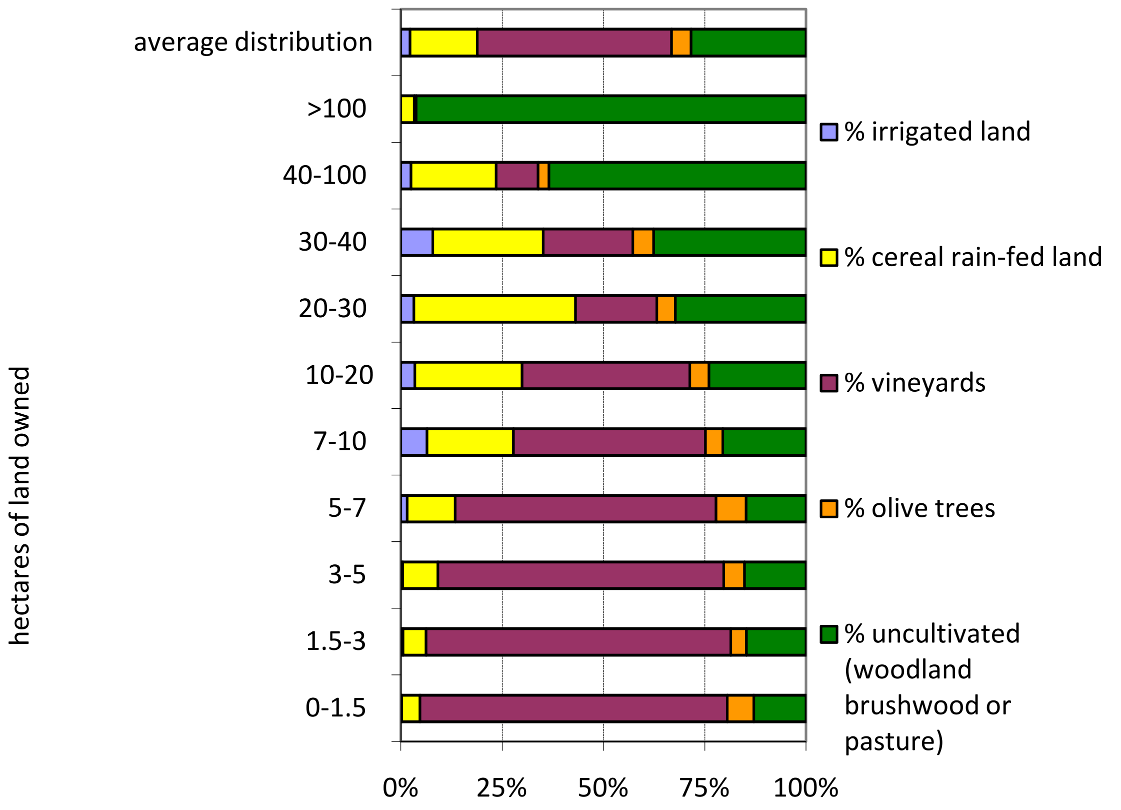

Figure 4. Allocation of land according to the range of land owned in Sentmenat (Vallèscomarca, Catalonia, c.1860). Source: from Garrabou et al.(2010).

Therefore, I have to conclude by raising a big question that deserves to be addressed in the future by joining Environmental History and Socio-Economic History standpoints:

would it have been possible to increase the capacity of agriculture to produce more in a sustainable way or was the only possible way industrial agriculture?

5. Acknowledgements

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