UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

TESE DE DOUTORAMENTO

INTENSIFICATION OF A PEASANT AGRICULTURE AND SOIL FERTILITY IN AN ATLANTIC TERRITORY: GALICIA, 1750-1900

Asdo. ....

Beatriz Corbacho González

PROGRAMA DE DOUTORAMENTO EN HISTORIA CONTEMPORÁNEA

FACULTADE DE XEOGRAFÍA E HISTORIA

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BEATRIZ CORBACHO GONZÁLEZ

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ABSTRACT

This dissertation is framed within the theory of social metabolism and reconstructs the land uses and productivity of the main crop rotations in two agroecosystems within the Atlantic territory of Galicia (NW Spain), Fonsagrada and Ribadavia. Both agroecosystems are complementary and representative of a diverse territory. We have applied the methodology of nutrient balances to the first one of these cases in order to assess its sustainability in the long term regarding the management of soil fertility. Our results confirm a similar evolution to other case studies within Europe in terms of soil exhaustion and nutrient imbalances towards the end of the 19th century after a long process of agricultural intensification. This metabolic rift has been connected with the general agrarian crisis that affected the continent at this point, and with the process of socioecological transition from an organic into an industrial metabolism.

KEY WORDS

Agrarian history, environmental history, social metabolism, soil fertility, nutrient balances, sustainability, metabolic rift, socioecologic transition

Campos de millo

Baixa o río entre as veigas
o tempo avanza lento
infranqueábel
e un lume queima a túa casa
constantemente.
Europa era mentira
as estatuas e os mitos
observan
os campos de millo
secaren
nos ollos das vacas
e todo estaba cheo de indicios
por exemplo nos cruceiros
coas ánimas
a xeografía xa falaba do noso atraso
claro
eramos un pobo labrego
no tempo dos sputniks.

Iñaki Varela Pérez
Do outro lado das portas

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[1] Formación de Personal Investigador.
[2] Construción Sustentable para o Medio Rural e Natural.
[3] Grupo de Investigación de Historia Empresarial e Sectorial. Pesca, Industria e Comercio.
[4] Laboratorio do Territorio.
[5] Economía Agroalimentaria e Medioambiental, Desenvolvemento Rural e Economía Social.
[6] Grupo de Investigación en Economía Ecolóxica e Agroecoloxía.
[7] Xestión de Residuos Orgánicos, Fertilización e Ecoloxía Agraria.
[8] Historia Agraria e Política do Mundo Rural.

attendance at the Annual Meeting of the Social Science History Association in Chicago in November 2016.

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[9] Instituto Nacional de Empleo.

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Intensification of a peasant agriculture and soil fertility in an Atlantic territory: Galicia, 1750-1900

Introduction

The interest on environmental issues reached Spanish agrarian history some forty years ago, where it has developed in tight collaboration with disciplines such as Agroecology, Ecological Economics or Ecology. The research we present in these pages is built upon this fruitful tradition, which has provided innovative theories and methodologies within the general field of social metabolism in order to study the coevolution between societies and nature in biophysical terms. Chapter 1 explains where our research project stands within the current historiographical context.

The sociometabolic approach leads to include the dematerialization debate in the research agenda, since the current socioecological crisis is one of the main intellectual challenges that has triggered the interest on environmental studies, whichever the perspective. This is chronologically far away from our own research, which focuses on the 18 th and 19th centuries, but sustainability concerns are also present in our work since agriculture is at the centre of the energy regimes and, after all, historical research is also aimed at understanding where we are today. Besides, the study of land management in the past can provide with more sustainable agricultural practices for the present.

In fact, previous research within Spanish environmental history had focused on Mediterranean areas with these initial objectives. Similar studies were needed for the Green Spain and this is the origin of this PhD dissertation, which deals with the main biophysical features of two case studies within the Atlantic territory of Galicia, Ribadavia and Fonsagrada. These locations were selected according to their suitability in bioclimatic terms but also to source availability and seriality.

One of the main objectives of the biophysical approach of social metabolism is to describe and analyze the process of socioecological transition from an agrarian metabolism into an industrial one according to different phases. We have focused on the first stage of this transition, where the optimization of the organic metabolism takes place by introducing new crops, supressing fallow and generally intensifying agricultural practices. The theoretical framework of social metabolism is explained in Chapter 2.

Chapters 3 and 4 deal with the design of the research and the sources it is based on, respectively. Most of the documents we have used are of fiscal nature: Ensenada's Cadastre in

1750s and *cartillas* for the 19th century. This relates with the three moments that we study in the period 1750-1900: 1750s, 1850/60s, and 1880s. We have criticized sources according to previous historiographical research and to the potential of our methodology, and we have also specified bibliographic sources that have provided biophysical data which were not consigned in these documents.

Chapter 5 explains how we proceeded in this research. Firstly, we reconstructed land uses and productivity of each agroecosystem and, for the case of Fonsagrada, we also applied the method of nutrient balances. Our methodological steps are explained in Appendixes 1 and 2 and results are described and analyzed in Chapter 6, the first part of which focuses on the case of Ribadavia, and the second one on Fonsagrada. Within this same chapter, we have included a reflection on migration from the biophysical perspective which arouse at the light of our results and has also been in the debate within Galician agrarian history for some time. Our research gives evidence of the relevance of material conditions in order to explain migration processes. In the case of Fonsagrada, total food availability increases through the period but decreases when distributed per capita, with a slight recovery towards the end of the 19th century. Migration, which is more important during the second half of this century, functions as a soil saving strategy and allows to sustain a bigger livestock head and to improve manure availability for cropland in a moment when there was not much further margin for cropland expansion and intensification. Thus nutrients are less imbalanced in 1887 than in 1852. Such fact shows that peasants had developed a deep and accurate knowledge of the land and its requirements.

Eventually, we compare our results with other similar research and conclude that the process of intensification led to soil exhaustion and productivity stagnation in the case of Fonsagrada, which was a common pattern within European agricultures towards the end of the 19th century. Nutrient balances indicate the existence of a long term process of soil depletion, mainly regarding potassium. Cropland productivity depended on the nutrients mobilized from more extensive rotations, which were the most affected after the process of agricultural intensification. Demographic pressure is connected with this trend, but at the same time our data show that agriculture was able to sustain an increasing population through a great part of the 18th and 19th centuries. Eventually, the equilibrium in land uses that allowed for this to happen was altered to the extent of generating a metabolic rift between nature and society.

Besides, our data also reveal the changing role of a common practice within Galician agriculture, the *estivadas*, a type of shifting agriculture that was also intensified through the 19th century. *Estivadas* were meant to regenerate shrub production, which was the basis of fertilization, but as we move forward in the study period we see that their food supply is more and more important regarding the critical context of the metabolic rift which, on the other hand, this practice also contributes to originate. Such results broaden the historiographical debate on migration and allow to overcome the backward image that has frequently been depicted of our agricultural past, as previous research had already criticized. There is in fact a process of agricultural intensification and improvements in land productivity, which are specially evident in the more intensive agroecosystem of Ribadavia.

Our main conclusions are summarized in Chapter 7, and are followed by a brief reflection on what should be done next. Finally, the Appendixes include detailed information on the methodological procedure. The estimation of nutrient flows is explained in Appendix 1. Steps to calcuate nutrient balances are detailed in Appendix 2, which includes the corresponding Excel spreadsheets in the attached CD. Appendix 3 consists on graphic representations of nutrient flows and their corresponding quantitative data, and 4 is a glossary of Galician and Spanish terms used in the text. Finally, Appendix 5 is an abstract of the dissertation in Galician which has been included in order to comply with the bureaucratic procedure.

Chapter 1. State of the art

In this chapter, we will describe the historiographical context in which this research is framed. In the first section, we introduce the so-called "backwardness debate" in Spanish agrarian historiography and explain how the biophysical perspective provided new arguments to overcome this ideological discussion. We also refer to similar research in other European and American institutions. The second section deals with previous research on the agrarian system of Galicia, which replicated the above-mentioned debate and also developed historiographical arguments for its refutation.

1.1. The biophysical perspective in agrarian history

Frequently within History, agriculture has been approached from its economic, technologic or institutional aspects, thus ignoring the "*natural preconditions of agriculture*" (Krausmann, 2006: 501). This standpoint has led to unfortunate comparisons of different agricultures by taking into account only crop yields, soil productivity, the adoption of particular technologies or market integration. As a result, a controversy originated in Spanish historiography after the reaction of certain authors to the inappropriate use of concepts such as "progress", "modernization", or "backwardness" when applied to the analysis of agriculture and economy. Spanish agriculture has often been depicted within liberal Economic History as technologically stagnated or unproductive in disregard of its environmental conditions, thus becoming responsible for a generally backward economy up to the years prior to the Civil War in Spain (1936-1939). See for instance Palafox (1991), Tortella (1994) or Simpson (1997). Besides, the exclusive consideration of market productions when studying productivity, frequently in monetary terms, makes the comparison with other agricultures still more inconclusive[10]. All biomass productions should be taken into account in order to precisely assess land productivity and the impact on soil fertility (González de Molina, 2000; Guzmán et al., 2010).

Mainstream historiography had assumed the modernization paradigm according to the British model, which was widely used in order to explain the introduction of capitalism and its related technological changes into different European agricultures. Therefore, the model of the Agricultural Revolution as described by Ernle at the beginning of the nineteen hundreds, and later on in the century critized and contested by authors such as Kerridge, Thirsk or Grigg[11], showed concrete aspects and stages that every agriculture had to go through in order

[10] Federico (2005) is a paradigmatic example of this stance. See also prior references such as B. H. Slicher van Bath (1966) or van Zanden (1991).

[11] See Chambers and Mingay (1966) for a description of the main quantitative and qualitative changes in English agriculture between 1750-1880; or Kerridge (1969) for the first arguments against the "*myth*" of the "Agricultural Revolution" as forged by Arthur Young, and later on Ernle and Toynbee. Kerridge's analysis and

to be considered "modern", which was made equal to "capitalist" since, eventually, the Agricultural Revolution would create the conditions for the Industrial Revolution to happen. Agricultures that did not follow such pattern were therefore considered "underdeveloped" and "backward". At the turn of the century, this paradigm would be definitely overcome by further research on land and labor productivity, environmental constraints to agricultural productions and market oportunities, thus resulting in a richer interpretation of European agrarian history and even of the British agriculture, which was not as productive nor revolutionary as initially depicted: big scale farming on enclosures performed similar yields and productivity as small scale agriculture on open fields which, besides, introduced most of the innovations (Allen, 2004 and 2008).

The historiographical reaction against these "*theories of modernization*", widely used by Spanish historians and economists during the period 1960-80s (Cardesín, 1992), started mainly within Economics with Naredo and Martínez Alier in the 1970s, but also with historians like Ramón Garrabou, Josep Pujol or Manuel González de Molina. The coetaneous *Grupo de Estudios de Historia Rural* (G.E.H.R.) would follow the modernization theories but with a more positive interpretation. A collective work edited in 1985 by García Sanz, Garrabou, Jesús Sanz, Barciela and Jiménez Blanco compiled several alternative approaches to the classic economic interpretation of agrarian changes. The authors follow the introduction of capitalism through the 19^{th} century and conclude that there was a process of market integration for food productions, which were more and more diversified due to the introduction of new crops such as maize or potatoes, and sufficed to sustain an increasing population. Their general interpretations contradicted the discourse on economic stagnation attributed to agricultural immobility, although land and labor were the prevalent factors and changes in their productivity were not relevant. The ongoing debate eventually encouraged another publication by some of these researchers and other colleagues who disagreed with the mainstream liberal interpretation and the *"backwardness theories"*. This research took the analysis out of the classic concept of *economic system* (Naredo, 2004) and its teleological reading in terms of progress. The result was the polemic *El pozo de todos los males*, by Pujol, González de Molina, Fernández Prieto, Gallego, and Garrabou (2001). The authors criticize the inexplicit ideological position of the developers of the *"backwardness theory"*, who identified capitalism with progress and industrialization, and their lack of argumentation regarding the analysis of capitalism in Spain by arguing that biophysical conditions should also be taken into account in agrarian research in order to assess growth possibilities more realistically. Thus their main conclusion is that Spanish agriculture successfully adapted to

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his chronological proposal refute the more canonic interpretation of Chambers and Mingay. Joan Thirsk (1987) or Grigg (1989) also continued this critical revision of the "Agricultural Revolution" and offered a deeper analysis by contributing regional research. A more biophysical perspective is offered by Chorley (1981) with a description of rotations and land productivity with a focus on nitrogen management. Overton (1996) agrees with the concept of Agricultural Revolution but expands its chronology back to 1500, thus describing a long-term process of yield increase through changes in rotations and manuring practices. For a more updated interpretation on agricultural changes in Britain, see Allen (2004).

market changes with the optimization of its growth possibilities during the 19th century, even when hydric deficit was a major constraint for intensification in most of the Peninsula and, along with other factors, did not allow for a wider increase in productivity. It was argued that Mediterranean Spanish agricultures should not be framed within the common Atlantic European ones. Their comparison was not productive nor appropriate because of the qualitative differences between them, starting by clima and soil types, which determined very particular bioclimatic regions with their corresponding potential vegetation and, also, agricultural systems. Thus the characteristic rotations of Atlantic mixed farming systems that included leguminous plants would not be viable within a Mediterranean clima with limited water availability. Besides, the authors explain that what occurred within Spain was not isolated from the rest of Europe, as it was part of a continental model of market expansion based on the territorial inequalities of the liberal economics, which generated tension between the centre and the periphery of the system with deep social, sectorial, and territorial inequalities. Pujol emphasizes the fact that the theoretical frames from classic economy which served to portray an underdeveloped agriculture and economy in 19th and 20th century Spain oversized market over other agents (social, political, environmental), thus offering a distorted image of the period, with a prevalence of feudalism in agriculture and nobility in society. *El Pozo* claims for more complex theoretical frameworks to explain the economic transformations of Spain. In this collective work, the authors develop three lines of research that challenged the classic agrarian discourse and led to new interpretations in the field of agrarian history. Firstly, they researched agrarian specialization and changes in land uses that ocurred at the time of expansion of capitalism and the subsequent market changes. Secondly, they approached technical change, as well as variations in yields and land productivity, along with the rationale behind them considering social, political and environmental factors. Lastly, they considered the productive potential regarding time and space as well as technical background (Pujol et al., 2001). For a more detailed historiographical description of the origin and development of this debate see the first chapter of the book, by Josep Pujol. The polemic would still continue in the pages of the specialized publication *Historia Agraria*[12], and would have echoes in more recent times with *Las Sombras del Progreso* (2010).

In this context, in the decade of 1990s it started to be evident that the interconection between society and environment had to be incorporated in agrarian history, which was more and more encouraged by the current context of socioecological crisis. This resulted in meetings in Barcelona and Santiago de Compostela which triggered new research on environmental history with a very political bias towards social ecologism by many of those researchers who were critisizing the theories of “backwardness”. At the end of the decade, the environmental paradigm had been introduced in the long and rich tradition of Spanish agrarian historiography, namely with the support of the SEHA[13], and it would soon consolidate as a valid alternative to the mainstream economic interpretation of agriculture, thus contributing to

[12] See for instance numbers 28, 33 or 40.
[13] Sociedad Española de Historia Agraria.

the overcoming of the debate in terms of “progress” versus “backwardness”. González de Molina has described this process, its influences and the initial research agenda, which was discussed in interdisciplinar contexts with agronomists, biologists, economists, or soil scientists. This allowed an integrated reading of agriculture both in the past and in the present (González de Molina, 2000). Challenges that were formulated at the moment are now being succesfully accomplished. Researchers from different disciplines have joined efforts in order to understand the ecological rationality of agroecosystems and the dynamic of their changes, and have elaborated innovative methodological proposals within the theoretical frame of social metabolism in order to study agriculture in the past. The main principle of this approach is the coevolution between social and natural systems, thus agriculture occupies a central role but urban and industrial metabolisms are considered as well.

At the moment, two groups are leading the research on environmental history in Spain: the Agroecosystems History Laboratory at the University Pablo de Olavide (Seville)[14], and the Department of Economic History and Institutions at the University of Barcelona[15]. Both teams are composed of researchers from different disciplines such as History, Economics, Agroecology or Biology, and belong to the international research project “Sustainable Farm Systems (SFS): Long Term Socio-Ecological Metabolism in Western Agriculture, 1750-2000”[16], which has applied the theory of social metabolism to different world scenarios. Our research is also linked to this project through our supervisor David Soto at the Agroecosystems History Laboratory in Seville. Both the Laboratory and the whole SFS team have always provided theoretical and methodological support to this research.

Within the Agroecosystems History Laboratory, González de Molina and Víctor Toledo are the authors of a theoretical proposal on social metabolism within environmental history that includes the analysis of all material flows in the different metabolisms as well as the explicit mention to inequality as a driving force for unsustainability and socioeconomic change (González de Molina and Toledo, 2011 and 2014). The main applied research of the team is

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[14] Researchers of the *Laboratorio de Historia de los Agroecosistemas*: Manuel González de Molina, Víctor Toledo, Roberto García Ruiz, Antonio Herrera González de Molina, Juan Infante-Amate, David Soto Fernández, Gloria I. Guzmán Casado, Inmaculada Villa Gil-Bermejo, Guiomar Carranza Gallego, and Eduardo Aguilera Fernández.

[15] Researchers: Enric Tello Aragay, Mª Àngels Alió Torres, Claudio Cattaneo, Josep Colomé Ferrer, Xavier Cussó Segura, Elena Domene Gómez, Ramón Garrabou Segura, Gabriel Jover Avellà, Joan Marull López, José Ramón Olarieta Alberdi, Jordi Planas Maresma, Jordi Roca Jusmet, Mónica Serrano Gutiérrez, Ricard Soto Company, Francesc Valls-Junyent, Roser Álvarez Klee, Lucía Díez Sanjuán, Nofre Fullana Llinàs, Inés Marco Lafuente, Marc Maynou Felker, José Luis Martínez González, Andrea Montero Mora, Roc Padró Caminal, Alexander Urrego Mesa, Carme Font Moragón, Elena Galán del Castillo, Joan Ramón Ostos Falder, and Lluís Parcerisas Benedé.

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on Mediterranean agriculture, namely in Andalucía (South of Spain). They have used the methodology of material flow accounting, mainly nutrient and energy balances but also hydric ones, in order to study the process of socio-ecological transition in different case studies and assess agricultural changes and long-term sustainability (Guzmán and González de Molina, 2006; Guzmán et al., 2011; Guzmán et al., 2014; Infante, 2014; Soto, 2015). The group has also integrated other topics such as the agrifood system (Infante-Amate et al., 2014a) or democratization (Herrera et al., 2013) and, along with other SFS members like Michael Neundlinger and Inés Marco, is currently working on a methodological proposal to include the issue of inequality within socioeconomic research according to access to land, livestock and other funds, and time budget analysis[17]. Neundlinger's and Villa's proposals have been recently defended as PhD dissertations on the sustainability cost of inequality (Neundlinger, 2017; Villa, 2017).

The group at the University of Barcelona has also been committed with the study of socioecological transitions and soil fertility in Catalonia and the Balearic Islands through the application of nutrient and energy balances, sometimes in collaboration with the Andalusian team (Garrabou and González de Molina, 2010; Galán 2014 and 2015; Tello, 2010; Galán et al., 2016), and has approached the connection between energy and landscape as well through a model that is currently being developed (Marull et al., 2016).

There is a third European team in the SFS project at the Institute of Social Ecology[18] in Vienna with a long and successful tradition in transdisciplinary research on environmental issues which dates back to the late 1990s when, as referred by Neundlinger, a team of ecologists, demographers and historians studied the changes in pre-industrial agriculture by linking environment, means of production and population data in several case studies in Austria. Winiwarter and Sonnlechner built up a model for the reconstruction of the main stocks and flows within an organic metabolism, to which Fridolin Krausmann would later add the more biophysical and quantitative approach by adapting the MEFA[19] methodology for historical research on the industrialization of agriculture and the impact of the introduction of fossil fuels. The researcher revealed how this process altered the nutrient cycles by opening them to market inputs, how the role of livestock changed within the agroecosystem, and how all these major changes affected soil fertility and agricultural landscapes (Krausmann, 2004; Neundlinger, 2017[20]). The application of the model in different case studies and chronologies has contributed to a wide overview of pre-industrial agroecosystems and their socio-ecological transition into industrial metabolisms in Austria (Krausmann, 2008 and 2011; Krausmann et al., 2008; Gingrich et al., 2013; Neundlinger et al., 2017). One of their main historic sources is the Franciscan Cadastre, a land survey from the beginning of the 19th

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[17] See their website for complete references: http://lha.es/es/PUBLICACIONES/.
[18] Helmut Haberl, Martin Schmid, Karl-Heinz Erb, Marina Fischer-Kowalski, Simone Gingrich, Fridolin Krausmann, Simron Jit Singh, Verena Winiwarter, among others.
[19] Material and Energy Flow Analysis.
[20] The text has been kindly provided by the author.

century, which has led to collaborations and similar research in neighbor countries (Grešlová et al., 2015; Fraňková and Cattaneo, 2017). Further theoretical and methodological debate within the group has been compiled in three major publications from this team that we would like to outline. In 2007, Fischer-Kowalski and Haberl edited *Socioecological Transitions and Global Change. Trajectories of Social Metabolism and Land Use*, which collects theoretical and methodological reflections within social metabolism addressed at studying change in land use and socioeconomic patterns, and applied research to case studies in Austria, United Kingdom and in developing countries. Later on, in 2013, this research line was followed in the *Long Term Socio-Ecological Research. Studies in Society-Nature Interactions Across Spatial and Temporal Scales* (Singh et al., 2013), where the concern of explaining the current socioecological crisis and its roots in the past are more evident, thus also aiming at suggesting future paths of sustainability. This approach has been inspired by the consolidated Long Term Ecological Research (LTER) which, according to the authors, was too limited to explain global environmental change. The proposal of the Vienna School combines theoretical and methodological elements from different disciplines around four main axis. Firstly, the metabolic approach allows for the integration of biophysical and socieconomic processes by studying physical stocks and flows. Secondly, the proposal incorporates the analysis of land use and landscapes in order to emphasize the importance of spatial patterns and to link them with social dynamics, thus giving evidence of how socioeconomic metabolisms transform landscapes. Agency of change within metabolism is also considered by including the governance approach in order to asses the *"organization of nature in the past"*. And lastly, the study of communication and knowledge allows to understand governance or how decisions are made (Haberl et al., 2006). In order to more explicitely include human agency in the biophysical approach, Neundlinger (2017) has developed a proposal to measure the inequality in access to resources and its associated sustainability cost as formulated by Guzmán et al. (2011). Lastly, the group's most recent compilation *Social Ecology. Society-Nature Relations across Time and Space* (Haberl et al., 2016) is a collective work with the most significant contributions of their research in social ecology with updated reviews of the main issues considered within LTSER. The book offers a state of the art in Social Ecology and deep insight into the main research of the Institute of Social Ecology. The Vienna School has built a very comprehensive sociometabolic approach to environmental issues by combining methods and theories from disciplines in Social Sciences, Humanities and Natural Sciences in order to study sociometabolic regimes and human *colonization* of nature (Fischer-Kowalski and Weisz, 2016).

The other two teams of the SFS project do their research on both North and South American cases. Within the Canadian team, located at the University of Saskatchewan and directed by Geoff Cunfer, researchers[21] have studied environmental history of the Great Plains (Cunfer, 2005), also from a soil perspective (Cunfer, 2004), and are currently developing nutrient and

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[21] Geoff Cunfer, Jim Clifford, Patrick Chasse, Andrew Watson, Joshua McFadyen, Jessica Dewitt, Laura Larsen, Chris Marsh, or Matt Todd.

energy balances for different case studies within the same region and other locations in Canada. Another main focus is the application of Historical GIS to the study of agricultural change through time and space[22].

The teams at the University of Colombia and Cali, led by Stefania Gallini and Olga Delgadillo-Vargas, respectively, are also currently working on the environmental history of certain regions in the country through the application of nutrient and energy balances.

Of course, agriculture from a biophysical perspective has also been addressed by researchers outside of the SFS project, and long ago before it existed. This tradition is especially fruitful regarding the energetic approach, highly influenced by the works of Georgescu-Roegen on economic processes and the entropy law, which questioned the conceptual problems within economic theory when dealing with sustainability. This author proposed a fund-flow theoretical model for the study of social metabolisms which has inspired many other proposals within social metabolism (Georgescu-Roegen, 1971, 1976). Even when our approach does not include the study of energy flows, we need to mention other relevant references at this respect: Giampietro et al. (2012) or Kander et al. (2013). The first provides the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM), which is a fund-flow methodology for a quantitative analysis of sociometabolic patterns. The author includes the corresponding theoretical discussion and examples of applied research and potential uses. Kander et al. analyze the economic history of Western Europe through the study of energy and material flow patterns in pre-industrial and industrial economies. The explanation is articulated around the concepts of *energy regime* and *transition* and puts the focus on the type of energy resources employed in each moment and their relation with economic growth and environment. Their approach connects recent *energy revolutions* with geopolitical changes and the spread of information. Eventually, the authors include a methodological description for quantifying energy consumption in a cross-country comparative perspective.

In this section, we have briefly explained how the "backwardness" debate orginated within Spanish historiography and how the adoption of a biophysical and multidisciplinary approach has contributed to its overcoming. We have also introduced the main groups with a similar research agenda. In the following section, we will see how the same debate reproduced itself in Galician historiography, which had so far not applied the biophysical approach to the study of agriculture in the past. This is the context where we frame our own research.

[22] For more detail on their research agenda see http://hgistest.usask.ca/index.php.

1.2. The agrarian history of Galicia revisited

In permanent dialogue with Spanish and European research on agriculture, Galicia's historiography has also been immersed in a debate on how its supposedly "backward" agrarian past could have conditioned an unfavourable economic situation at the present. The debate evolved with the arguments for and against the theory of modernization and, generally speaking, there were two main readings on agriculture as either backward and responsible for the current underdevelopment due to a belated industrialization and urbanization, or, on the other hand, as part of the varied array of agricultures in Europe which had not followed the English model of agricultural revolution and introduction of capitalism.

This dualism in terms of "progress" versus "backwardness", and "change" versus "continuity" has been fortunately overcome in Galician historiography as well, and although it remains in the subconscious of society, researchers tend to conjugate aspects of both readings in their work nowadays[23]. For this reason, the prevailing vision on Galicia's agriculture during the Ancien Regime and the 19th century refers to the absence of structural change as a limiting factor of the productive capacity of households, but along with a compatible integration into the market and the development of a capitalist economy. Historiography has eventually composed a picture of an intensive agriculture which, with no more than a 25% of cropland, sustained among the highest population densities within Spain at the end of the Ancien Regime (Eiras Roel, 1992a). Thus the acknowledgement of constraints such as the *foro* contract, the smallholding tenure, the lack of capital and scarce monetarization of the peasant economy, or the low technical level, should not obliterate the meaningful transformations that peasants performed between the 17-19th centuries generally accross Galicia. Through this period, in different waves, smallholding households performed both an extensification and intensification process that sustained an increasing demographic pressure but also dealt with the new monetary requirements of the market economy and the liberal State (Artiaga et al., 1993). Thus the agriculture of the second half of the 19th century provided satisfactory levels of resource production while its economic structure located itself in a less positive balance (Villares, 1990).

Within historiography on Galician agriculture, regarding the period we study, there are several authors who are essential in order to understand the origin of our own proposal. Although not all of them were directly involved in the "backwardness debate", they have all contributed to build the current historiographical interpretation of the country's agriculture. We have grouped them according to discipline and research topics even when they do not belong to well defined research teams and, in many cases, do not even share and intellectual tradition.

[23] For more detail on this debate, see Fernández Prieto (2000c and 2016), Díaz-Geada (2013) or Soto (2015).

First of all, our colleagues from the Modern History Department[24] described and analyzed the agrarian system and its changes between the 16th and 18th centuries and beginning of the 19th. The research of the French geographer Bouhier is coetaneous of this group's first approach to rural Galicia. This author developed his research on Galicia during the 1960s, and published the results under the title *La Galice. Essai geographique d'analyse et d'interpretation d'un vieux complexe agraire* in 1979[25]. Although he was not a member of this Department, we will include his contributions in the same section due to the chronological coincidence and the methodological and content connections with these researchers, who were initially inspired by the French school of *Annales*. Besides, his work is of utter importance to understand Galicia's agrarian past and inspired many of the coetaneus researchers.

In a second second group we mainly include economists such as Xosé Manuel Beiras, José Colino Sueiras, Emilio Pérez Touriño, or economic historians such as María Xosé Rodríguez Galdo, Fausto Dopico or Xan Carmona. From different perspectives, they contributed the most to the description of a backward economy in Galicia. In many ways, they held agriculture responsible for the situation of economic underdevelopment from which they were interpretating the past, mostly between the decades of 1960 and 1980.

Finally, our colleagues at the Contemporary History Department[26] studied our most immediate agrarian past and processes such as transformations in land tenure and peasant access to land, agrarian mobilisation, agricultural changes and technical innovation. As a result, they built a discourse of innovation and adaptation which disagreed with the previous economic interpretation of agricultural transformations. They were doing so from a different socioeconomic context as well, mostly in the 1990s, and put the focus on varied topics and processes. In the following section, we will mainly refer to those aspects of their work which connect with our own.

The description of the agrarian system and its changes through the Ancien Regime and the 19th century

In the 1960s, a renewal movement was started by Eiras Roel within the Modern History Department at the University of Santiago de Compostela according to the *Annales* proposals. The main target was to elaborate a global discourse on society and its changes and continuities through a detailed analysis of the different structures of human life in the past. As Saavedra puts it, it was the French influence, namely that of Labrousse, Goubert and Le Roy Ladurie, which determined the research of this group, thus being a history of *agrarian*

[24] Faculty of History, Art and Geography, University of Santiago de Compostela.
[25] We have used the Galician edition of 2001.
[26] Faculty of History, Art and Geography, University of Santiago de Compostela.

civilization although lacking the technical approach that British academics were developing at that time[27] (Saavedra, 2003: 97).

With society at the core of their research, rural Galicia was approached under a socioeconomic scope, and usually in very quantitative terms, thus analyzing production and yields, land and livestock tenure, the *foro* regime, taxation, series of prices, rotations and new crops from America or fertilizing practices. More qualitative aspects such as sociability, religiosity, social conflict or customs and usages (i. e. inheritance practices, commons) were included in their research agenda[28]. Demography had a very important place within most of these studies, which connected different demographic variabilities such as nupciality, age of marriage, fertility, birth, and mortality rates with the changes in agrarian production, thus establishing their interrelations and determining the demographic strategies to get over production crisis or stagnation periods in order to avoid abrupt mortality crisis. Results outlined the dependence between population and resources in a small-scale pre-capitalist agriculture (Pérez García, 1986; Saavedra, 1992b).

Besides, the renewal efforts included sources as well. Thus cadastral and jurisdictional records or notarial registries from archives belonging to town councils, municipalities, parishes, and ecclesiastical institutions as well as private archives started to be incorporated in the works of Antonio Eiras Roel and his fellows at the Deparment, namely Baudilio Barreiro Mallón, José Manuel Pérez García, Juan E. Gelabert, Pegerto Saavedra Fernández, Ramón Villares, Ofelia Rey Castelao, or Hortensio Sobrado Correa. Their research agenda focused on regions with sources that allowed for very thorough studies on all the aspects of the socioeconomic life between the 16th century and the end of the 18th or even the beginning of the following one. Thus a huge difference was detected between coastal and inner regions, as Bouhier would also describe in his research on the whole territory of Galicia (Bouhier, 2001). Bouhier's research on the agricultural geography of Galicia was done over the course of 16 years and was first published in 1979. The author explains the different forms of agricultural organization, the agricultural system, its structure and its origins, also remarking the importance of *monte* (uncultivated land) as the support of cropland. Such a global but also detailed and exhaustive approach had not been done before within Galician agrarian history nor rural studies, and it remains until today as the basic reference on the agriculture of the region in all its main aspects.

All of these authors collaborated in the description of a *complex* agrarian system and its spatial and time variations witin the period between the 16th and 19th centuries. They described and analyzed the configuration of a mixed farming system and its intensification in terms of increase in cultivated surface and yields, a reduction of fallow along with the introduction of

[27] See for instance Chambers and Mingay (1966), Kerridge (1969), Thirsk (1987), Grigg (1989), Chorley (1981) or Overton (1996).
[28] For more detail on the social history of Galicia see Burgo López, 2003, and Saavedra, 2003.

American crops such as maize and potatoes, and the subsequent changes in rotation systems and agrarian production, as well as its connection with changes in population. This was mostly possible through the study of strategic local cases. Results confronted the theory that smallholding was a constraint to the increase of agricultural productivity and to the introduction of technical innovations, even though when many of them considered that such a fragmentation pattern in the use of land was an obstacle to changes and innovation. Bouhier even compared Galicia and Castile in terms of grain yields according to Ensenada's Cadastre and to statistic reports from the late 19th century, and concluded that there was a generally higher level of productivity in the first case in the 18th century, and that such level increased all through the 19th century, even for vineyard, and especially when considering other harvests such as potatoes or chestnuts (Bouhier, 2001: 1,092-1,114).

However, most studies lacked a comparative perspective and coastal regions received preferent attention, as well as the 17th and 18th centuries, which are better known than the 16th (Saavedra, 2003). Barreiro researched the region of Xallas, in the province of Coruña (1973), and Pérez García the region of A Lanzada and the South of Pontevedra (1975, 1982 and 2000). Rey Castelao studied the region of the Ulla river in Coruña (1981). Gelabert focused on the region of Santiago, Coruña, between 1500-1640 (1981), thus strenghtening the idea of an "*arcaic"* agrarian system (Saavedra, 2003). The main research in the inner region of Galicia was conducted by Pegerto Saavedra and Hortensio Sobrado, both of whom focused on the province of Lugo. Saavedra researched the regions of Burón and Mondoñedo (1979 and 1985), and Sobrado focused on the region of Castroverde (1992).

These studies constructed a deep explanation of the agrarian system and its geographical variations in the period between the 16th and 18th centuries, which emphasized the integration between uncultivated land, livestock and croppland. The introduction of new crops (maize, beans, potatoes) and changes in rotations, cultivated surface or livestock management were also described and interpretated as a sign of a dynamic agriculture which allowed for Galician population to almost quintuplicate between 1500-1800 (Saavedra, 1992b). The role of *monte* was pointed out as central in agriculture. A lot has been said about this resource in Galicia (Bouhier, 2001; García Fernández, 1975; Saavedra, 1982, Balboa, 1990; GEPC, 2004 and 2006), which can be summarized in the fact that the use of these uncultivated surfaces made it possible for agroecosystems to function and even to intensificate cropping when required. In this research, our aim is to approach the limits of this process and its impact on *monte* areas and, generally, on soil fertility.

These previous researchers described a process of agrarian intensification that supports most of our results, namely those of yields and surface changes. All this evidence of intensification would be inscribed within the historical concept of First Agricultural Revolution, thus affirming the innovative capacity of a small-scale agriculture which, at the time, was not connected to an integrated market (Saavedra, 1992a). Despite the relevance of their contributions to the agrarian history of Galicia, these authors never took direct part in the "backwardness" debate.

However, there is a problem regarding most of their data on productions and surfaces, which are offered in local units. Converters into the metric system were difficult to obtain until 1985, when Fernández Justo published her research on the traditional metric system and offered equivalences for different measure units at local scale for the whole territory of Galicia. Results which do not follow the metric system are therefore not easily comparable. However, we do acknowledge the logic behind those "traditional" ways of measuring and their meaningful significance. Regarding yields, traditional measures put capacity (mostly grain) in relation with land productivity, thus expressing the amount of a given seed that the field could contain. Thus measures varied according to local conditions, either geographical, climatic, or edafological. Communities built their meaning with a specific logic which still needs to be studied (Castro Redondo, 2016).

On the other hand, yields in Galician historiographical research refer only to the part of biomass production which is harvested for human consumption but excludes other equally important productions such as straw and generally all aerial net primary production that would have different final uses such as feedstuff for livestock, fuel, compost or manure. These by-products were also a target of the harvest and used to have much higher yields than nowadays because seed selection favoured all those diverse uses of crops. Such varieties also had a more efficient nitrogen cycle according to applied research undertaken at the Agroecosystems History Laboratory of the University Pablo de Olavide in Seville (Guzmán et al., 2010). On the other hand, Galician agriculture functioned on the basis of very complex crop associations. These crop rotations are locally adapted to the productive system, thus increasing their productivity (Lloveras and Alonso, 1982). Therefore, the comparison of one single product which is part of a multiannual rotation distorts reality. We need to consider land productivity by estimating average annual production per land unit regarding all the years of the crop association. Our main indicator is the total output (including by-products) divided by the corresponding agricultural area, which is one of the most useful and common indicators of land productivity (Overton, 1996: 72). Besides, productivity data in dry matter also allow for better comparability with other agroecosystems.

Regarding biophysical aspects, some of these previous studies also showed environmental concern and offered more complete visions of the agrarian system by describing and analyzing its different aspects: population, agrarian production, physical environment, clima, livestock, croppland, complementary and integrated uses of *monte*, prizes, market, transport, consumption, migration, etc. But nature seemed to be reduced to a description of physical environment and climatic conditions both as a conditioning and explicative factor for agrarian production and harvest variations, like in Gelabert's work (1981). Pérez García designed a model that aimed at explaining all the above-mentioned aspects and their connections, but putting population at the beginning of the agrarian system and in the centre of the explanation

(Pérez García, 1975). Bouhier (2001) offered a more comprehensive approach at this respect by describing climatic and geographic regions and their corresponding variations in the agrarian system, as well as the connection with soil fertility. Without making it an explicit objective of his research, this Geographer challenged the backwardness paradigm regarding pre-capitalist agriculture in Galicia already in the 1970s by describing a complex agrarian system which depended on the integration of agriculture, livestock and *monte,* and was able to increase land productivity in the long term.

Taking all these previous research into account, our study aims at completing the image of agroecosystems in terms of land productivity and inner circulation of nutrients, so that we can assess soil fertility and the impact of agrarian intensification in the most accurate possible way. However, these previous results of our local agrarian history had already proved the territory of Galicia to be amongst the most productive ones in 18th century Europe, with yields per unit of surface that returned between 5 to 7 times the input of seed. This was particularly the case of coastal regions, where maize was the main responsible for the yield increase due to its higher output when compared to traditional cereals, especially when associated with both beans and fodder, as it was the case (Pérez García, 1982; Bouhier, 2001).

The Economists introduce the "backwardness" debate

The arguments for backwardness were mainly introduced in the academic world after the 1960s by economists who studied how industrialization of agriculture was happening in Galicia in the second half of the 20th century (Colino and Touriño, 1983), which other authors even questioned to be occurring (Beiras, 1967 and 1972). The end of Franco's dictatorship, the period when they were doing their research and which most of them studied, was an appropriate context to demand economic developement. Thus their conclusions on the lack of industrialization or market integration were used as an argument against an oppresive government, and even against the political and economic centralism of the State. Beiras elaborated the first formulation of the backwardness paradigm, and later on it was also developed within Economic History by authors like Rodríguez Galdo or Fausto Dopico, who mainly studied agricultural changes in the 18th and 19th centuries.

Their general interpretation of Galicia's agricultural history blamed land tenure (commons, smallholding and *foro* contract), subsistence polyculture, and a predominant rural society for the reluctance towards the introduction of technical, social and political changes. Their quantitative and economic analysis of the socioeconomic structure was necessary at the time, but their interpretation in terms of what it implied for the present was too judgemental. As explained by Fernández Prieto, this academic debate had also a translation into an *"ahistorical myth"* that still functions as an interpretative tool regarding political and social issues. And this applies not only to the past but also to the present by blaming the (still) rural prevalence within the country. Thus the past was turned into tradition, which they described as opposed to modernization. Migration is one of those emblematic topics that has been interpretated as a collective failure at the light of this paradigm, since after the flow to America in the late 19th and early 20th centuries, it was repeating itself again in 1970s although with new destinations in Europe (Fernández Prieto, 2016).

Beiras formulated his idea of the economic backwardness of Galicia in the late 1960s and early 1970s under a colonial approach, which reaffirmed Galician nacionalist project and explained the economy of the country regarding its dependency from the centre of the Spanish State. According to his proposals, which excluded the analysis of livestock, Galician agriculture between 1929 and 1959 had not yet been industrialized and was mainly oriented towards self-consumption. His general vision on a backward economy was contested by other authors, mainly by Colino and Touriño (1983), who analyzed the process of market integration of Galician agriculture between the 1960s and 1970s by studying livestock productions as well, which allows them to deny the subsistence character of agriculture. However, they still sustain the idea of backwardness regarding the general trend of European agricultures. López Iglesias (1995) would later on replicate the backwardness paradigm but excluding the characteristic colonial approach of Beiras. This author rooted backwardness mainly in the smallholding and its low labor productivity, which constrained competitiveness and thus resulted in a reduced agrarian rent per household. As Soto explains (2015), the main conclusion of these authors, even with certain nuances and from different approaches, is the subsistence character of Galician agriculture in the stages prior to market integration, which mostly took place in the second half of the 20th century. As we will see in the following section, this fact has been refuted in more recent times by historical research (Villares, 1982; Carmona, 1990; Fernández Prieto, 1992; Martínez López, 2000; Soto Fernández, 2006). However, this topic exceeds our research scope[29], and we will only focus on the authors who applied the backwardness theories to the analysis of the transformations occurred during the 18th and 19th centuries, which is our study period.

Within Economic History, Rodríguez Galdo and Dopico (1981) are explicit about the "*underdevelopment*" of Galicia, which they root in the prominence of the "*traditional agrarian society*" and in "*the social relationships within the rural world",* which were permeated but not erradicated with the penetration of capitalist relations of production. These authors formulate the contradictions that arise from the fact that, even within a process of growth in agrarian production and population along the 19th century, peasants were increasingly in debt, very vulnerable to subsistence crisis, and forced to migrate, whereas most of the agrarian rent was being detracted by rentier landlords who owned the direct domain of the land. For these researchers, this was an evidence of limited and insufficient productive structures, which were based on the accumulation of labor and on the intensive use of a fragmented land but not on the increase of labor productivity, as it had happened in

[29] For more detail, see Fernández Prieto (1992 and 2000b and 2000c) or Soto (2011 and 2015).

England or France along the 18th century, where industry could also absorb the excedent population from rural areas. The *underdevelopment* in Galicia is interpretated as the result of the integration in a capitalist economy under the domination of other territories, as Carmona would later explain regarding what he describes as the first general crisis of Galicia's economic structure, which occurred after 1830/40 and was related with the failure of the introduction of capitalism in the region (Carmona, 1990).

This reading is also a product of the ideological discourse of national affirmation of Galicia, which was being constructed at the time. We agree that inequality in the access to resources (namely land) and appropriation of surplus (in the form of rents) with peasant exploitation by feudal landlords are in the origin of poverty and social conflict. However, the means of production, and namely smallholdings in the case of Galicia, have been proved capable of sustaining an increasing population by adapting to the introduction of new crops and a process of agrarian intensification even within very constrained boundaries (Villares, 1982; Saavedra, 1992a; Soto, 2006; Carreira and Carral., 2014). For this matter, population increase and migration processes that occurred during the 19th century in Galicia can also be seen as the sign of a highly productive agriculture. In fact, some of these previous works also emphasize the achievements in terms of increasing yields and land productivity, which made it possible to face the demand of an increasing population and still satisfy the corresponding rents to the landlords (García Fernández, 1975), but the common interpretation of the moment can be summarized as "*growth without modernization"* (Rodríguez Galdo, 2000). All of it in a context in which liberal reforms did not succeed to turn tenants into landowners due to the continued existence of a dissociation between "direct" and "useful" domains of land through the *foro* contract. The ruling class was acting as rentier, not as landowner, and those who had the means to introduce innovations had not the interest to do so, whereas tenants were unable to do it within the existing relations of production (Villares, 1982). However, if technical innovation did not happen in Galicia during the 19th century it was mainly because the potential agents, the peasants themselves, had different concerns at the moment, namely to gain full ownership of the land they worked. Besides, the technical innovations that the supporters of the backwardness paradigm expected to have happened in Galicia were also anachronistic. Their look at the past was biased by their conclusions regarding the socioeconomic conditions they lived in (Fernández Prieto, 1992).

Supporters of the "backwardness" theory of Galician agriculture and, by extension, economy, arouse from other disciplines as well. We would like to consider the contribution of the Geographer García Fernández, whose physical description of the agrarian landscape of Galicia set an example that Bouhier would later follow and develop in much more depth. However, García Fernández described Galicia in the 19th century as insufficiently "*developed*" because of its subsistence agriculture based on polyculture and not *yet* "*industrialized*". As mentioned before, he clearly blames *foro* contracts for land fragmentation (*minifundismo*), and therefore for the lack of modernization since he atributes smallholdings and subsistence polyculture with the incapability of adapting to changes related with capitalist market economies. This implies the assumption that mechanization could actually not adapt to the spatial organization and exonerates industry from any responsibility. On the other hand, his thorough description of the agrarian system offers a very comprehensive picture of how intensification occurred and how the agrarian system worked and could adapt to it, also taking into account geographical variations. Thus, according to this author, smallholdings were protagonists of intensification as their subsistence was compromised by an increasing need for foodstuff due to demographic growth, and the pressure of having to pay rents to the landlords, which were also increasing through the period as a result of bigger harvests after the introduction of new crops (García Fernández, 1975).

The refutation of a backward agriculture

This refutation has been possible with historical research, which located the object of study (agriculture) in its context, and analyzed it with appropriate methodology. Most of the research at this respect has been done within the Department of Contemporary History, by many of the members of the current HISTAGRA research group. Within their contributions, there have been four main research topics: land tenure, agrarianism, commercialization of agrarian production, and technical and productive changes. Their results defined the four most significant processes within our contemporary rural history: the achievement of land ownership by peasants, commercialization of agrarian production, technical innovation, and social articulation of peasant society (Fernández Prieto, 2000b). In the following paragraphs, we offer a summary of their major contributions to the overcoming of the backwardness myth. However, many authors still sustained that, despite the obvious changes in agricultural practices during the 18th and 19th centuries, the socioeconomic structure was a major constraint to economic development due to its Ancien regime characteristics: land tenure (mainly in ecclesiastical and nobility mortmains), smallholding, limited market integration, etc. (Villares, 1982; Carmona, 1990).

Villares accomplished a long-term analysis of the transformation from feudal territorial land into capitalist property at the beginning of the 20th century along with paralel transformations in agriculture, thus explaining how the smallholding agriculture consolidated in Galicia. He describes an increase in cultivated land, and the introduction and expansion of new crops such as maize and potatoes along the 17th and 18th centuries, which resulted in new rotations with less fallow periods and a progressive switch towards spring cereal instead of winter ones, along with the intensification of fertilizer needs and a paralel livestock specialization in certain regions. However, land structure remained invariable in its small and fragmented scale, and it still showed plenty of characteristics of the Ancien Regime such as the tax and land contract formulas, which have been at the very centre of the discussion of Galician agriculture in terms of “underdevelopment” and “backwardness”. Confiscation laws of ecclesiastical and nobility manors after 1830s had not granted peasants with access to land.

These decrees only meant a transfer of rents but not property, which was not clearly differentiated in *foro* contracts, as García Fernández had already explained (1975). As a result, the class committed to production was focused on subsistence agriculture even at the end of the 19th century. The author locates the end of the expansion of cultivated land around 1880s, when the impact of the agrarian crisis was first noticed after the incorporation of American agrarian production into the global market. This crisis forced further structural transformations in old European agricultures, and the same happened in Galicia, where *foro* contracts were eventually abolished and peasants obtained land ownership during the first third of the 20th century (Villares, 1982 and 2000). According to Fernández Prieto, the impact of the agrarian crisis of the late 19th century accelerated deep changes that were rooted in the previous intensification process, which eventually led to peasant land ownership, the expansion of market economy, and a process of productive renovation (Fernández Prieto, 1992 and 2000). On the other hand, Villares pointed at land fragmentation and the lack of capital as constraints to the introduction of technology and the insertion of Galician agriculture in the market, which was limited to local fairs where peasants took their excedent. Subsistence crisis and demographic pressure on top of this "*traditional*" or "*arcaic*" socioeconomic structure would result in a process of migration (Villares, 1996). At this respect, his conclusions were more similar to those economic historians who replicated the backwardness myth (Rodríguez Galdo and Dopico, 1981; Carmona, 1990).

About a decade later, Fernández Prieto studied the introduction of scientific knowledge in Galician rural world at the turn of the 19th century and beginning of the 20th, which was mainly related with the innovations of the so-called second and third waves of industrialization: inorganic fertilizers, fossil-fueled machinery, and breed selection. The main goal of his research was to identify the agents of such changes, thus concluding there was a shared protagonism between society and State, and that peasants led the adaptation process of agriculture according to their own interest and the requirements of the inner market with a high degree of social, environmental and technical rationality. Fernández Prieto was among the first historians who openly challenged the "backwardness" theories of the previous economic researchers on Galician agriculture by affirming the existence of social and technical innovation, thus putting changes into historical context as Villares had started to do in his own research on land ownership. Both proposals are framed within a European historiographical context where the teleological interpretations of the Agricultural Revolution under the paradigm of modernization were being questioned for developing an ideological discourse in terms of progress. Besides, the very "revolutionary" nature of this process was challenged by more moderate readings on productivity changes, which were not that abrupt until the 20th century with the massive incorporation of fossil fuels. These alternative interpretations denied that enclosures of the 18th century had been determinant for the productivity increase, which had mainly been a result of a long-term process of nitrogen accumulation in the soil related with the introduction of leguminous plants at small scale farming (Chorley, 1981; Allen, 2004).

Within Economics, Xan Carmona, who would mostly identify with the backwardness paradigm in the beginning of his career, also took part in this renovation by describing the monetarization of Galician peasant's economy by means of livestock specialization within a mixed farming regime. Although, according to the author, the socio-economic structure was not the most appropriate for this specialization, peasants managed to integrate livestock breeding with agrarian use and commercialization, first to England in the second half of the 19th century, and secondly to the inner Spanish market, thus acquiring capital that, among other requirements such as paying taxes or *foro* rents, would later serve to gain access to land (Carmona, 2000).

With these results, research started to contradict the modernization theory by proving a dynamic society, with peasants willing to introduce changes by means of strategic adaptation to the new socioeconomic conditions. The idea of unlimited progress was questioned, and there were even new approaches to the impact of these innovations. Balboa (1990) studied the resources of *monte* and its changes through the past centuries, and Balboa and Fernández Prieto (1996) compiled their knowledge on technical change and natural resources in an article on fertilization with an environmental approach. Sobrado (2004) showed similar concern in his article on fertilization in Galicia, where he describes local practices and connects them with soil fertility. However, the author partially reproduced the discourse of the technicians he cites from the 19th century, who disdained peasant knowledge by considering their practices outdated and unscientific.

Generally, the contributions of historical research proved that the so-called "traditional" agriculture was not a synonym of "backward", and that "modernization" had an environmental impact that had to be included in agrarian research as well. The idea that advanced organic agriculture[30] in pre-capitalist Galicia was ecologically sustainable prevailed in the absence of further research. The environmental paradigm did not have much continuity, except for the thesis of Soto (2006), and a book chapter by Soto and Fernández Prieto (2010), where Galician mixed farming is compared with Mediterranean agricultures from an environmental perspective. In his thesis, Soto focused on the main magnitudes of Galician agriculture at a regional scale and their transformations in the long term, between 1750 and 1980s, which had not been researched with such detail and integration except for Bouhier and the local case studies referred above, and for the first time included agriculture after the Civil War. These macromagnitudes refer mainly to cultivated surface, rotations and crop associations, and yields, and are analyzed both in quantitative and qualitative terms. The author studies their evolution by connecting them with transformations that have been associated with the First, Second and Third waves of the Agricultural Revolution, and offers an environmental interpretation of Galician agriculture, where mainly nutrients, but also water

[30] We use this concept as formulated by Wrigley, according to whom advanced organic economies were distinguished by a series of elements such as a "*rising productivity per head on the land, urbanization, occupational change, and increased trade and commerce*" (2006: 469). In comparison with organic economies, advanced ones achieve a higher margin of production or "surplus" once the subsitence needs are met.

in certain regions during the summer, were among the most important limiting factors (Soto, 2006). More recently, Soto also performed a biophysical approach to the industrialization of Galician agriculture between 1960 and 2012 by analyzing changes in biomass flows and showing the environmental impact of the industrialization process (Soto, 2015).

Besides, other researchers also approached environmental conflict such as the opposition to the installation of a paper production factory (Rico Boquete, 1997) and nuclear power plants (López and Lanero, 2011), or conflicts over *monte* resources and changes in their management in the 19th and 20th centuries (GEPC, 2004 and 2006; Freire Cedeira, 2014).

Our research is therefore built upon these previous works, on top of which we would like to add the biophysical approach. This perspective within Agrarian History is the culmination of a long tradition of agroecological and environmental research in permanent multidisciplinary dialogue, and includes methods from Agroecology and the theory of Social Metabolism, which allow to build a different interpretation of our agrarian past. Agriculture is at the heart of this research and is studied within its environmental limits, thus questioning and challenging the previous economic literature which compared completely different agrarian systems by only taking into account crop yields or indicators such as gross national product or net income, and concluded that Spanish agriculture, and namely Galician one, were not as modern and advanced as other European regions in terms of market integration of agrarian production, land productivity or industrialization.

Our focus is on biophysical aspects of the intensification process and its consequences within a given agroecosystem in terms of soil fertility. This approach does not deny nor invalidate economic variables, but its coordinates are located in a different sphere which aims at understanding sustainability problems and environmental degradation, as well as natural constraints to agriculture. This is important in order to understand the transition from a solar based agriculture into a fossil-fueled one. Therefore, socioeconomic aspects are not taken into account in this research. Agriculture has frequently been approached from that point of view, and from a political perspective too. Land tenure and its transformations have been widely studied within Galicia, as well as the organization of agrarian production, demographic patterns, social structure, and even intangible aspects such as religiosity and access to culture in the Ancien Regime. Our historical approach on agriculture is therefore centered on the environmental limits of intensification and the impact of this process on soil fertility.

The ecological paradigm is the next step that Galician historiography needs to take after such a rich and fruitful research on socioeconomic and political issues within agrarian history. It will also provide more arguments in order to refutate and definitely overcome the backwardness debate as other colleagues have done and are still doing within the Spanish teams of the SFS project.

Chapter 2. Theoretical framework

2.1. The social metabolism applied to agrarian history

Within the ecological paradigm, environmental history is a very appropriate hybrid discipline to frame the study of human-nature interaction in the past, thus combining the biophysical perspective with the approach of the social sciences. Since humans alter ecosystems in order to produce raw materials and energy for their daily needs, we will use the concept of agroecosystem to refer to these human-modified ecosystems (Altieri, 1989; Margalef, 1979, as explained in González de Molina and Toledo, 2011). Humans appropriate nature in order to survive, just as agroecosystems require energy and material inputs in order to reproduce themselves due to their instability -whereas ecosystems are able of self-maintenance, self-repairing and self-production (Gliessman, 1998, cited in González de Molina, 2011). Therefore, the biological concept of "metabolism" is applied to society in order to refer to its exchange of energy and materials with the surrounding environment in order to function (Fischer-Kowalski and Haberl, 2000).

As explained by Fischer-Kowalski and Haberl (2000 and 2007b), it was mainly Karl Marx who first formulated the idea of social metabolism and used it in his analysis of capitalism. According to González de Molina and Toledo (2011), the concept was brought back to use after the 1960s and has become very popular ever since within Ecological Economics and other disciplines, especially for energy and, secondarily, material flow accounting. For this reason, specific methodologies have been developed to account for all kinds of flows and at different scales, although with a priority focus on the transformation of the energetic metabolism. See for instance the MEFA (Material and Energy Flow Accounting) methodological framework or the use of the concepts of NPP (Net Primary Production) and HANPP (Human Appropriation of Net Primary Production) as indicators for analyzing human-nature interaction in terms of human impact on ecological flows of energy and materials (Schandl et al., 2002: Fischer-Kowalski and Haberl, 2007b; Haberl et al., 2013).

In our case, we will use the social metabolism proposal as described by González de Molina and Víctor Toledo in their publication of 2011 *Metabolismos, naturaleza e historia. Hacia una teoría de las transformaciones socioecológicas*, and in their last updated edition, which was published in English in 2014 under the title *The Social Metabolism. A Socio-Ecological Theory of Historical Change*. This theoretical framework addresses the process of coevolution between social and natural systems, which implies that the historical paths of either nature and society are only completely understood when analyzed together by taking their interactions into account.

Social metabolism deals with the functionning of a given agroecosystem mostly by analyzing the material, information, and energy flows that occur within its boundaries due to the human-nature interaction through the different metabolic processes: appropiation, circulation, transformation, consumption, and excretion. The size and functionning of these flows determine the configuration of the metabolism. Besides, through these processes, a "*reciprocal determination"* occurs by means of which a portion of nature is "*socialized*" and a portion of society is "*naturalized*" (González de Molina and Toledo, 2011: 60), since *"the form in which human beings are organized in society will determine the way in which they affect, transform, and appropriate nature, which in turn conditions the way in which societies become configured"* (González de Molina and Toledo, 2014: 60). Or as explained by Fischer-Kowalski and Haberl, in this co-evolutionary process

> *"societies become structurally coupled with parts of their environment, leading to a process where both mutually constrain each other's future evolutionary options. The co-evolutionary process is then maintained by the specific exchange relationship with the environment, by the particular way a society interacts with certain natural systems. In this co-evolutionary process, we can distinguish ideal-typical "states", that is, patterns of society-nature interactions that remain in a more or less dynamic equilibrium over long periods of time ("sociocecological regimes"), and also periods of transition*", (Fischer-Kowalski and Haberl, 2007a: 14)[31].

This theoretical proposal of social metabolism has recently been under discussion within the international research project *Sustainable Farm Systems*, where accounting methods for both nutrients and energy flows within agroecosystems in the past have been elaborated during the last years. The fact that particular issues of the methods have not yet been completely agreed upon has added difficulties to our work, but it has also enriched it and given us the possibility to discuss our results in conferences and both in presential and online meetings. As Sieferle remarked in 1980s, and it is valid still today, environmental history is a young discipline and there has not yet been an agreement on "*its subject matter or methodological foundations",* which will be, either way, approached from an interdisciplinary perspective due to the "*dynamics of natural and social processes"* (Sieferle, 2001a: preface).

In the next section we will refer how González de Molina and Toledo articulated an environmental interpretation of history by using Sieferle's proposal on appropiation modes and their corresponding metabolisms. Moreover, a theoretical explanation of the process of change from one metabolism into another has been elaborated by the authors according to the rich tradition in this research line, thus allowing to analyze socio-ecological transitions.

[31] For a review on different approaches on co-evolution between nature and society, see González de Molina and Toledo, 2014: 21-25.

2.2. Socio-Ecological Transition (SET): waves and driving forces

The concept of Socio-Ecological Transition challenges the paradigm of the theory of growth and modernization and the terms in which it was used to analyze agrarian changes through the last centuries in what has been called "Agricultural Revolution" generally across Europe. Concepts matter not only because they name reality but also because of their ideological baggage, which we want to make explicit and avoid when necessary. The concept of "modernization" implies a linear and incremental evolution towards an improved situation. On the contrary, "transition" allows to interpretate qualitative differences between two different states. This proposal emerged within the context of the systems theory, where it was often applied to the analysis of ecosystems, and it has been recently incorporated in socioecological systems research. As defined by Fischer-Kowalski and Haberl, the socioecological transition is *"a transition from one socioecological regime to another"*, where a socioecological regime is *"a specific fundamental pattern of interaction between (human) society and natural systems"* (Fischer-Kowalski and Haberl, 2007b: 8). The study of transitions allows therefore to approach the functionning and sustainability of the different regimes or metabolisms according to the size and structure of their material flows. Within all the different proposals that have emerged within the paradigm of transition[32], we opt for the one developed by González de Molina and Toledo (2011 and 2014), who focus on the transition from an agrarian into an industrial metabolism.

The concept of "Agricultural Revolution" has been questioned before, and initially by the supporters of the backwardness theory. This is coherent with their denial of most changes in agriculture of the 18th and 19th centuries. Rodríguez Galdo and Dopico (1981) refuted the "revolutionary" reading that had been done of such processes in the case of Galicia during the 19th century because nothing had actually changed in the socioeconomic structure. García Fernández even denies that the process of intensification that occurred in Galicia during the 18th and 19th centuries were actually a consequence of the Agricultural Revolution since it was mainly the result of labor accumulation and not of an increase in labor productivity, and it did not include the introduction of industrial fertilizers and new farming tools (García Fernández, 1975). Therefore, what is striking for these authors who studied the past from the backwardness perspective, is the fact that agrarian production actually increased within the conditions of an advanced organic economy. Changes in cropping such as the introduction of new plants and more complex associations along with the incorporation of leguminous and fodder crops and the supression of fallow are part of the first stage of what has been called Agricultural Revolution, and it does take place in Galicia between the 17th and the end of the 19th century, depending on the region, as our colleagues from the Modern History Department or David Soto have demonstrated and even these economists have described (Saavedra, 1979

[32] For more detail on these proposals, see González de Molina and Toledo (2014) and Fischer-Kowalski and Haberl (2007b).

and 1990; Pérez García, 1975, 1978 and 1982; Sobrado, 2001; Soto, 2006). Our research offers two more case studies of such intensification process.

However, we prefer not to use the concept of Agricultural Revolution as it had been originally formulated by the British historiography of the late 19th and beginning of the 20th century, especially by Ernle. One of the main problems with this concept is that it refers to the case of English agriculture, which was elevated to the category of paradigm within part of the European historiography through the past century. The first critical voices appeared in the 1960s when research emphasized the long-term perspective of agricultural change and its slow rythm, thus rooting its associated transformations in the Middle Ages (Chambers and Mingay, 1966; Kerridge, 1969; Chorley, 1981; Allen, 2004). On the other hand, the description of this process of agrarian change does not necessarily match what happens elsewhere because the paradigm does not consider environmental nor socioeconomic differences. Besides, agricultural transformations do not necessarily have to trigger industrialization. At the light of these general assumptions, agricultures that did not follow the standardized pattern of agricultural change were seen as outdated and underdeveloped. Eventually, the discourse around Agricultural Revolution legitimated the outcome of the process, namely capitalism, as the only possible option.

Within agrarian studies, the ecological paradigm allows to approach agricultures within their natural constraints and potential. González de Molina and Toledo include elements from other researchers and elaborate a more global and complex theoretical model. They incorporate Sieferle's analysis of energy systems, which provides further understanding in the configuration of the different "*social formations*". Thus, according to the energy regime, Sieferle determines the existence of three main different types of social metabolisms: hunter-gatherer, agrarian, and industrial. Hunter-gatherer societies are based on an uncontrolled solar energy system; agrarian societies do control this solar energy in order to produce biomass; and industrial societies incorporate and depend on fossil fuels. Fischer-Kowalski et al. (2014) have worked further on this proposal of re-writing human history according to these three "*modes of subsistence*", which are analyzed in relation with population dynamics, energy regimes and the derived human impact on the Earth system regarding changes in the carbon cycle.

In this research, our main interest is obviously the agrarian metabolism, which transforms solar energy through "*bioconversion or altering the use of space*". For this reason, agrarian metabolisms are highly dependent on the territory. As Sieferle puts it:

> *"The overall area of a landscape determined the theoretical total quantity of energy available in this landscape. The upper limit could only be surpassed if it was possible to increase the area, for example by spatial expansion, or through the import of energy fixed in biomass, that is by equivalents of space. There were limits to these imports because of the transportation costs mentioned above. Within a certain territory, specific areas had to be*

dedicated to each form of energy, which involved a zero sum game: the increase of one kind of energy was only achieved at the expense of another, since it involved alternative uses of a given total area" (Sieferle, 2001a: 25).

This "*general dependence"* endows agrarian metabolisms with certain characteristic traits such as the tendency to a decentralized population pattern with neighboring "*scarcity islands"* which could not be appropriated due to the energy cost of transport. At the same time, dependence and decentralization on the territory result in a tendency towards a permanent *"stationary state"*, except for occasional processes of "*growth"*[33] which are mainly related with the opening of new land. However, the common trend is towards land and energy scarcity, which requires optimizing the use of land, although efficiency can be improved with cultivation techniques such as crop breeding, fertilization, etc. Thus, according to Sieferle, *"there are always methods of innovation even if these remain within certain limits"* (Sieferle, 2001a: 27). Already in 1980s, when *The Subterranean Forest* was firts published, Sieferle remarked this dynamic character of agrarian societies:

> *"In agrarian societies, especially in agrarian civilizations, a series of processes would always be initiated that had an essentially dynamic character and strove towards increased access to resources. This must not be understood as an inherent tendency towards "development" or "progress". Agrarian civilizations could, as far as their technical and economic profile was concerned, remain stable in the medium term and, in any case, did not tend towards overreaching themselves. At the same time it cannot be overlooked that certain technical skills were increased over longer periods of time within their framework, so that the impression may arise that forces effective in the long term and which could be understood as "modernisation" were operative.*
> *No historical teleology need be surmised to understand these tendencies towards dynamism. Much is explained because agrarian production repeatedly gave rise to problems, of which solutions had to be attempted. In the first place this applies to agriculture itself, continually threatened by soil destruction and struggling with erosion, new pests and nutrient scarcity. It reacted by developing new methods of cultivation – breeding, fertilisation, crop rotation, draught power, tools. (...) This does not need to be seen as an autonomous tendency towards progress, but can be understood as a cascade of reactions to looming scarcity"* (Sieferle, 2001a: 31-32).

The author also explains the dynamics of demography, with a tendency towards population growth that is naturally controlled by epidemics or by famine, wars or the migration of the population surplus to industrial towns. This explains wide fluctuations within population numbers in agrarian societies. *"Mature, highly developed agrarian civilisations were usually overpopulated, which generally exerted a permanent pressure that could lead to both conflicts and innovations in the resource base"* (Sieferle, 2001a: 33).

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[33] Quotation marks in original text.

Besides, agrarian societies were vulnerable in a way that was unknown to hunter-gatherers. Even if the energy flow was constant, and agrarian societies were energetically sustainable, this does not mean that sustainability included material aspects as well. On the contrary, the intervention in ecosystems implied the possibility of destroying the own natural subsistence basis by means of erosion or salinization of soils, deforestation, lost of species and biodiversity, etc. (Sieferle, 2001a: 33). *"Therefore, a difficult balance between traditionalism and willingness to innovate with the complementary dangers of rigidification and self-destruction was at stake"* (Sieferle, 2001a: 35). This should alert about the trap of considering that all advanced organic agricultures were sustainable *per se*. Both side effects related with the intervention in natural processes and natural processes themselves "*put the final test of environmental compatibility of certain production processes so far into the future that the learning curve could be catastrophic if not lethal"* (Sieferle, 2001a: 39).

The incorporation of Sieferle's contribution to the analysis of societies from a metabolic perspective leads to a new reading of history. See for example the paper where Krausmann, Schandl and Sieferle apply the theory of social metabolism to the study of the industrialization of the agrarian regime in Austria and the United Kingdom. The authors compare both cases by analyzing the change in the relationships between the energy system, land use and human labor (Krausmann et al., 2008). Another revealing research on industrialization under the sociometabolic paradigm has been conducted by González de Molina and Guzmán, where they analyze the case of Santa Fe, in Granada (González de Molina and Guzmán, 2006).

Within sociometabolic research, the process of appropriation serves as a defining element of metabolism because it is the *nodal point* that articulates ecological and social processes. Therefore, their configuration is the key to detect changes through time, and it can be determined by attending to the following aspects: degree of transformation of the appropiated ecosystems, energy source employed in appropiation, and type of manipulation of the ecological processes and its components. Thus hunter-gatherers lived under an extractive metabolism, with a very low degree of transformation and manipulation, although with the risk of over-exploitation. After the development of agriculture, between 10,000 to 12,000 years ago, organic or agrarian metabolisms are defined by human manipulation and *domestication* of vegetal and animal species which are most useful for society, thus resulting in a *domestication of landscape* as well. This situation of "*colonization"* led to an ongoing growth of the scale of metabolism due to increasing levels of consumption of materials and energy (Fischer-Kowalski and Haberl, 2000: 23-26). This consumption would show an exponential growth with the use of fossil fuels in the process of appropiation, which gave place to the industrial metabolism, characterized for the decoupling of the metabolism from land in the supply of energy and materials (González de Molina and Toledo, 2011: 118-139).
Now that we have briefly explained the main concepts of social metabolism and described the agrarian one with a little more detail, we will go on with the theoretical explanation of the transition from an organic metabolism into an industrial one, that is to say the

industrialization of agriculture. González de Molina and Toledo describe the process in three waves, which actually refer to the changes implied within the so-called First, Second and Third Agricultural Revolutions (González de Molina and Toledo, 2011 and 2014).

The first wave occurred within the limits of the agrarian system, and it can be described as an "*optimization of its possibilities raising biomass production"*. This optimization is related either to endogenous or exogenous pressure, which in any case prove the agrarian metabolism unable to meet demands. According to Sieferle, population growth as well as increases in consumption or trade pressure are the main triggers of imbalances in land uses. At the same time, the resulting land scarcity would be related with institutional changes, especially in feudal regimes. Among these changes, the commodification of land and natural resources were frequent, as it happend with enclosurements all over Europe or the mortmain abolition laws, which in Galicia eventually ended up supressing the *foro* contracts and allowing peasants to get access to land ownership. Besides, these changes are usually related with an increase in social inequalities. The second wave is related with the introduction of inorganic fertilizers, generally speaking towards the end of the 19th century, thus causing a *methamorphosis* in the agrarian metabolism and overcoming the constraints of nutrient scarcity, which also allowed to reduce the "*land cost of fertilization"*. As a result, agrarian production started to depend on the *subsoil* instead of the soil (Sieferle, 2001a: 39-41).

The third wave implies the introduction of machinery to replace human and animal labor, thus completing the energy transition to fossil fuels and eliminating the limitations of the organic metabolism. This process of mechanization was later on complemented with the so-called "*technological package*" of the Green Revolution in the late 1950s (González de Molina, 2010a; González de Molina and Toledo, 2011 and 2014). All in all, the result is an increased pressure on agroecosystems in order to extract more and more biomass. In fact, recent research is also pointing at a sort of fourth wave, which is related with the externalization of this pressure on agroecosystems to foreign countries through international trade (Soto et al., 2016c).

Finally, the authors relate this process of SET with one or several of the following driving forces: changes in the provision and quality of natural resources; population size and structure; inequality in the access to energy, water or material flows; technological or institutional changes; economic exchange; political-militar relations between metabolisms; ideas about nature; environmental conflict, or chance (González de Molina, 2010b; González de Molina and Toledo, 2011 and 2014).

On the other hand, the concept of "metabolic rift", of marxist inspiration, allows to refer to the changes related with the outcome of the above-mentioned agricultural transformations from a biophysical perspective by incorporating the relationship between society and nature as well. The metabolic rift as first enunciated by Foster refers to the gap *"between human* *production and its natural conditions"* (Foster, 1999: 370) and the consequences of capitalist agriculture over soil fertility and nutrient depletion:

> *"The first such break [in nutrient cycling], associated with the second agricultural revolution, is often conceived in essentially the same terms in which it was originally discussed by Liebig and Marx and is seen as related to the physical removal of human beings from the land. This resulted in the failure to recycle human organic wastes back to the land, as well as the associated break in the metabolic cycle and the net loss to the soil arising from the transfer of organic products (food and fiber) over hundreds and thousands of miles. It was these developments that made the creation of a fertilizer industry necessary. A subsequent break occurred with the third agricultural revolution (the rise of agribusiness), which was associated in its early stages with the removal of large animals from farms, the creation of centralized feedlots, and the replacement of animal traction with farm machinery. No longer was it necessary to grow legumes, which had the beneficial effect of naturally fixing nitrogen in the soil, in order to feed ruminant animals. Hence, the dependence on fertilizer nitrogen increased, with all sorts of negative environmental consequences (...)"* (Foster, 1999: 400).

Later on, the concept would be further developed by Foster, Clark and York (2010) and Schneider and McMichael (2010) so as to adapt it to the current situation of global change and include the whole scope of ecological rifts instead of considering only the one referred to nutrient cycling. We have also applied this concept in our research.

Thus, we aim at describing the first steps of an Atlantic agrarian metabolism into its industrialization. We want to assess the sustainability of the process and detect where its limitations were. However, we stop right before the incorporation of industrial fertilizers and the mechanization of agricultural tasks.

Chapter 3. Designing our research on Galician agriculture

One of the aims of this dissertation is to play a part in the introduction of the ecological paradigm in Galician agrarian historiography, which has recently produced some relevant contributions in the field (see for instance Soto, 2006 and 2015). It is evident that this kind of research requires of an interdisciplinary approach that, as historians, we are unable to fulfil by ourselves. This is without a doubt very enriching and provides more insight in the topics we study, but it also brings along some technical difficulties. At this respect, we have faced several problems and delays. Fortunately, Roc Padró Caminal[34] selflessly offered to collaborate with us and has elaborated a model for estimating the nutrient balances of Fonsagrada, one of our case studies.

As explained in previous sections, the consolidation of environmental history as a discipline and the recent development of consistent methodologies within the theoretical framework of social metabolism has led to important contributions in Spanish agrarian history. A similar approach is very much needed in Galician historiography in order to complete the renewal of the discourse on the agricultural past and to definitely refute persistent ideas on economic backwardness and stagnation. David Soto Fernández, supervisor of this research, started his career at the University of Santiago de Compostela and under supervision of Lourenzo Fernández Prieto as well. This dissertation is the result of combining their approaches to agrarian history and their innovative ideas. The original project included up to four case studies and the construction of both nutrient and energy balances for all of them between the period 1750-2000. This would allow to study the whole process of socioecological transition in the context of an Atlantic agriculture.

Our first step was to locate the necessary fiscal and statistical sources to obtain information on agricultural management, land uses, surface and yields data. We visited the provincial archives in Ourense, Pontevedra, and Lugo, as well as several municipal archives in all four provinces: Lalín, A Estrada, Vila de Cruces, Silleda, Teo, Negreira, A Baña, Bembibre, Betanzos, Narón, Arzúa, Melide, Toques, Palas de Rei, Taboada, Fonsagrada, Ribadeo, and Ribadavia. Taking these sources and Ensenada's Cadastre[35] into account, two case studies were selected: Ribadavia, in the province of Ourense, and Fonsagrada, in the province of Lugo.

In this first moment, we detected that sources for the 20th century are not easily available due to their fragmentation and lack of coherence. Ensenada's Cadastre is also not complete for all

[34] Roc Padrí is a forestry Engineer and MA on Soil and Water Management (University of Lleida, 2012), and is currently a PhD candidate at the Economic History Department at the University of Barcelona, where he researches on Catalonian agriculture by constructing nutrient and energy balances, but also on a model to integrate landscape in research.

[35] This cadastre from 1750s is our main source for the 18th century, as we will explain in the corresponding section.

municipalities, which means that some of the potential cases were soon discarded. Eventually, from the remaining municipalities we picked those with more complete and reliable sources. Besides, geographical criteria were also applied, since we needed at least one case study to be located in the most characteristic Atlantic or Oceanic climate. One along the coast would have been more appropriate, but Fonsagrada has shown the best source availability, and is a perfect representation of preindustrial agriculture with a historical practice of polyculture and mixed farming and a high degree of geographical isolation. On the other hand, Ribadavia is a good counterexample due to its high degree of specialization, which was not frequent in Galician organic agricultures, and its introduction of monetary flows into its economy from a very early stage. Besides, sources for both cases allowed to construct agrarian productions for three moments along the study period, althoug Ribadavia is not as complete as Fonsagrada.

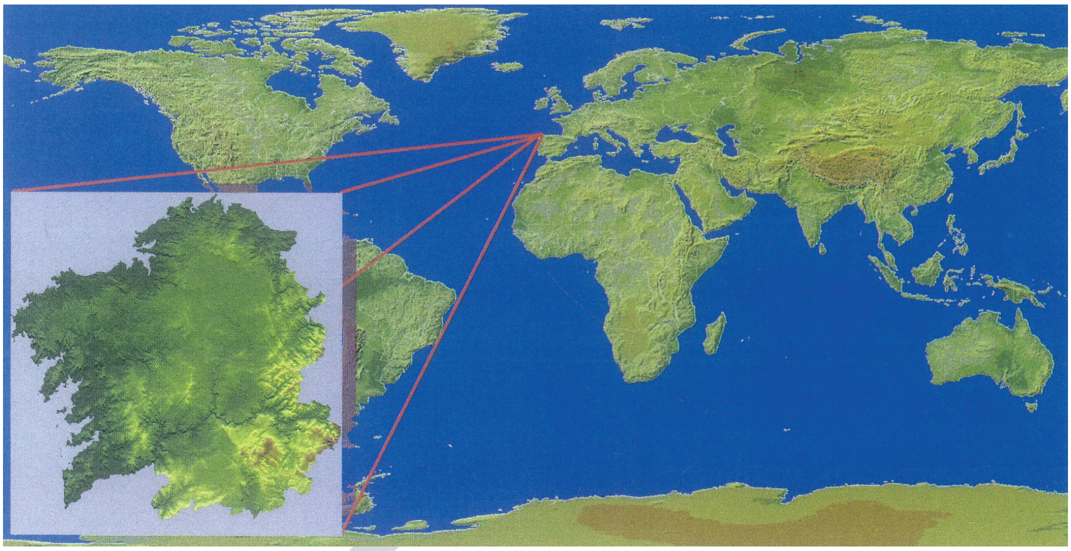
All in all, we decided to concentrate our efforts in the agricultural changes of the 18th and 19th centuries, which can be identified with the first wave of the socioecological transition. Thus the chronology of our case studies finally comprehends the period between 1750-1900, and nutrient balances have only been performed for Fonsagrada, thus discarding the energy analysis as well. As a result, we have focused on the process of agricultural intensification and its impact on soil fertility.

As with many thesis dissertations, the initial research plan turned out to be too ambitious and the idea of including up to four case studies with their corresponding nutrient and energy balances was soon abandoned. Such a task must be undertaken in the future since source availability is relatively good for several places and in different moments, although with seriality constraints in many cases. Even when fiscal and statistical sources for the 19th century are less abundant than in other Spanish territories due to the late consolidation of the municipal reform in Galicia, sources allow for more studies in this same research line. This will allow a much better territorial representation and detailed knowledge on the agroecosystems functionning.

3.1. Two case studies: Ribadavia and Fonsagrada

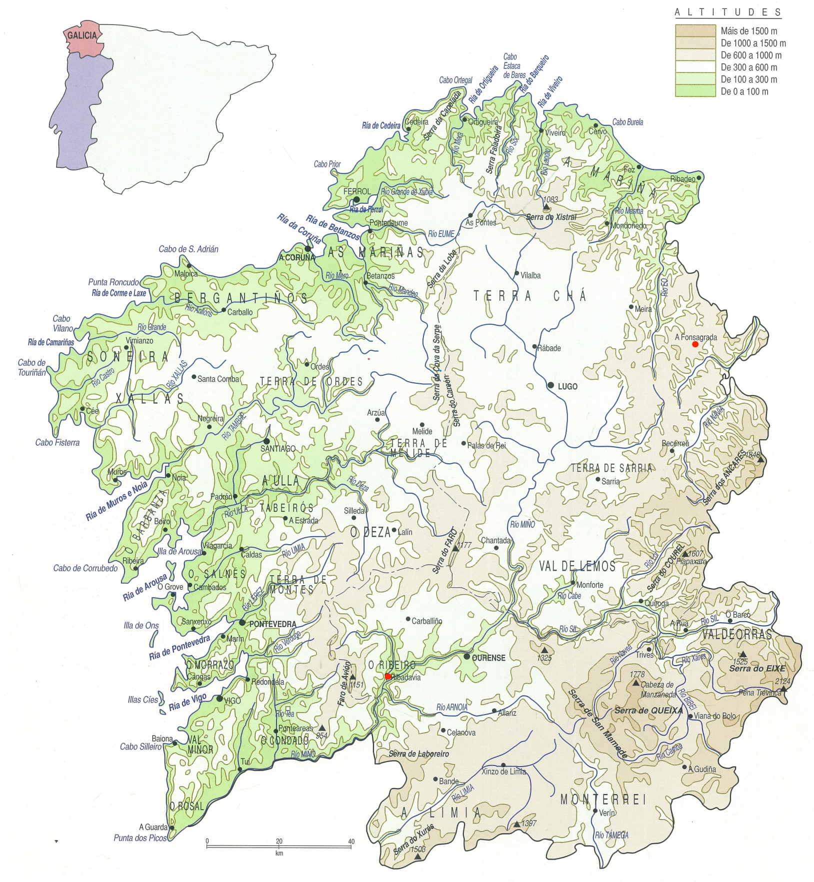
Both of our cases belong to the inner territory of Galicia, which has not been addressed by historiography as much as coastal areas. However, their climate and agricultural patterns differ enormously as well.

Map 1. The location of Galicia on a world map



Source: Martínez Cortizas et al., 1999: 13.

Map 2. The location of Ribadavia and Fonsagrada within Galicia



Map source: Romaní, 1994: 6.

Ribadavia has an arid climate, which has been classified as oceanic-mediterranean. Such climate shows the lowest average rainfall within the whole country, generally between 700-800 mm yearly, mostly concentrated in fall and winter and with summer drought which can go over 450 mm by September. Land is densely populated and articulated in a network, although not as much as along the Atlantic coast (Díaz-Fierros, 1979; Pérez Alberti, 1982).

On the other hand, Fonsagrada is located in the Eastern Mountains, with a "*mountainious oceanic*"[36] climate under continental influence, as it is common in these regions over 600-700 meters above sea level. The municipality is located between 700-800 meters over the sea level. Isolation and harsh climate are characteristic. It is among the regions with the lowest demographic densities in Galicia nowadays, and parishes are smaller than in the provinces of Pontevedra and Coruña, mainly when compared with the most coastal areas.

These socio-demographic patterns developed particular inheritance systems and household structures that conditioned the way in which land was appropriated, all of it in a process of mutual interactions which have been widely described by our colleagues at the Modern History Department. Fonsagrada's polycrop agriculture is mainly oriented towards self-consumption, and shows characteristics of both extensive and intensive mixed farming systems. However, it was not alien to market exchanges and, as Saavedra has pointed out, self-sufficiency was not the norm among peasants in Galicia although social inequality was not so pronounced in these mountainious regions as along the coast. With a bigger family structure and abundant labor force, it was not necessary to work for others in exchange for a wage, and the extra hands were easily occupied in rural industries such as the linen clothing, or worked as blacksmiths, although the main market exchanges in the region of Fonsagrada were those related with livestock, which was even exported to Castile at least from the 16th century. Seasonal migration was also frequent in these mountains, especially among young men, and was actually related with the commercialization of both cattle and textil manufactures, which migrants took along with them to Castile. But local markets such as the ones in Burón or, later on, in Fonsagrada, were also relevant in the Ancien Regime, and new ones appeared along the 19th century (Saavedra, 1991).

On the other hand, Ribadavia's economy is centered in vineyard cultivation, which functions as a cash crop, thus allowing for early market integration and resulting in a different pattern of intensification. With a market-oriented production, food and fertilizers had to be imported into the agroecosystem. Besides, crop rotations are different in both cases. Fonsagrada grows the typical crops in the inner regions of Galicia, where rye is the main cereal and potato is introduced along the 19th century, but there is a also bovine livestock specialization towards the end of the century with the corresponding increase in pasture surface and fodder crops. Being a vineyard monoculture, Ribadavia has been heavily affected by fluctuations in external wine demand and prize fluctuations, as well as by plagues.

[36] "Oceánico de montaña" (Pérez Alberti, 1982).

These two cases offer a complementary picture of the territory of Galicia. Because of its climate and mixed farming system, Fonsagrada is representative of most of the inner mountainious territory and *agras*[37] system according to Bouhier's classification (Bouhier, 2001), as we will see. The intensification pattern in Ribadavia is generally more alike to the one along the coast and to other vineyard specialization regions where Mediterranean-like climate is predominant. Its land organization system is not very representative within Galicia and, according to Bouhier, it is mainly characterized by its terraces and heavily conditioned by vineyard specialization. Besides, both regions have been the object of study of previous research within agrarian history, which has been very useful for our own work.

3.2. Objectives

The objectives of this research are tightly connected with open questions which arose from previous historiographical research, mainly from David Soto's thesis (Soto, 2006).

We aim at describing the process of agrarian intensification in two case studies within an Atlantic territory, Ribadavia and Fonsagrada, between 1750-1900. We develop a biophysical perspective that pays attention to changes in rotations, land uses, surface, and land productivity, but also to livestock management and manure availability. These transformations are connected with the first wave of the Socio-Ecological Transition. Thus our main objective is to explain agricultural intensification with biophysical elements in order to contribute to a better understanding of a process that has not been sufficiently addressed by Galician historiography.

Our secondary objectives are to connect the intensification process with its environmental limits and its impacts on soil fertility. For this purpose, we will present nutrient balances and nutrient flow diagrams for the case study of Fonsagrada. We will analyse the functionning of this agroecosystem in terms of soil fertility and nutrient management and determine whether its pattern of intensification was sustainable in the long term regarding nutrient management. This methodology allows to assess the environmental impact of agrarian practices and their territorial cost. Eventually, it also enables to compare our results with similar research in Mediterranean Spain (Andalucia, Catalonia and Balearic Islands), Austria or, in a near future, also Colombia, Canada and the US.

Finally, we would like to approach the study of migration from a biophysical perspective as well.

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[37] Type of agricultural land organization.

3.3. Hypothesis

Previous research on socioecological transitions has demonstrated that agrarian intensification in Mediterranean Spain during the eighteen hundreds was conditioned and limited by a structural lack of organic fertilizing materials. Demographic growth along with institutional changes linked with the liberal revolution and the expansion of capitalist markets led to an increasing pressure on land. In Mediterranean Spain, the introduction of mixed farming techniques was not possible due to bioclimatic conditions, thus having a more reduced livestock head and less manure availability and, all in all, a different pattern of intensification. Pastureland turned into cultivated land thus making it impossible to keep up with the previous size of livestock head, and therefore ending up in fertilizer scarcity and sustainability problems. This structural deficit of nutrients would only be overcome with the development and distribution of sinthetical fertilizers after the turn of the century, which allowed land productivity to increase but resulted in new sustainability problems (Guzmán and González de Molina, 2006; Garrabou and González de Molina, 2010).

In the light of such results, we wondered if intensification would have any such limitations in an Atlantic territory with a mixed farming agriculture and higher water availability. According to this general question, our hypothesis are as follows:

1. The intensification process in the case studies we analyze must have been limited by nutrient availability and likely resulted in nutrient mining in the soil. This must have been especially critical in the case of Ribadavia, with a vineyard monoculture which was market-oriented, and probably less relevant in the case of Fonsagrada, with a higher degree of self-sufficiency.

2. Nutrient cycles must have been altered through the intensification process. In an Atlantic agriculture such as Galician, it is common for pastureland surface to increase all through the 19th century in order to sustain an increasing livestock head (Soto, 2006).

    2.1. There is a secondary hypothesis related with the previous one, especially for the case of Fonsagrada. Livestock management must have adapted to the process of agrarian intensification in order to increase manure availability.

3. Our hypothesis of the existence of a soil mining process is related with the over-exploitation of *monte* (uncultivated areas), on which cropland depended for nutrient replenishment. This has been demonstrated by previous research on agriculture and soil fertility generally for Western and central Europe (Shiel, 2006a and 2006b; Sattari, 2014), and hypothesized by Galician historiography (Bouhier, 2001; Balboa, 1990; Soto, 2006). Besides, research on soils in Galicia during the decades of 1960

and 1970 concluded that phosphorus scarcity was common in *monte* areas (Gil-Sotres and Díaz-Fierros, 1979).

4. In both case studies, we hypothesize that the intensification pattern was not sustainable in the long term. However, performance must have been more balanced than in other bioclimatic regions such as the Mediterranean (Garrabou and González de Molina, 2010; Galán, 2015).

5. In the case of Ribadavia, unsustainability must have been related with vineyard monoculture.

Chapter 4. Sources

Sources for a biophysical study on soil fertility with nutrient balances must inform on several aspects related to agrarian production: land uses, yields, surface, types of crops, land management, and livestock numbers.

Qualitative aspects such as land management and crop rotations have been widely researched within Galician agriculture, mainly by Bouhier, but our colleagues at the Modern History Department have also contributed with essential research on agriculture at local scale, and David Soto at an aggregated level, as previously detailed. These studies have been very useful in order to assess different aspects of land management, but they also served as contrast data for our own estimations and for qualitative information from the sources.

The rest of the data, which are mainly quantitative, come mostly from fiscal sources, namely Ensenada's Cadastre from 1750s and *cartillas* or production assessments from 1850s and 1880s. In the absence of relevant data, we have also used agrarian literature and other statistical records from the 19th century or compendiums by engineers from the 19th and 20th centuries. From all of them, fiscal sources are obviously the most problematic ones due to their nature, which encouraged fraud in the declarations in order to reduce the tax burden.

There are also other fiscal sources that we have not used because of their well-known unreliability such as the *Censo de Frutos y Manufacturas* from 1799 (Fontana, 1967), and the records by the *Junta General de Estadística* from 1857 (GEHR, 1991). The first one has been used by Saavedra Fernández in his research on the region of Burón (1979), but mainly as a qualitative source and to compare its declared yields with other sources, thus concluding its utility in order to observe how potato is introduced in the region but its inaccuracy regarding quantitative information. Therefore, we have not used any of these documents. A third one is the *Cuadernos Generales de la Riqueza*, elaborated between 1818-1820 by the Minister of Finance Martín de Garay. Although the local archive of Betanzos seems to have the complete series of these statistics, their poor conservation state disuaded us from using them, especially because sources were not complete for the rest of the period in that municipality. Unfortunately, we have not located this document in any other archive so far. The failure to conclude such a fiscal initiative of one single cadastre is in the origin of the documents we have used fot the 19th century[38]: *cartillas evaluatorias,* which are the basis for the composition of *amillaramientos* (Bringas, 2003). Both are statistical records of wealth, and the first ones have provided our research with most of the quantitative data required. In the following sections, we will comment on all different types of sources used in this study.

[38] Ensenada's Cadastre was the first attempt.

4.1. Ensenada's Cadastre

This cadastre is the result of a fiscal reform that first attempted to homogenize taxation under the Crown of Castile by eliminating multiple and varied forms of taxation and implementing a single proportional share to each individual according to wealth. The main enquiries started by decree on October 1749 and expected every household head, either secular or ecclesiastic, to declare their wealth in any form (land, houses, livestock, rents, agrarian productions), and to describe them in terms of surface, productivity, etc. Qualified experts in every village would be in charge of determining yields for every crop according to soil quality as well as livestock productions. Along with the public reading of the list of properties, this measure was aimed at preventing owners from concealing information. However, yield declarations were also subject to fraud due to the fact that technicians could have economic interests in the locality (they used to belong to nobility and local elites) or because they had been bribed to do so. Besides, there were still several other ways for individuals to conceal part of their wealth, the most common of which would be the reduction of either declared surface or the underestimation of the quality of the soil (Camarero, 1999; Saavedra, 2011).

Even though the so-called "*Única contribución*"[39] never became a reality due to the opposition of privileged social states, namely clergy and nobility, it left a huge amount of documents and information that have been widely used by historians. Researchers have often questioned its reliability due to its fiscal nature and the common vocation of individuals to conceal part of their wealth in order to avoid heavy charges (Camarero, 1999; Pro, 1992). Besides, its elaboration in Galicia was considerably difficult regarding technical issues such as the high degree of land fragmentation, the complex polycrop system, the scattered population, and the linguistic barrier in an oral culture where only Galician was spoken but Spanish was used by the administration. The final outcome is therefore heterogeneous in terms of reliability and thoroughness, also according to the technicians who were in charge in every parish, which was the territorial unit most frequently used for the cadastral register. Despite its reliability issues when it comes to quantitative information and the fact that the cartography chapter was generally not accomplished for Galicia, there is no better source than this for studying the society and economy of the 18th century, essentially because there are no better ones. Besides, no historical source is alien to such problems (Fernández González, 1995; Soto, 2006; Saavedra, 2011).

Regarding our case studies, this source provides information on surface distribution, crop system, yields, and livestock numbers. We have used the information as stated in the original documents, as we had no way to correct it. We know there is a problem of information concealment, and therefore a margin of error in our results, but this seems to be within acceptable limits and, besides, the resulting pattern is coherent when compared with other

[39] "Only contribution" or "single tax" (own translation).

research and with our own data for the 19th century. Pérez García has established that agricultures with higher productivity have shown the higher rates of information concealment, which mainly correspond with coastal regions. Inner regions with lower productivity have lower percentages of fraude in their yield declarations. With higher production, the higher the fraude would be, which is especially problematic with wine (Pérez García, 1982). Soto's research concludes that the main problems in surface concealment also took place along the coast, which matches the previous pattern. This means that data seem generally more reliable for the case of Fonsagrada than for Ribadavia. On the other hand, we have some contrast data for Ribadavia provided by prior research on the region (Domínguez Castro, 1992).

Surface data are the most problematic, as other authors have demonstrated before (Fernández González, 1995; Villares, 1982; Bouhier, 2001; Saavedra, 2011). However, they also give evidence that most of this undeclared surface corresponds mostly to *monte* (uncultivated land), due to the fact that it was considered improductive, or actually to land which was not proper for agricultural uses at all since it made no sense to cadastre surfaces with low or null taxable base. And, after all, the general reliability (not accuracy) of surface data in declarations of owned land by individuals has been proved too (Pro, 1992).

Saavedra offers some relevant data at this respect: about 27.3% of the total territory of Galicia was declared in the cadastre as cropland, chestnut groves and *monte*, out of which a 12.5% was exclusively cropland. Cropland, pastureland, chestnut groves and vineyard are also under-reported in terms of surface and/or yields. Soto's data show that about the 71% of the total surface of Galicia is not declared in Ensenada's cadastre, and, at the time, about the ¾ of the territory was occupied by *monte* (Balboa, 1990). In fact, most of this undeclared territory corresponded to the commons, namely *monte* surface, but also different types of uncultivated land (roads, buildings, rivers, etc.). According to Saavedra, these numbers match those of the cadastre of 1957-63 regarding the outcome of cropland expansion along the 19th century, although cropland must have been more than just the 12.5% of the territory in 1750s. Saavedra includes an interesting datum from Lucas Labrada, who states that about a 20% of the total surface of Galicia was cropland in 1800. This percentage seems too high for 1750s. However, it helps setting a margin of error to the data extracted from Ensenada's Cadastre (Saavedra, 2007 and 2011).

Another problem when considering fraud related to surface declarations is the registration of good quality soils as medium or low quality ones. This would reduce the tax burden too. However, in the case of Fonsagrada, Saavedra generally validates soil distribution in Ensenada's Cadastre according to qualities, although fraud is also evident in quantitative terms, either in cropland or, more likely, in *monte* and other uncultivated areas (Saavedra, 1979).

Besides, as we have also done in both of our cases, Fernández González (1995) and Villares (1982) suggest that declared land in Ensenada's cadastre must be compared with actual surface data in order to assess the accuracy of the source but also keeping in mind that surface data in the sources are very likely to have been under-reported. In Chantada (Lugo), Villares accounts for up to a 17.7% of cultivated land over the total of actual surface, which is, according to his research, a feasable number. Fernández González reminds that the problem is in the general lack of correspondence between the units cadastred in 1750s and the outcome of the administrative reform of the 19th century, which introduced municipalities in Galicia despite their lack of tradition, thus altering the previous territorial arrangement.

Therefore, all this previous research concludes that the huge difference between cadastred and actual surface is mainly due to the fact that both commons (mainly *monte*) and uncultivated land (including buildings, roads, etc.) were not frequently nor accurately declared (Villares, 1982; Saavedra, 2007; Bouhier, 2001). We have criticized surface data for Ribavadia and Fonsagrada in each corresponding section.

Besides, comparison in the long term with data provided by sources from the 19th century proves the data valid in relative terms, since the changes show internal coherence. At this respect, our data are coherent with Saavedra's conclusions: regarding the whole agroecosystem and its regional specificities, data from the Cadastre show a high degree of internal coherence in terms of crops, rotations, livestock composition and territorial distribution according to type and age, average plot size, and yields (Saavedra, 2011). Fernández González (1995) had previously proved this internal coherence of the cadastre at aggregated scale regarding agrarian macro-magnitudes, especially for livestock numbers, which Saavedra admits to be quite reliable as well. However, again, we question the validity of absolute numbers, as well as in the case of the census of 1860, which consigns about a 20% less livestock than Ensenada's Cadastre since, apart from fraud, there are also technical issues that compromise their reliability, as stated by Saavedra. Regarding this change in livestock when compared with the census of 1860, the author concludes that data are not coherent since the abrupt reduction of bovine head in 1860 would not correspond the agrarian changes of cropland and pastureland expansion that occurred along the 19th century. On the other hand, Saavedra agrees with the increasing trend of mules and donkeys along the period, since mules were exported from the province of Lugo to Castile, and donkeys were used as studs for this purpose (Saavedra, 2011), as it had been demonstrated within the general evolution of livestock in the rest of the territories of Spain (García Sanz, 1994)[40].

[40] This debate regarding the reliability of livestock censuses of the 19th century had been previously developed by Spanish agrarian historiography. Both censuses from 1860 and 1891 have been critized by the GEHR (1991) and García Sanz (1994). The authors concluded that the census of 1891 is not reliable at all due to the fact that offspring are not included, whereas the data from 1865 are acceptable and do include offspring. Generally, livestock statistics are not very much reliable until 1927. For a detailed overview on this issue, see also Soto et al., 2016a.

Our data show that the reduction of bovine shown by the census of 1860 is coherent with agrarian intensification due to the process of animal stabling, which requires less individuals in order to be able to keep an intensive management in stables that allows for more manure production. Cordero et al. have proved Ensenada's livestock data valid, especially for bovines, mules, pigs, horses, and donkeys. Bovine was the most important type of livestock within the agroecosystem and was declared in quite abundant numbers all through the territory, although the most numerous head was undoubtedly that of sheep and goats. Eiras Roel used Ensenada's Cadastre in his research on geographical determinants of livestock distribution, also concluding the utility and "*logic coherence*" of the data (Eiras Roel, 1983: 138). According to these authors, livestock in Ensenada's Cadastre shows a very coherent household and geographical distribution. Generally, it is more abundant in the inner regions of Galicia, where extensive agriculture allowed for more pastureland availability, than along the coast (especially the West and South coast), with less land availability due to demographic pressure but with more complex rotations that produced livestock feedstuff (corn, fodder, turnips). However, it is precisely along the West coast and in regions with more intensive agriculture where livestock production per hectare is higher, mainly regarding bovine cattle. However, if its distribution is measured by households then its productions would be higher in inner regions. Therefore, bovine livestock and human density have a positive correlation within an agrarian system where agriculture and animal husbandry are complementary and interdepedent activities, where the capability of sustaining livestock depends on the potential of agriculture (including uncultivated land such as *monte* and temporary fallow) in the same way as the potential of agriculture is connected with livestock availability. Thus, generally speaking, high agrarian productivity, and high population and livestock densities are characteristic of the regional pattern along the West and South coast of Galicia, especially in the lowlands.

On the contrary, inner regions and highlands show progressively lower values of these three variables, although with regional exceptions. Certain highlands would have relativetly higher bovine density when *cortiñas*[41] allowed for their feeding during winter. Pigs show less abrupt variations due to its popular character, since most houses had at least one. However, sheep and goats, more dependent on *monte* surface and less integrated within the agrarian system than cows, are far more abundant in the highlands and inner regions, as well as equines and mules, although none of them are as important as bovines in economic terms (Eiras Roel, 1983). Bovine labor force and manure were essential for such an intensive agriculture, apart from other productions such as milk, meat, leather or cash in exchange for calves. Therefore, regions with more absolute livestock numbers used to have lower livestock density because of higher land availability but higher livestock units per household. Our livestock data for

[41] Type of rotation that is similar to vegetable gardens in its intensive management and its location near the houses but included also cereal and other crops such as turnips, especially for testing purposes before wider cultivation.

Fonsagrada and Ribadavia match this territorial trend as described by previous research (Cordero et al., 1983; Eiras Roel, 1983).

Regarding population data as reported in the different documents of Ensenada's Cadastre, we have followed Saavedra's estimations for Fonsagrada (Saavedra, 1979). This author had access to Ensenada's "*Vecindario*"[42] from 1759 and other population data from previous documents, mainly collected in 1752. Criteria for "neighbor" accounting differ in both years and would require further research, since "neighbor" did not always refer to household head and seems to have included men between 18 and 60 years of age as well (Saavedra, 2007 and 2011). In the case of Ribadavia, data are so incomplete that we are not able to estimate its population in the time of Ensenada. However, despite some deficiencies and inaccuracies regarding population, namely women, the Cadastre has huge potential for demographic studies regarding for instance population densities, family structure and other socioeconomic aspects in both rural and urban Galicias (Dubert, 1992).

Finally, the biophysical approach functions as a double check for sources since it measures the capability of feeding both livestock and people with the declared productions. This allows us to assess whether livestock head was either under or over-declared, and whether agrarian production was plausible according to the nutritional requirements of both humans and livestock.

4.2. Land productivity assessments from the 19th century (*cartillas evaluatorias*)

Agrarian statistics started to be elaborated in Spain after the 1890s by a specific organism called *Servicio Agronómico* and its *Junta Consultiva Agronómica* (JCA). The first attemps had been done at provincial and national scale in 1857, 1859, and 1865, but they did not have continuity in time and their general reliability has been put into question. Therefore, our knowledge on agrarian production during most part of the century is scarce, fragmented and defficient (GEHR, 1991).

The main documents we have used are called *cartillas evaluatorias*, which are accounts for both income and expenditure at local scale and have fiscal objectives. Regarding agriculture, *cartillas* offer productions and expenses per land unit according to soil quality, either in traditional measures or, towards the end of the century, also in metric system units. These documents recorded productions at municipal scale, and completed other documents called *amillaramientos*, which collected the same information but individually, thus referred to landowners and tenants, and informed on land use, surface, and net income. Eventually there

[42] *Vecindario:* list of neighbors. Ensenada's Cadastre included the corresponding book to each cadastred territory.

was also a summary of total productions and expenses with the resulting tax burden according to the pre-established quota. In the second half of the 19th century, none of these documents were sistematically elaborated within Galicia, and not at all apparently in the provinces of Pontevedra and Coruña (Pro, 1992 and 1995). We have located the fragmented *amillaramiento* of Fonsagrada for the year 1881, which includes only eleven parishes (less than half of the total) but it would be useful for a future research line on inequality in access to resources.

Amillaramientos and *cartillas* were elaborated by an expert committee, the *Junta Pericial*, which was composed of local administrators and the major contributors of the municipality (Pro, 1995). These documents started to be elaborated after fiscal instructions in 1850 and 1853, thus replacing previous wealth declarations, which were, according to Artola, more reliable documents since individual declarations for the *amillaramientos* were not double-checked by the administration (Artola, 1986). According to Pro, concealed surface by *amillaramientos* in Spain was of 40% average, although it could reach the 85% in certain regions (Pro, 2000). Vallejo Pousada agrees with this criticism regarding information inaccuracies in *amillaramientos* (Vallejo, 2001), and both authors agree on the fact that this was due to a political problem, which conditioned the negotiation of the tax quota distribution, and can be summarized under the concept of *caciquismo* (political patronage). The State had given up on developing general statistics and conferred the duty of distributing this taxation quota to the local elites in the *Junta Pericial*. This increased their possibilities to influence taxation in their own benefit, which resulted in an overcharge of agricultural activities, and namely of peasants, who did not have it so easy to conceal their wealth in these declarations (Pro, 1995; Muro et al., 1996; Vallejo, 2000; Fontana, 1980). *Amillaramientos* are therefore the product of a biased and inefficient administration, and hindered the whole fiscal system of the *Contribución de Inmuebles, Cultivo y Ganadería*[43] in terms of efficiency and equity. As a result, property concealment and fiscal fraud persevered during the rest of the 19th century. In order to alleviate this situation, the *Comisión de Estadística* (Statistics Committee) started to construct territorial statistics in a separate way from the fiscal ones. These statistics aimed at the final elaboration of a general cadastre, which would not be accomplished until the 20th century (Vallejo, 2001).

However, there were improvements in the knowledge of the territory, its productions and yields, and between 1850-55, the Statistics Comittee formed the *Estadística Administrativa* (Administrative Statistics). Their priority was to build a population census, which was concluded in 1857 and consumed most of their resources in that decade, thus limiting the dedication to other statistics such as the agrarian ones (Muro et al., 1996). The final results of the *Estadística Administrativa* are offered at provincial scale and mainly as a summary of net income and tax burden, which are not of interest for our research. These were the first efforts

[43] Building, harvest and livestock taxation records.

at building national statistics on agriculture, livestock farming, industry, infrastructure, and population, along with a physical and political geographical description. However, due to the lack of resources and the urgent need of statistics to be used with fiscal objectives and correct the *amillaramientos*, these first questionaries sent out to municipalities were reduced to just agriculture, livestock, and transport infrastructure, with a special emphasis on agrarian and animal productions. This was the main strategy for obtaining statistic information of the territory for the rest of the century (Muro et al., 1996). We have used part of the corresponding interrogatories for both Fonsagrada and Ribadavia between 1850-1860 and 1876. Apart from the above-mentioned problems of reliability, there is another issue of concern regarding these statistics of 1857, which is related with the poor harvests of the beginning of the decade. This resulted in declared yields and prizes not being representative of the period. For this reason, the questionaries sent out to local administrations after 1859 required average production data of several years, usually from five to eight (Muro et al., 1996). We have used this type of records, which mostly refer to a five year period.

As mentioned before, *cartillas* are a complementary document to *amillaramientos*, and were used in order to negotiate the distribution of the quota of every village in a final document which consisted in a list of taxpayers and their corresponding taxable wealth. According to Vallejo, the administration used the *cartillas* in order to prove that global rent was under-estimated, but this was always dependent on local aspects. Therefore, the validity of the source must be tested at local scale. General conclusions about ther reliability are not appropriate (Vallejo, 2000: 117). In fact, some local studies have proved these documents unreliable, in the province of Cádiz for instance (Pro, 1995) or even generally for the whole territory of Galicia, although the author exposes only two examples of the province of Lugo (Dopico, 2000).

On the contrary, other authors have used both *cartillas* and *amillaramientos* by contrasting their data with agronomic literature or private documents such as notarial protocols, and have proved their relative reliability. This has been the case of the province of Córdoba (Mata and Muñoz, 1999), Santa Fe, in the province of Granada (González de Molina and Guzmán, 2006), Baena, Castilleja de la Cuesta and Montefrío, in the provinces of Córdoba, Sevilla and Granada, respectively (González de Molina et al., 2010; González de Molina et al., 2015), and in several municipalities of Andalusia (Infante-Amate, 2014) and in Catalonia (Cussó et al., 2006).

Mata and Muñoz point out that *amillaramientos* and *cartillas* are not only useful in quantitative terms (tax burden, surface or yields), but also because of their information regarding socioeconomic aspects such as the organization of agrarian production. Besides, in their case studies in the province of Córdoba, they have checked that fraud affects mainly those less productive areas, and declarations are proportional to the importance of crops and reflect the social and agroecological organization of the agrarian system quite reliably. These authors also insist that one of the main frauds was the under-valoration of land qualities, instead of simply not declaring them (Mata and Muñoz, 1999). In the other Andalusian cases and in the Catalonian ones, sources were also tested with a biophysical approach by means of estimating either nutrient or energy balances. The main conclusion within this research is similar to Mata and Muñoz's, since they prove sources valid and demonstrate that fraud is more related with soil qualities than with yields, which are coherent also when contrasted with other sources such as notarial protocols or agronomic literature (González de Molina et al., 2015).

Definitely, as it occurred with Ensenada's Cadastre, first quality soils used to be declared as lower quality, which was enough to decrease the tax burden. Initially, in our case studies, we intended to assume that all surface was of midium quality in order to correct this biased information. However, we decided to weight yields according to soil qualities as declared because this would also allow to critizise the sources, and the results are in fact coherent, as we will see.

We have also used contrast information from other coetaneus statistics has been used in both cases. However, such statistics from 1857, 1876 and 1887, which were meant to either study the agrarian crisis of the end of the 19th century, to complete the *cartillas* and *amillaramientos,* or simply a failed attempt to construct national statistics, are also fragmented and not very reliable according to the GEHR (1991). Therefore, we have used two more methods to critizise these sources. Firstly, we have considered the internal coherence of the document regarding both land uses distribution and yields as declared, but also in comparison with previous data from Ensenada's Cadastre and with all the coetaneous information available for both moments in the 19th century. Secondly, we have applied a proxy method by estimating food availability and requirements in every moment, thus assessing whether declared productions sufficed to feed all declared livestock and human population.

There are two *cartillas* for each of our case studies. In Ribadavia, the first one is from 1860 (AHPOu, Facenda, C459/03), and the second one from 1888 (AHPOu, Facenda, C459/10). The first *cartilla* available for Fonsagrada is from 1852 (AHPL, Facenda, C14491), and the second one from 1886 (AHPL, Facenda, C14492). Most of their data seem coherent when compared with data from Ensenada's Cadastre and current agrarian historiography on the period. However, in the case of Ribadavia, the latest *cartilla* does not include surface data, which has been taken from 1860 as well. In the case of Fonsagrada, the *cartilla* from 1886 is almost identical to the previous one. We have used it as a guide but final data for the decade of 1880s are from related statistics that served to the elaboration of *cartillas* and *amillaramientos*, and yields are in most cases those of the *cartilla* from 1852. Land use distribution is from agricultural statistics from 1887[44], and livestock numbers from 1876[45].

[44] *"Riqueza rústica y pecuaria"*, Municipality of Fonsagrada, AHPL, Facenda, C14491.
[45] *"Estadística Agraria. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491.

This last document collects also surface but does not disaggregate by rotation. It only details irrigated and non-irrigated cropland, meadows and non-cultivated surface. Data are supposed to refer to the *Partido Judicial* (Judicial District) of Fonsagrada but actually include only the parishes that belonged to the municipality of Fonsagrada at the time. Besides, when compared with surface data from 1887, land distribution does not seem coherent, thus we discarded its use. The attached livestock census in statistics from 1876 seems reliable enough and data have been incorporated to the analysis of the year 1887 since there are no better livestock censuses in this decade.

Regarding land use distribution, data are coherent both in relative and absolute terms. When compared with declared surface in 1752, there is a huge increase in the case of Fonsagrada. The case of Ribadavia is different at this respect because we do not have comparative surface data from 1750s at municipal scale, and either way there was little land availability for further expansion of cropland when compared with Fonsagrada.

Finally, regarding livestock numbers, *cartillas* seem to be more problematic. According to Vallejo, this is due to the fact that statistics distinguished between livestock for meat production for the market and livestock for labor, which complicated the declarations particularly in the case of Galicia, where bovine livestock combined both aspects (Vallejo, 2001). In Fonsagrada, we have used a livestock *cartilla* from 1855[46]. In the case of Ribadavia, the *cartilla* from 1860 includes lower livestock numbers than a previous statistics from 1857[47], which we have finally used. This is a questionary on livestock elaborated by the *Comisión de Estadística General del Reino*, iniciated in 1856. Similar questionaries were undertaken later on in 1859 and 1861 in Ribadavia[48] but because not all municipalities replied to the questionary, final results were not published. For the study of the decade of 1880s in Fonsagrada we have used the same type of statistics from 1876[49], which included coherent livestock data, as explained before.

Sources for information on yields, livestock numbers and surface are mainly of fiscal nature. Their concealment degree is different, being Ensenada's Cadastre generally more reliable than the *cartillas* according to the above-mentioned literature revision. The most optimistic reviews on agrarian statistics and fiscal sources from the 19th century are those of the GEHR (1991) or Muro et al. (1996), who remark the efforts involved in the development of national statistics although with certain doubts on their accuracy. The most critical position of Pro Ruiz denies any reliability to statistics in general until the end of the 19th century (1992, 1999 and 2000). Between these extreme stances, we have chosen the experimental option as suggested by Vallejo (2000) and developed by Mata and Muñoz (1999), Cussó et al. (2006), González de Molina and Guzmán (2006), González de Molina et al. (2015) or Infante-Amate

[46] AHPL, Facenda, C14205.
[47] AHPOu, Facenda, C459/04.
[48] AHPOu, Facenda, C459/01.
[49] AHPL, Facenda, C14491.

(2014). We have used *cartillas* and livestock and population censuses from the 19th century in Fonsagrada and Ribadavia. In the case of Fonsagrada, we have also used *cartillas* from neighbor municipalities in order to complete missing data: Castroverde (1888), Becerreá (1881), and Pedrafita do Cebreiro (1888)[50]. The *cartilla* from Rendar (1852)[51], which is further away, was used for chestnut yields, since they were either missing or too low in all other *cartillas*. This was likely related with the expansion of common fungal infections that affected chestnut groves (*soutos*) towards the end of the century. Besides, in this same case we have applied biophysical methodology which has allowed to double check the statistics. Thus food availability, estimated according to declared productions and converted into energy, was eventually distributed within declared livestock numbers and population according to specific nutritional requirements. The results are within an acceptable margin for all three moments, as we will see. In the case of Ribadavia we have limited our contrast to other data offered by previous research.

Finally, by using data as offered in the original documents we are showing the most conservative option. And even in this case, nutrient problems are already visible in the beginning of the study period in Fonsagrada. The internal coherence of the results and its comparison with the rest of the period validates the data from these sources, even though reality must have been certainly different and yields, surface and livestock numbers slightly higher than declared, and so must have been nutrient problems too. So far, this is just a hypothesis and the issue remains open for further research.

4.3. Statistic reports by the *Junta Consultiva Agronómica* (JCA)

These statistical documents were elaborated after 1890 and represent the first sistematic attempt to register agrarian productions and land uses in order to develop national statistics by using the province as the main territorial unit. As Soto points out, the most problematic reports from the JCA are those referred to livestock and forest productions, which we have not used (Soto, 2006). Generally, the reliability and global coherence of these sources has been established by historiography, except for the livestock census of 1891, as we have already indicated. For more detail on their characteristics and elaboration process, see GEHR (1991), Pro (1999, 2000) or Muro et al. (1996).

However, for the specficic territory of Galicia its general reliability has been questioned by Soto (2002), who claims that the interrogatories and procedure focused on Mediterranean productions and did not adapt well to the conditions of Galician mixed-farming agriculture and its characteristic land fragmentation. This author has studied the methodology of such

[50] AHPL, Facenda, C14459.
[51] AHPL, Facenda, C14491.

statistics and critisized its internal coherence by comparing them with other qualitative sources, thus concluding that their general reliability is compromised in the case of Galicia. The main problems are in miss-representation of long-term changes in land use distribution and in under-estimated yields. Therefore, data must be carefully contrasted.

In our case, we have used both qualitative and quantitative data from such reports. Both types of data are coherent with the results of historiographical research on Galician agriculture. Besides, specific numeric data have only been used when missing in *cartillas*, which are our main sources. This quantitative information refers mostly to grain/straw ratio for cereal crops and yields of meadows and turnips, which we obtained according to the corresponding provincial productions. Its impact in the final result is therefore not very relevant in quantitative terms. Besides, due to the provincial scale, we have not used surface data, which are the most problematic.

As it will be specified in the corresponding sections, we have used data from the following reports by the *Junta Consultiva Agronómica*:

- *El regadío en España* (Ministerio de Agricultura, 1904)
- *Prados y pastos* (Ministerio de Agricultura, 1905)
- *Avance estadístico de la riqueza que en España representa la producción media anual de árboles y arbustos frutales. Tubérculos, raíces y bulbos* (Ministerio de Fomento, 1913)
- *Avance estadístico de la riqueza que en España presenta la producción media anual en el decenio de 1903 á 1912 de cereales y leguminosas, vid y olivo y aprovechamientos diversos derivados de estos cultivos* (Ministerio de Fomento, 1915)
- *Medios que se utilizan para suministrar el riego a las tierras y distribución de los cultivos en la zona regable* (Ministerio de Fomento, 1918)

Eventually, with the aim of contrasting our livestock data from local *cartillas* and fragmented statistics, we have also used both censuses from 1865 (JGE, 1868), and 1891 (Ministerio de Agricultura, 1982). Due to their different scale, the *Partido Judicial*[52], we aproximated municipal livestock numbers by assuming that their livestock density would be the same as the density within the whole *Partido Judicial*. These estimations offered lower livestock numbers than the *cartilla* and were eventually not used in the research. Their reliability has also been questioned by the GEHR and Soto, especially that of the census of 1891 (GEHR, 1991; Soto, 2006).

[52] This type of territorial division refers to several municipalities that are under the same judicial jurisdiction. In the case of Fonsagrada, the Partido Judicial included the municipalites of Baleira, Fonsagrada, Meira, and Navia de Suarna in 1860.

4.4. Population censuses

The elaboration of population censuses was part of the development of the territorial statistics that we have just mentioned. Thus the first available census in the 19th century is that of 1857. Despite being a first attempt, Muro et al. describe it as a "*modern*" census since it is based on nominal accountancy and inspired by International Conferences on Statistics that had taken place in Paris and Brussels in previous years. The success of this first census is explained by the specialized bureaucracy created *ad hoc*. Despite some irregularities and changes in the criteria on the go that altered its elaboration, the reliability of this first census in quantitative terms is good enough. Following ones would include more data than just total population numbers, thus becoming richer sources for the study of demography (Muro et al., 1996; Pro, 2000).

All these censuses can be consulted online at the website of the *Instituto Nacional de Estadística* (INE). We have used municipal data for both Fonsagrada and Ribadavia by accounting only for *de facto*[53] population data, thus deducting passers-by when they had also been included. We have used censuses for the following years: 1857, 1860, 1877, 1887, 1897, 1900, 1910, 1920, 1930, 1940, 1950, 1960, 1970. We have included data for the 20th century in order to offer a long-term view of the demographic evolution.

Censuses between 1857 and 1877 (both inclusive) only account for *de facto* population. This number includes passers-by, which are also disaggregated. We have deducted passers-by from *de facto* population when possible in order to use the closest number to actual population. The two first censuses (1857 and 1860) also disaggregate population according to age. Marital status is specified only until 1887. Only the census of 1887 excludes passers-by from the disaggregated numbers, which means we have used *de facto* population as it is given but we do not know whether passers-by are included or not. The censuses from 1897 until 1950 account simply "*present*" and "*absent residents*", and include *de jure* population as well. Censuses from the years 1960 and 1970 only account for *de facto* and *de jure* population, without further information.

4.5. Specialized agrarian literature

Agrarian literature offers more reliability than the previous sources since their authors were trained in the scientific method, and the information we have taken from them usually refers to weight or density of certain productions, grain/straw ratio, plantation framework, yields, animal productions, etc., which are the result of an observation and measurement process with

[53] *De facto* population refers to the total number of people that were present at the moment of the headcount. D*e jure* population includes all the individuals entitled to live in the municipality, whether present or not.

traditional livestock breeds and crop varieties (prior to the introduction of hybrid seeds). Our main source at this respect has been Soroa's compendium on agriculture, published in 1953 under the title *Prontuario del agricultor y ganadero*. We have also used contrast data for livestock bedding from Cascón Martínez (1918), who developed a study on animal productions and manure: *El estiércol y la alimentación animal*. However, his data have not been used in our case studies because the observations described correspond to a farm in Valladolid (Castile), within a completely different agroecosystem.

Regarding *monte* productions, which are usually under-represented in our sources, we have taken into account data from Hernández Robredo (1936), and more recent studies, which offer a higher degree of accuracy and reliability (Sineiro, 1978, 1982 and 1983; Iglesias, 1985).

Definitely, most of our data regarding the estimation of agrarian productions are from historical sources. Technical information and data for the elaboration of nutrient balances are from specialized literature that will be cited in due course.

Chapter 5. Methodology

In the following sections we will deal with the different methodological procedures applied in this research. Within Galician agrarian historiography, the most innovative one contributed by this research is the nutrient balance technique as developed by García-Ruiz et al. (2012), which we have applied in colaboration with Roc Padró to three years in the case of Fonsagrada: 1752, 1852, and 1887. Prior to this step, we constructed the material flows within the agroecosystem by accounting for all outputs in the form of harvest and inputs of fertilizers, mainly manure. The case of Ribadavia has very fragmented information for 1750/60s and data for 1880s are also not very complete. However, information for the year 1860 is satisfactory and ready to apply this technique in the future, which could shed light not only on the environmental consequences of intensification but also on the impact of vineyard monoculture.

5.1. Estimation of agrarian production and land productivity

Yields and productivity in general have been widely studied within Spanish and Galician historiography in order to assess agriculture and its changes, also from different theoretical and methodological approaches (Simpson, 1997; Bringas, 2000; González de Molina and Guzmán, 2006; Pérez García, 1975, 1982 and 2000; Saavedra, 1979 and 1985; Gelabert, 1981; Rey Castelao, 1981; Sobrado, 2001; Soto Fernández, 2006). Critics have pointed out at difficulties that arise within such analysis in Galician cases: the use of varied local measures without a stable equivalence, geographical differences that translate into different rotation systems and therefore different yields, varied soil qualities with their corresponding yields, etc. (Pérez García, 1982). As a consequence, comparison between yields becomes sterile when the biophysical context is not taken into account and, especially, when yields are presented in traditional units, or isolated from the whole rotation scale.

These difficulties can be partially overcome by assessing productivity at rotation scale with all its associated crops and their corresponding by-products. Fallow must be considered too, as well as bioclimatic conditions (González de Molina and Guzmán, 2006; González de Molina, 2010a and 2010b). Crop rotation is a means of manipulating the nutrient supply for given species that we want to benefit, reduces soil erosion, and provides varied crops, which softens the impact of pests and the consequent subsistence crisis (Shiel, 2006a). Therefore this strategy needs to be taken into account when assessing both land productivity and fertility management. In this research, we account biophysical flows related with the nutrient cycle, mainly harvest and manure doses. We have not accounted for root biomass.

Regarding the methodological procedure, once the required documents were collected in the corresponding archives and online repositories, we classified the information for every different moment of our study on a basic Excel spread-sheet according to three main categories: land uses, yields, and livestock. Yields and land uses data were matched together according to their respective crop rotations, soil qualities, and surface data. Missing information on specific yields was completed with data from the above mentioned sources, and average yields were estimated according to soil quality and including all by-products. The criteria in order to find appropriate information to replace missing data is both chronological and varietal. The closer in time and space to our cases and period of study, the better. From more contemporary literature, we have preferred, when available, data obtained from studies with traditional varieties of plants. Source reliability is, of course, another main criterion.

In a second step, we converted all traditional units into the metric system according to Fernández Justo's proposal on equivalences (1985), which has been contrasted or completed when necessary with original data on conversions from local sources and with the document *Equivalencias entre las pesas y medidas usadas antiguamente en las diversas provincias de España y las legales del sistema métrico-decimal* (IGI, 1886). Finally, we calculated all productions. By-products and dry matter content were obtained according to converters assembled by Guzmán et al. (2014). Livestock data in number of heads according to species were converted into Livestock Units of 500 kg each (LU-500 kg). For this purpose, we used live weight data as collected in *La ganadería en España* (Ministerio de Agricultura, 1892), and in the *Estudio de la ganadería en España* (Ministerio de Fomento, 1920), which collects data of the year 1917.

These are our core data, with which we operated in order to study changes in land uses, yields, livestock density, and land productivity. The basis of the analysis is always the rotation scale at municipal level, by accounting for all different crops that are associated on a given surface. Therefore, land productivity is addressed from a crop association perspective, thus offering average yields of the total number of years and productions of each rotation, but also at aggregated cropland and agroecosystem scales by estimating total annual production according to these criteria and then dividing by total surface. Yields per hectare of a given crop is a different indicator that we have also used and included when necessary.

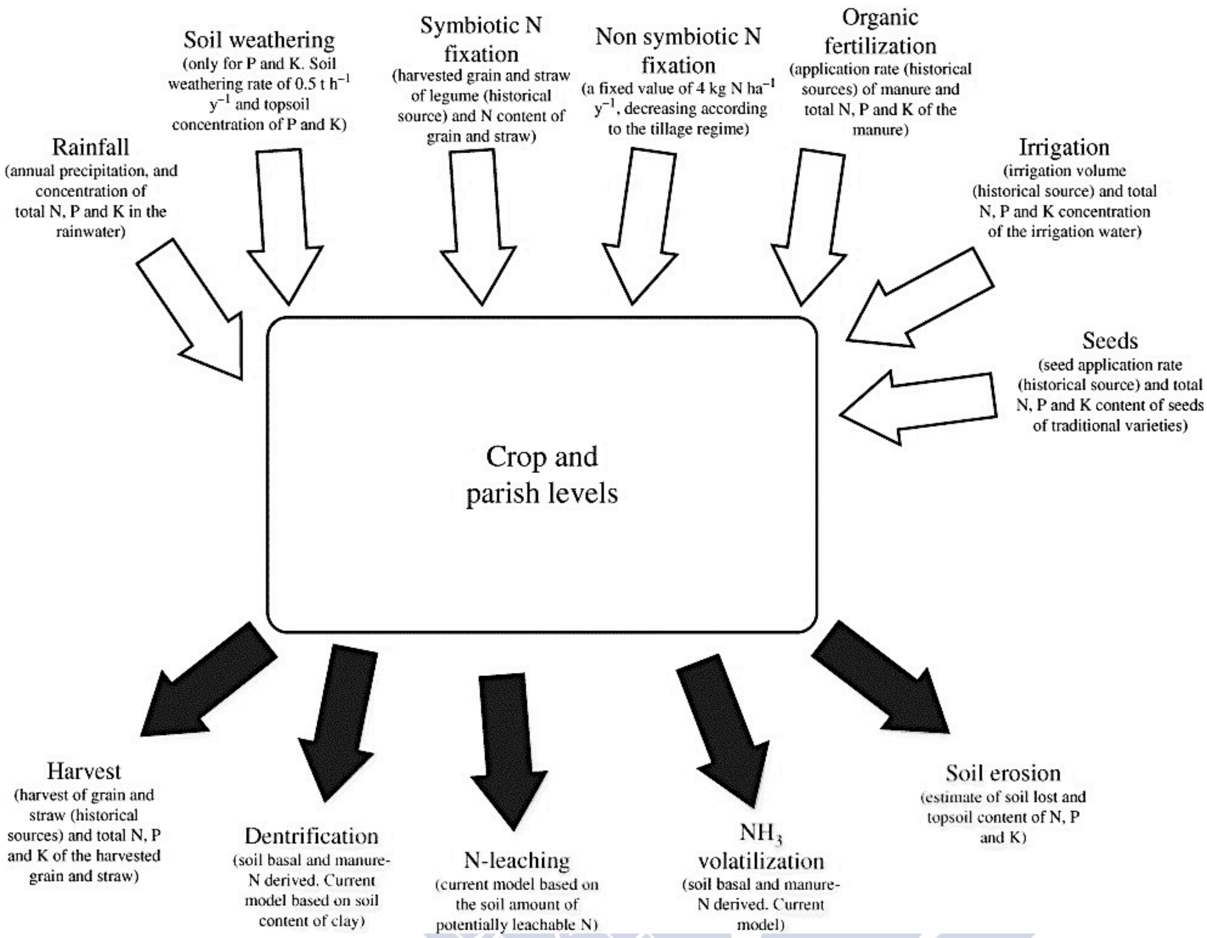
5.2. Biophysical accounting: nutrient flows and balances

The replenishment of soil fertility in agrarian metabolisms is essential for the reproduction of society and its material conditions. Among nutrients, nitrogen, phosphorus, and potassium, along with a moderate pH, satisfy the major nutritional requirements of plants. This is the reason why nutrient balances (either historical or not) have mainly focused on these three particular ones, especially on nitrogen for its determinant influence on crop yields in the short term. Other nutrients are obviously needed too, although under low intensity cropping they would only become scarce in extreme situations, for instance in sandy soils. Another important fact is that leguminous plants are responsible for most of nitrogen in the soil, but they also require phosphorus, and all these three nutrients should be balanced and proportional among them for a better soil health and optimal plant nutrition (García-Ruiz et al., 2012; Shiel, 2006b).

Due to the obvious impossibility to analyze nutrient content of soils in the past, a methodology has been developed in order to estimate all kinds of soil inputs and outputs regarding the flows of these three main nutrients: nitrogen (N), phosphorous (P), and potassium (K). The results allow to assess the functionning of a given agroecosystem, and the management of soil fertility and its changes through time in terms of sustaintability. Even though absolute numbers are not completely accurate, the degree of coherence of the results confirms their validity and allows to detect errors in the estimations. In our case, having balances for three different years enables to evaluate this coherence also within a long-term trend.

Since our main aim is to assess soil fertility in the past and in relationship with the intensification process, we have applied the methodological proposal of historical nutrient balances as developed by García-Ruiz et al. (2012). The basic purpose of this method is to estimate inputs and outputs of nutrients in order to check whether their harvested amounts are sufficiently replenished, thus assessing long-term sustainability of fertility management in agroecosystems of the past. So far, this is not new in agroecology or material flow accounting methods developed within the theory of social metabolism. What is new in this proposal of nutrient accountancy is the inclusion of the processes of denitrification, nitrogen leaching, ammonia volatilization, and soil weathering. Besides, the analysis incorporates both phosphorous and potassium flows, which were not usually accounted for in previous proposals. The method combines historical information with clima and soil data, plus current models for N, P and K cycling. Therefore, it requires a multidisciplinary approach. Estimations of missing data such as nutrient content of soils in the past are based on specialized literature and current information. The following figure offers an overview of the main processes included in the analysis as well as the basic scheme of the functionning of the model.

Illustration 1. Inputs and outps of nitrogen, phosphorus, and potassium



Source: García-Ruiz et al., 2012: 653.

The figure represents the application of the method to crop and parish levels, but there are other possibilities too. In our case, sources are mainly at municipal level, which has conditioned the scale of our research. The analysis of inputs and outputs of nutrients allows to know how they flow within or even outside of the agroecosystem boundaries, according to qualitative information. This is a previous step to the estimation of balances, and allows to construct flow diagrams that show the main functionning of the agroecosystem and its structure in terms of nutrient management.

Regarding the interpretation of results, negative values in the balance obviously indicate net losses of nutrients, whereas positive ones mean over-replenishment. The type of crop and its association, as well as the nutrient involved must also be considered. Nitrogen losses are more limitant in the short term, whereas negative balances for phosphorous and potassium are only conditioning in the long term. For a more detailed insight into the methodology see García-Ruiz et al. (2010 and 2012), or other case studies where historical nutrient balances have been applied (González de Molina and Guzmán, 2006; Tello et al., 2010; Galán, 2015; Infante-Amate, 2014; Gingrich et al., 2015; Güldner et al., 2016; Delgadillo-Vargas et al., 2016; Neundlinger and Güldner, 2017).

Both reports on flow reconstruction and balance estimation with our methodological steps and data sources for Fonsagrada can be found in Appendixes 1 and 2. The graphic representation of nutrient flows is in Appendix 3 and it offers an approximate idea of what the structure of the agroecosystem was in terms of soil fertility. Quantitative data of the flows are also included.

Chapter 6. Two cases of agricultural intensification in Galicia: towards a mixed farming system

The case studies of Ribadavia and Fonsagrada illustrate how the changes associated to the First Agrarian Revolution developed in Galicia from the middle of the 18th century and up to the end of the eighteen hundreds. As explained before, this process has been described in detail by Galician historiography, both at local scale (Barreiro, 1973; Pérez García, 1975; Saavedra, 1979 and 1985; Gelabert, 1981; Rey Castelao, 1981; Sobrado, 2001; Cardesín, 1992), and from a more general scope (García Fernández, 1975; Bouhier, 2001; Rodríguez Galdo, 2000; Rodríguez Galdo and Dopico, 1980 and 1981; Fernández Prieto, 1992; Balboa and Fernández Prieto, 1996; Soto, 2006; Fernández Prieto and Soto, 2010). Thus the connection between population growth and the increase in agrarian production has been established, as well as the link between this increase in agrarian production with the introduction of new crops such as maize or potatoes in more and more complex rotations, as well as the expansion of cultivated surface already since the 18th century. Fernández González (1995) concluded that there had been a considerable increase in agrarian production per male worker between 1750 and 1900, which was not based on a production increase per worked hour nor on industrial inputs. Soto (2006) has confirmed this increase in labor productivity, thus refuting previous theories on the stagnation of such variable as stated by Rodríguez Galdo and Dopico (1981). Our data go in this same direction, as we will see.

All these changes are intrinsecally related with a progressive intensification in livestock management as well, and therefore higher manure and labor force availability. At the same time, the process of livestock stabling required the cultivation of foodstuff for animals too. The main open question from previous research (Soto, 2006; Fernández Prieto and Soto, 2010) is related with the limits of the intensification process within the context of an advanced organic agriculture in Galicia, whether it resulted in nutrient imbalances in the soil that required the introduction of inorganic fertilizers in order to keep expanding land productivity or not. Research has proved the exhaustion of this intensification process in other European regions such as Austria or the United Kingdom (Krausmann et al., 2008) as well as in Mediterranean Spain (González de Molina and Guzmán, 2006; Tello et al., 2010; González de Molina et al., 2015).

We have picked two complementary case studies that allow to analyze such process from an environmental perspective. Agricultural change between 1750 and the end of the 19th century in Galicia is a process of change and adaptation in the productive strategy which in the case of Fonsagrada went through both extensification and intensification of agricultural management in order to increase biomass production and resulted in a process of nutrient mining, as well as in Ribadavia, where this must have been connected with the vineyard monoculture and its market-oriented production.

Historiography has also established three main patterns of agricultural intensification, which can actually be reduced to two with a transition one: coastal regions, inner regions and a transition area in between. Coastal regions are more densely populated, have a higher degree of land fragmentation, and smaller livestock head. Since the beginning of the 17th century, maize, in association with beans, is progressively incorporated along the occidental coast, where it is completely consolidated within cropland in the 18th century. As a result, there are more complex rotations and maize takes over fallow completely. Inner regions introduce mainly potatoes in their rotations, since it adapts better to the clima, but only towards the end of the 18th century, thus becoming one of the main crops along the following century (García Fernández, 1975; Saavedra, 1979; Bouhier, 2001). This territory is less populated, has a much bigger livestock head, and fallow is still part of the cropping system in the first half of the 19th century, being reduced with the progressive incorporation of potatoes as summer crop. Transition areas are characterized by the slower path of innovations in cropland (which they receive from the coast), and by their more similar population structure and field organization to the inner regions. In our case, Fonsagrada represents the pattern of inner valleys whereas Ribadavia, despite its location in the province of Ourense, is better framed within the coastal pattern although its adoption of maize takes place later, along the 18th century. Due to its specialized agriculture, it will show some peculiarities such as a high population density.

As a result of intensification, the mixed farming that had been developing on Galician territory since at least the 17th century is consolidated towards the end of the eighteen hundreds. At this precise moment, we have hypothesized and demonstrated that it starts showing signs of exhaustion in the case of Fonsagrada. This would be related with the territorial limits of the intensification process within an organic metabolism.

6.1. Galicia, an Atlantic territory

It has been frequently said that the territory of Galicia has a long history of humanization which was more notorious precisely with the introduction of agriculture and livestock farming towards 5,500 B. P., which resulted in a progressive deforestation after 3,000 B.P., thus replacing forest with the shrub formations that are so common in mountainious Galicia nowadays. The use of fire has been a key element in such landscape transformation (Guitián, 1993 and 2001). Anthropization was particularly notorious between 1480 and 1520, and in the 19th century following the different rythms of agricultural intensification through the territory. Agriculture developed on the basis of uncultivated areas (*monte*), which also had a function within the agroecosystem and were, therefore, modified by human action with deep consequences on the landscape (Saavedra, 1990 and 2015).

This process of intensification between the 16th and 19th centuries helped achieve high population densities and high pressure over the land, which has led some authors to affirm that it could no longer be sustained, thus triggering conflictivity over resources, namely over commons during the 16th century (Rey Castelao, 1995), and the development of regulatory mechanisms of population such as the control of nupciality and reproduction as well as migration processes generally across Galicia although in different waves (Eiras Roel, 1996). Of course, within this expanded history of *land colonization* (Haberl et al., 2016), there are different demographic and socioeconomic patterns, which are in a tight relationship with their environment and agrarian systems.

Being an oceanic country, Galicia is amongst the most rainy regions in Europe. But even though the Atlantic influence acts all over the territory, there are big climate oscilations between Oceanic, with a homogeneous annual distribution of rainfall, and some areas which have been considered Sub-Oceanic, Continental or even with a Mediterranean or "*subtropicalized*" pattern due to seasoned rainfall. Geomorphology, altitude and distance to the sea explain the variability within clima and rainfall distribution. Mountains along the Western coast isolate the inner regions from the humid winds from the sea (Pérez Alberti, 1982; Martínez Cortizas et al., 1999).

García Fernández (1975), Bouhier (2001) and later on Fernández Prieto and Soto (2010) have defined and justified the suitability of the concept of "Atlantic Spain", mostly according to the Atlantic influence on the climate but also in opposition to the Mediterranean Spain. Bouhier considers that this Atlantic influence expands through the territory between the Portuguese side of the Miño river until the Basque Country along the Cantabric Mountains (Asturias and Cantabria). Such territory shares some characteristics in spatial organization, agrarian landscape, and even languages such as Galician, all of which results from the interaction betwen rural communities, Geography and Ecology through time. Climate, although with regional variations, is characterized by abundant rainfall all year-round[54], a high degree of humidity, and the corresponding vegetation cover to this bioclimatic conditions, with native forests and shrubland areas of *Ulex* and *Ericaceae* species. See for instance Aguiar et al., 2009 and 2011, who describe an identic agrarian system in the North of Portugal regarding the integration between *monte* and cropland by means of livestock, or García Fernández (1975), who analyzed the North Atlantic and Cantabric region in bioclimatic terms, and Berriochoa (2012), who depicts a very similar agrarian system in the Basque province of Gipuzkoa. For this reason, political divisions of the territory blur when it comes to cultural and ecological aspects.

For the territory of Galicia, Bouhier (2001) has described two main geographical regions with two sub-divisions, which more or less match the political borders of the four provincies: North and South Galicia, that is to say the more Oceanic North and the more Mediterranean South. In the North, the province of Lugo would be a continuation of the province of Coruña

[54] Yearly averages in most meteorological stations in Galicia are over 1,000 mm, in some of them even over 2,000 mm. Less rainy regions reach at least the 800 mm (Bouhier, 2001).

in terms of humid and rainy weather, and the province of Ourense follows the geographic patterns of the coastal province of Pontevedra, with milder temperatures and drier weather (Bouhier, 2001). In terms of rainfall, Díaz-Fierros points out the widespread existence of two seasons. The humid season would be from October til March or May, and the dry one during the rest of the months. Only the Cantabric region would show lower variations in this seasonality. During the dry season, water scarcity is common (Díaz-Fierros, 1971).

In this research we focus on two patterns of agrarian intensification which are representative of these two main geographical regions. Fonsagrada is within the characteristic Oceanic climate, although under Continental influence. And Ribadavia is in a more Mediterranean-like climate. However, there should be a third pattern at least to include the coast, which would be a more "Atlantic" and properly Oceanic example, for which we have unfortunately not located enough sources so far.

Territorial organization in Galicia

It is necessary to clarify some concepts regarding territorial organization in Galicia in order to understand how sources have conditioned the geographical boundaries of our case studies, and how land appropriation used to take place generally all through the country.

Ensenada's Cadastre offers information at both *parroquia* (parish) and *couto* levels in our case studies, being parishes the main cadastral entities in the whole territory of Galicia. *Couto* is a manor territory with its own justice administration, which used to be a privilege granted by the king to a feudal lord. In the case of Fonsagrada, there were four *coutos*, which remained outside of the jurisdiction of the Altamira Count and therefore did not pay the corresponding rents to this landlord (Saavedra, 1979). Parish refers to the territory under the ecclesiastical jurisdiction of a church with its corresponding priest, although it also functioned as the territorial unit for local administration in terms of economic organization, taxation, levies, etc., in the late Ancien Regime and all through the modern period. Towards 1800, every parish was composed of between 7.5 to 8 *aldeas* (hamlets) or population nucleus, thus the parish network was dense, and it also remained stable over the territory between at least the Middle Ages and the late 19th century (Saavedra, 2015).

Our sources from the 19th century offer information at municipal scale according to the territorial reform of 1833, which grouped parishes into municipalities. This territorial arrangement remained more or less the same until today (Precedo Ledo, 1998). Therefore we have used current municipal limits as boundaries for our case studies. This allows us to complete surface data in the past by estimating uncultivated land, which mainly referred to *monte* surfaces.

Political changes in the ascription of parishes to the corresponding municipalities through time must have not altered, however, the rationality of the agroecosystem during the study period, even after the reform of 1833, which meant that *aldeas* were deprived of political entity despite being the primary nucleus for habitat. An *aldea* is a group of houses with its own agrarian area, which is organized according to smaller plots of cropland (Precedo Ledo and Gallego Priego, 2001). According to Saavedra, *aldeas* are the *planning centers* of landscape organization. Contrary to their relevance, these population communities rarely appear on historical sources, which were elaborated according to either civil or eccleasiastic administrative circumscriptions such as judicial jurisdictions or parishes, respectively. Thus *aldeas* lacked legal recognition since no political authority emanated from them. They were composed of families, the heads of which met in *concellos* (councils) in order to regulate collective serfdom, mutual help and the appropriation of common pool resources. The network formed by these communities was consolidated already in the 16th century and the demographic increase did not imply an increase in the number of *aldeas* but in their number of households, thus emphasizing their character of *neighbor communities* (Saavedra, 2015: 209-217).

Labor used to be a collective task within each *aldea*, which is the common basic territorial unit for land appropriation and is composed of households. Before the general absence of local data for *aldeas* all through the period, we have built our research at municipal scale, which in 1750s requires summing up all data at parish level as declared in Ensenada's Cadastre. *Aldeas* are population nucleus, and parishes may comprehend several of them, thus articulating the sparse habitat and becoming through history as the actual economic units for land organization. However, according to their historical evolution, a few *aldeas* have become parishes themselves (Torres Luna et al., 1985). Besides, other political and fiscal boundaries existed as well, and all of them overlapped on the territory thus resulting in a complex matrix of demarcations[55].

Apart from these legal and bureaucratic distinctions, there is an important consideration regarding land appropriation. The nucleus of the *aldea* was the main decision-making agent for collective labor and land organization and appropriation. Family household and rural community are the social constituents that *define* the agrarian system. The communal arrangement regarding collective property aims at the reproduction of family households, which cannot subsist independently. Thus communal strategies are essential for individual reproduction (Balboa, 1990: 44-47).

Neither parishes nor *aldeas* were considered by the liberal reformers in the new territorial arrangements constructed through the 19th century. However, this would not alter the main productive characteristics of the agrarian system, although institutional variables were indeed

[55] For a wider overview on demarcations in the Ancien Regime prior to the introduction of municipalities, see Saavedra, 2013 and 2015.

affected and resulted in peasant contestation, which was considerably succesful to counteract them -especially regarding changes in the legal rights over common resources (Balboa, 1990). Multifunctionality was present in the decision-making process, and land was organised according to different and complementary uses. Apart from the main distinction within appropriated land, which is either cultivated or uncultivated (*monte*), cultivated land was divided in vegetable gardens, sometimes *cortiñas* as well, and more general labor land called *labradío*, where the main crops were harvested: mostly cereal[56] but also potatoes, turnips and maize. In the case of Ribadavia, most of the surface is dedicated to vineyard, although there are some vines in Fonsagrada as well. Chestnut groves were of great importance since they provided wood, firewood, leaves for compost, and most important, chestnuts, which were an essential part of peasants and livestock diets. Every household used to have between one or several dozens of these trees for their own consumption, depending on the region, and they were more abundant in the inner provinces of Lugo and Ourense. Groves were located either surrounding the *aldea* or at the limit of *labradío*, sometimes on slopes which were not proper for other uses (Guitián, 1993). The fact that inner regions had more abundant livestock than coastal ones was the translation of meadows and pastureland availability as well, which did not directly compete with human cropland. Therefore grasslands, either natural or artificial, were also an iconic element of agrarian landscapes in Galicia, mainly in inner areas such as Fonsagrada. Along the coast and in certain vineyard regions within Ourense such as the Ribeiro, high human density and viticulture did not leave enough room for pastureland and livestock was reduced to the minimum required for labor. According to Saavedra, cows, goats and sheep used to spend months on the mountains, which reduced the amount of available manure for the crops (Saavedra, 1990 and 1992c). Thus the landscape had a few distinguishable elements that were codependent within the agrarian system, and were mainly put in relation by means of livestock as nutrient transfer.

Regarding bio-geographical regions and how they translated into land structure, the most clear classification is that of Bouhier (2001), who distinguishes four main types of agricultural organization: terraced fields, enclosed fields, *agras* and openfields. Our case studies belong to two different patterns. Ribadavia shows a particular type of terraced land, and Fonsagrada is representative of the *agra* pattern, as we will explain in the correponding sections.

We hope to describe the sustainability pattern of each of these case studies. It might seem too simplifying for such a complex territory but it makes sense according to the general characteristics of the agrarian system in Galicia and even its regional specifities. More similar research on other forms of land organization is required.

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[56] Cereal covered most of the surface and provided peasants with what they ate the most: bread. Cereal surface used to be called "*terras de pan levar*" (land of bread).

A word on fertilization

In this section we will briefly introduce some concepts regarding fertilizers and soil fertility. We will also refer to previous historical research on fertilization and nutrient balances in order to contextualize our own research. Eventually, we will describe the basic characteristics of soil fertility management in Galicia.

Firstly, we would like to include some concepts that will be useful in our description. Soil fertility is referred to as the capability of the soil to fulfill plant needs in the different nutritional stages. The concept of "fertilizer" has conventionally been applied to the inorganic chemical products that contain one or more of the three primary macro-elementes: nitrogen, phosphorus, and potassium. "Organic fertilizers" are derived from vegetal or animal products whereas "mineral" or "chemichal" ones are an industrial product. Organic fertilizers provide soils with less nutrients than mineral ones but, on the other hand, they supply organic matter as well (Domínguez Vivancos, 1984: 178-183). This contribution guarantees a slower and progressive release of nutrients since they remain in the soil much longer than with mineral fertilizers, which are more easily washed due to their soluble condition. This humus from vegetal origin estimulates soil microbial life and root activity and constitutes a source and reserve of nutrients for them (Domínguez Vivancos, 1984; Urbano Terrón, 2001). All in all, soils are biological organisms that contain dissolved and undissolved minerals, organic matter, and other both organic and inorganic substances, apart from living organisms such as worms or bacteria, which contribute to the transformation of soils regarding both chemical composition and structure. Therefore soil fertility is determined by many different factors that go far beyond climate, weather conditions, and land management (Pfeiffer, 2004: 40).

As stressed out by McNeill and Winiwarter, "*soils have their own histories, both natural and human"*, are not static elements, and their renewal occurs at a very slow pace. Therefore their maintenance has been essential for agrarian societies. In fact, human intervention in nutrient cycles and agricultural management has compromised ecosystem sustainability both in the past and in the present (McNeill and Winiwarter, 2006: 1-6). The increase in the demand of food production is a very relevant conditioning factor of soil fertility, which usually implies the expansion of the cultivated area and/or more intensive cropping of pre-existing cropland, but cultivated soils do not have an unlimited capacity to increase their productivity, which is also not directly proportionate to the amount of fertilizer applied. As living entities, soils have a *"load limit"*. They can still produce for some time under overload conditions, but their deterioration will sooner or later reveal the symptoms (Pfeiffer, 2004: 48-49). According to Shiel, the use of land for agrarian production leads to the reduction of overall fertility, mainly by reducing the humus content of soils. Therefore, whichever solution is taken to compensate for the increasing food output leads to deterioration of some soil properties. This results in slower plant growth and, frequently, in higher rates of soil erosion as well. Among others, parent material of soil, clima, topography, humus content, acidity, soil wetness, temperature, management of fertility, cultivation, or even the sequence of crops produced are important factors to consider when addressing soil fertility. In the case of mature soils which have a long history of cultivation and high levels of acidity, nitrogen and phosphorus availability tend to be scarce, thus making nutrient replenishment a difficult task. Shiel also points out the fact that soil exhaustion processes occurred in the past too, as in Ancient Rome and Athens for instance, where grain was imported from the fertile valleys of Egypt once local soils had been depleted. Besides, European agricultures also showed signs of decreasing productivity before the introduction of innovations associated with the Agricultural Revolution, which helped overcome nutrient scarcity in the arable. New rotations and an increasing manure availability in different forms provided organic matter content and an improvement in soil structure by aiding natural processes that occur in the soil (Pfeiffer, 2004; Shiel, 2006a and 2006b). However, in many cases, this was not enough to keep up with nutrient extractions, as current research is starting to demonstrate. According to González de Molina, nutrient scarcity has been a structural factor in the agriculture of the Iberian Peninsula, mainly in those Mediterranean regions with low average rainfall. Fertilizers are one of the factors that can limit agrarian production along with population, labor force and arable land (González de Molina, 2010a). Regarding nutrients, long-term sustainability is only achieved when harvested nutrients are fully replenished (García-Ruiz et al., 2012).

Such topic has been addressed before within social metabolism by applying the technique of nutrient balances (González de Molina and Guzmán, 2006; Tello et al., 2010 and 2012; Infante-Amate, 2014; Galán, 2014 and 2015; Gingrich et al., 2015; González de Molina et al., 2015; Güldner et al., 2016; Neundlinger and Güldner, 2017). There is a general conclusion within these studies regarding pre-industrial agricultures, which were more or less balanced in the 18th or beginning of the 19th centuries but show exhaustion symptons after a process of agricultural intensification, mostly towards the end of the 19th century. As a result of an increasing population, growing agricultural output -accompanied or not by productive specialization- soon exceeded the organic capacity of replenishing soil nutrients, which seems to have only been overcome with the introduction of industrial fertilizers.

We share with this previous research the common objective of finding out if the pattern of agricultural intensification reached its limits within an organic metabolism, and if so, why and when. Infante-Amate (2014), González de Molina and Guzmán (2006), and González de Molina et al. (2015) have concluded that this was the case in Andalusia, where nutrient balances prove the intensification pattern unsustainable as it was based on nutrient mining due to a structural lack of fertilizers, thus breaking previous balances of a more integrated agriculture. Since cropland progressively took over pastureland, livestock head decreased considerably between 1750 and a century later, thus reducing manure availability and the fertilization capacity. As a consequence, most yields stagnated towards the last decades of the 19th century. Similar conclusions can be found in Tello et al. (2010 and 2012) and Galán (2015), who prove vineyard specialization in Sentmenat (province of Barcelona) also unsustainable in the long term, at least towards 1860, and after a process of expansion and intensification in a context of scarcity of fertilizers. Although in this case vineyard monoculture allowed for considerable savings of nitrogen and phosphorus, which were imported in the form of foodstuff, manure scarcity led to a labor-intensive fertility strategy which relied mostly on human and animal labor and imposed more constraints to fertility in both technical and economic requirements than biophysical conditions. Gingrich et al. (2015) conclude that pre-industrial agriculture was considerably balanced, at least for nitrogen, in two case studies in the Austrian Alps towards the beginning of the 19th century, although the authors suggest that there must have been a process of soil depletion in the long term too. Güldner et al. (2015) study a particular case in Austria where nitrogen and potassium extractions for the warfare industry during the 18th and 19th centuries contributed to the depletion of agricultural soils as well.

The outcome of this agricultural exhaustion in Spanish historiography has been generally referred to as "*crisis agraria finisecular*", an agrarian crisis that occurred towards the end of the 19th century widely across Europe when cheap cereal started to be imported from America. The biophysical perspective has allowed to re-interpretate this situation as the encounter of two different fertility systems. European agricultures were meeting their intensification limits towards the end of the 19th century as a result of a long history of agriculture and crop intensification whereas the agricultural frontier in America or Australia could easily expand further away by exploiting unspoiled nutrient reserves with a lower land and labor cost. This crisis created a proper context for the introduction of mineral fertilizers and further intensification and industrialization in European agricultures (Cunfer and Krausmann, 2009; González de Molina, 2010a).

We have hypothesized that the situation in Galicia was not an exception to this soil depletion processes related with agricultural intensification. Therefore, in this research we aim at approaching the managament of soil fertility and assessing the impact of intensification on the availability of three major nutrients: nitrogen, phosphorus, and potassium. We lack training in the involved disciplines that should address soil fertility in its whole. Therefore, our reading is mostly historical and focuses on agricultural changes in the long term and their connection with fertility management, which has been technically assessed by our colleague from the SFS project Roc Padró.

In this research we will not deal with industrial fertilizers since they were barely known at the end of the period we consider and their use only started to be common in the first third of the 20th century (Fernández Prieto, 1992). We focus therefore in organic fertilizers. The main form of manure in Galicia is the result of livestock liquid and solid excreta and the materials that are used for their bedding in the stable, usually called *esquilmo*, which is composed of gorse species and other shrubs as well as materials such as domestic residues, leaves or garden by-products. According to Urbano Terrón, the quality of this kind of manure is determined by the nature of bedding, the type of livestock and the hypothetical losses that occur during its elaboration. This author provides information on bedding and animal excreta in kg/ha that we have used as contrast for our estimations (Urbano Terrón, 2001). For the case of Ribadavia we must also consider green manure. Previous research has described the use of *Ulex* as green manure, which was cut and and buried in holes between vineyard lines (Domínguez Castro, 1992 and 2001). According to Urbano Terrón, green manure contributes to sustaining the organic fertility of soils because of its quick evolution into humus with a high nitrogen content, which helps to sustain biological activity. Amongst its benefits, the author mentions the following: improvement of the structure of superficial soil horizons, mulching and better subsoil water and nutrient management with deep plant rooting, improvement in adventitious vegetation control or defense against erosion. However, some adverse side effects might occur as well such as problems with hydric balances when applied at the wrong time, impoverishment of organic matter in the soils when intensively cultivated, or plague propagation (Urbano Terrón, 2001).

Regarding our particular case studies, we need to consider the general peculiarities of the soils and fertilization management in agroecosystems in the NW of the Iberian Peninsula[57], which used to be based on *monte*, especially on gorse (*Ulex*) but also on other varieties of shrubs with less appropriate characteristics for manure production.

Illustration 2. ***Ulex Europaeus***

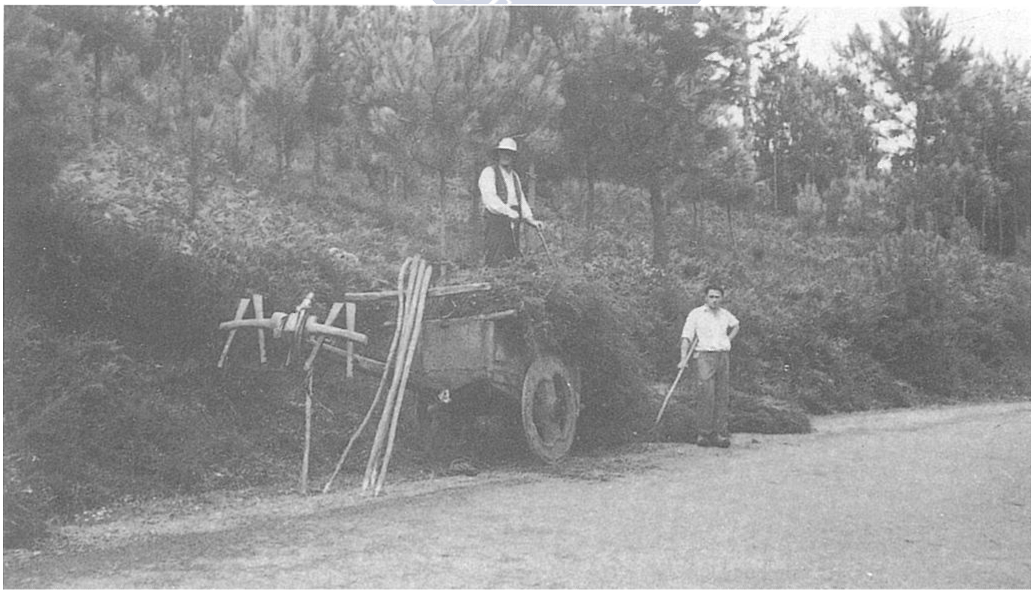
Source: http://www.rios-galegos.com/plan15.htm.

[57] Including the North of Portugal and most of Asturias and Cantabria, which share at some extent similar oro-climatic conditions and the use of *Ulex* varieties as fertilizing material. Sineiro locates the natural regions of gorse in wide areas of Western Europe: from the N. W. of the Iberian Peninsula until Denmark, including the British Islands. It has also been naturalized in Central Europe, the Balcans and Italy, and introduced in New Zealand and some areas of Australia, West of the USA and South America (Sineiro, 1983: 519). According to Bouhier, this fertility management, which was based on the use of *monte* was common to many other Atlantic regions of Europe. However, in none of them the development of this practice and its duration was as remarkable as the Galician case, along with the North of Portugal, which is considered a natural extension (Bouhier, 1984).

In Galicia the following varieties of gorse can be found: *Ulex Europaeus, Ulex Gallii, Ulex Minor* and *Ulex Nanus*, the most common of which has been the *Europeus*. Gorse is a prickly leguminous plant that used to be sowed in *monte* surfaces all through Galicia. Seeds were even sold at markets, namely those of the *Ulex Europaeus* variety. This is the reason of its wide expansion in the territory even nowadays, when it is no longer so massively used (Bouhier, 2001; Sineiro, 1983). It was mainly used as bedding for animals in stables, where it fermented along with their excreta and produced high quality manure for the crops. Gorse was also used as green manure in certain cases. This means that it had to be cut before spines got too hard (Balboa, 2000). Different types of shrub were collected along with gorse but this plant was the main protagonist in the intensification pattern that agriculture followed in this region due to its high content in nitrogen. Iglesias analyzed soils that had been fertilized with gorse, either green or composted with cow manure as it used to be done in traditional management, and compared both applications with unfertilized adjacent fields. The author concludes that both forms of gorse fertilization supply organic matter, which improves the soil properties. When applied as green manure, it contributes to an increase of the 98% of organic matter, which is about the 73% with farmyard manure. The supply of nitrogen is relevant too, especially in the case of farmyard manure as it includes livestock urine, with an increase near to the 100% and about a 42% in the case of green manure (Iglesias, 1985).

Apart from this fertilizing capacity, gorse was very versatile as it served both as bedding and feedstuff for livestock, but also as fuel. It required, however, a lot of labor. Gorse had to be cut, transported and buried among vineyards or added to the stables as needed, and then collected and transported to the fields, where it was spread and buried. Manure was removed from the stables twice or three times a year, right before planting (Bouhier, 2001; Balboa, 1990).

Illustration 3. Two men loading a cart with gorse



Source: Bouhier, 2001, vol. II: 981. Unknown year, ca. 1960/70s.

According to Sineiro, after several cuts, gorse starts growing slower and more woody. When cut for livestock bedding, gorse plants are usually between 3 to 6 years old, as Bouhier verified for the 19th century. When this shrub is used for firewood, management is different since woody parts are prioritized: plants are more separate from one another and get cut after 8 to 12 years, or even between 16 and 20, being completely pulled out and planted again after its life cycle is exhausted. This requires a new *estivada* and a new gorse plantation (Bouhier, 2001; Sineiro, 1983). For this purpose, from time to time, when it was more convenient for the plant, land was broken with a sort of shifting agriculture technique called *estivada* or *roza*, when cereal was also planted. In the spring, when rain is less frequent, land is first broken by digging with a hoe, thus separating the vegetal cover from the soil. After some months, around July or August, when vegetation is dry, it is stuck up in piles or rows and then burned for several days. After that, ashes are scattered all through the broken surface. Later in the automn, with the first rains, both cereal (usually rye) and gorse are sown together because their of their different cycles since gorse takes longer to grow. Gorse plants accumulate big amounts of seeds in the land where they grow. These seeds have a latency period that can last more than thirty years and comes to an end with temperature changes. This fact explains why fire was used in order to regenerate shrub production, mainly in the form of *estivadas*, since gorse management under successive cuts is affected in its growth and density (Sineiro, 1978). Besides, due to the action of fire, *estivadas* also help cleaning the soil from bugs or adventitious plants, thus acting as a plague controler. It also contributes to soil mineralization, reduces soil acidity and mobilizes fertilizer materials in the ashes. Besides, fire improves the structure of clay soils like Galician ones. Therefore *estivadas* do not only supply an extra crop, but are mainly intended at regenerating shrub production, which is essential for fertilization. However, it has been observed by Bouhier that, even when the intensification of *estivadas* was initially related with demographic pressure, such a process resulted in soil depletion in the long term with the decrease of gorse productivity and, eventually, in the reduction and disappearance of the practice of *estivadas* along the 19th century. Therefore, according to this author, intensification could only be restarted after the introduction of superphosphate fertilizers towards the end of the 19th century (Bouhier, 2001). The case of Fonsagrada will allow some more insight into this practice, especially considering that *estivadas* were not reduced in the municipality during the 19th century but, on the contrary, they were also intensified by expanding their surface and reducing the span of time between them.

Monte areas are therefore essential in the management of soil fertility. Such surface has commonly been defined as the opposite of cultivated land. Towards the end of the 18th century, cropland occupied no more than the 20% of the territory of Galicia, perhaps the 30% in some regions along the coast but even less than the 15% in inner mountains. Thus *monte* occupied the remaining territory, about the 80% of Galicia (Saavedra, 2015). These percentages showed regional variations according to the differences in the agrarian system and soil fertility. According to Bouhier, who analyzed data from Ensenada's Cadastre (1752), cropland occupied between the 20 and 45% of the agrarian surface along the Atlantic coast with the highest values in the whole territory of Galicia. These percentages were similar in the SE openfields of Ourense: between 25 and 45%. Along the Cantabric coast, cropland ranged betwen the 30 and 35%. In the lowlands of the province of Lugo, such percentages would be between 12.5 and 25%, and between 7.5 and 25% in the Eastern mountains. All these data have been corrected by Bouhier according to his estimations on under-declarations of surface, and cropland includes vegetable gardens, both irrigated and non-irrigated rotations, meadows, *soutos* and vineyard. For the particular case of Fonsagrada, according to data as declared in the Cadastre, this author determines that cropland was about the 5% of the total agrarian surface or about the 7.5% if surface under-estimation is considered (Bouhier, 2001). At the beginning of the 20th century, *monte* occupied about a 70% of the whole territory (Balboa, 2000). Bouhier observed that an average of the 70% of the agrarian system in Galicia was still composed of *monte* towards 1960, which provided the remaining 30% of cropland with the required nutrients, along with industrial fertilizers, which were used as a complement at the time (Bouhier, 2001).

Although this ratio was changeable over time and, especially across the territory, it illustrates the dependence on great part of the territory in order for nutrients to be replenished in cultivated soils. The proportion between *monte* and cropland had to be kept within balance, otherwise production levels would be easily affected if, for instance, too much *monte* surface was broken and transformed into permanent cropping (Balboa, 2000). This dependence has conditioned peasants' decision-making processes all through time. Ribadavia and Fonsagrada allow to take a closer look at these determinants and at the intensification process through the study period, where we observe an increase in cultivated land, and changes in crop rotations, and land productivity.

In fact, agrarian literature from the middle of the 19th century and after shows a huge concern about this land-breaking process which, according to engineers and experts of the moment, would inevitably lead to an imbalance between cultivated and uncultivated land due to the lack of fertilizing materials such as manure in a context of demographic pressure (Villares, 1982).

Monte was therefore mainly used as a nutrient provider for crops, but not only since it also provided pasture, firewood, wild berries, medicinal plants, wood, hunt or wood charcoal, as well as basic environmental services. It was continually and intensely exploited and for varied purposes, but mostly in the form of shrub for fertilization, pasture, and firewood (Balboa, 2000). The community organized the appropriation of *monte* either in a collective way or alloted to neighbors individually, depending on the type of use and land tenure. This was the way to guarantee the required nutrients for every household's cropped surface, although distribution was not necessarily equitative since appropriation of *monte* resources depended on the household potential, especially on their access to cropland surface, livestock and labor, as Balboa has demonstrated (Balboa, 1990 and 2000).

The multifunctional role of *monte* and its integration within the agrarian system has been pointed out by previous researchers, who also mention that, along with the agricultural intensification of the 19th century, gorse started to be cultivated in *monte* surface in order to provide crops with more primary material for manure. This process has been connected with *monte* individualization along the 19th century, but also with the liberal attack on collective land tenure. Generally across Galicia during the second half of the 19th century, and even before in the southeastern regions, many neighbors started to enclose areas of *monte* for their particular use, which was also in the origin of conflicts within the communities due to the lost of common pasture and other resources. The origin of such conflicts was mostly in the contradiction between liberal measures and the customary law regarding *monte* tenure (private verus collective property), but also in the productive use of such resource. The informal "privatization" secured the property of *monte* and the access to its vital resources by the communities during a long period when collective property was not legally recognized and commons were expropiated from rural communities and mostly attributed to councils (Bouhier, 2001; Balboa, 1990; Pérez García, 2000; Soto, 2006).

During the 19th century and most of the 20th, rural communities managed to oppose and resist the liberal attemps of expropiation of their common pool resources. This was not possible anymore during the Francoist dictatorship, when administration took over these resources by force and imposed an aggresive forestation policy. Eventually, between 1960 and 1980, and after a long socio-environmental conflict over *monte* regarding the liberal measures for their privatization and the changes in productive strategies, collective property would be legally recognized and restored to the communities they belonged to (García Fernández, 1975; Bouhier, 2001; Balboa, 1990; GEPC, 2004 and 2006; Freire, 2014). But it was too late for a resource that was starting to lose its varied functions within the agrarian system, and was now definitely embracing the energy regime and the appropriation mode of the industrial metabolism with the introduction of the technological package of the so-called Green Revolution (Soto, 2011).

However, the distribution of *monte* among the members of the communities in the 19th century did not modify its appropriation and, although it meant the beginning of forestation on such surfaces after 1860s, this was still within the logic of complementary and integrated uses (Bouhier, 2001; Balboa, 1990; Soto, 2006; GEPC, 2006). This strategy served the agrarian intensification, especially in the regions with more intensive agriculture where *estivadas* or *rozas*[58] had already disappeared by the beginning of the 19th century in order to intensify gorse production, as demonstrated by Pérez García (1979). In inner and mountainious regions like Fonsagrada, pasture and crops in *estivadas* on *monte* surface were also relevant all through the study period, and along the Cantabric coast such crops were also

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[58] Names differ according to the region and even at very local scale. *Estivada* and *seara* are common from inner territories, *rozas* is mostly from the South Atlantic coast areas, but in the same province of Pontevedra they were also called *cachadas* (Bouhier, 2001).

common, as well as the appropriation in form of both pasture and gorse for manure production.

Therefore, there is an initial extensive response to agrarian requirements which consists in clearing more *monte* surface for *estivadas*. Later on, privatization was meant at intensifying *monte* use as well as cropland, for instance by planting gorse in order to obtain more manure (Bouhier, 2001). However, Pérez García studied cases along the South coast of Pontevedra, namely in the Rías Baixas, where agrarian intensification and paralel transformations in livestock management, rural landscape, and demographic structure had occurred mainly during the 17th century and showed this individual exploitation of *monte* in a previous moment than the more general trend described by Bouhier. In this case, the ratio between cropland and *monte* is 1/3 to 2/3, respectively, which is more or less maintained during the period between the 17th and 19th centuries. The author establishes manure needs per household through time according to Díaz de Rábago, who observed that between 40 to 50 carts of *esquilmo* were required at the beginning of a crop rotation towards 1880, usually biannual ones (Pérez García, 2000). These data are, however, difficult to compare with ours since the use of carts per household differs from our units (kg/ha). If we consider that an average cart of *esquilmo* weights 550 kg, as collected in the corresponding report by the JCA (Ministerio de Agricultura, 1892), forty-five carts would be equal to 24,750 kg of *esquilmo*. Other report from 1895 by an engineer from Pontevedra also included estimations on gorse needs for fertilizing purposes, concluding that between 2 and 2.3 ha of shrub in *monte* would be needed for every cultivated hectare. Such report was elaborated for the Foreign Office of New Zealand regarding the interest in importing gorse as fodder for livestock (cited in Fernández Prieto and Soto, 2010: 245).

On the other hand, Bouhier estimated the average weight of a cart of gorse in 400 kg (Bouhier, 2001: 851), but the most problematic unit is actually "household", which does not take rotation requirements into account and differs a lot in its average surface according to socioeconomic regions within Galicia. According to Bouhier, in the 1960s between 20 to 40 carts of gorse would be required annually for every household hectare, which is equal to 8-16 t/ha according to this author's estimates (Bouhier, 2001: 854). Therefore, every cultivated hectare would require between one to two hectares of *monte*. Our data for Fonsagrada indicate that *esquilmo* appropriation changes all through the study period, thus adapting to the different requirements, and goes from 590 kg per cultivated hectare in 1752, to 1,062 kg/ha in 1852 and 2,106 kg/ha in 1887 (fresh matter). This translates into the following average data of available manure per cultivated surface unit: 1.4 t/ha, 4.6 t/ha, and 5 t/ha (fresh matter), respectively. When data are disaggregated, requirements show differences according to each fertilized rotation and considered nutrients. Besides, taking into account the margin of error in our estimations, the situation of soils seems generally balanced in cropland in all three moments but with a process of soil degradation in *monte* and meadows, as we will see. If we consider exclusively the manure used in vegetable gardens, which occupied a much smaller surface than the cereal rotation but were more intensely managed, then every hectare received

13 t of manure in 1752; 14.8 t in 1852, and 14.2 t in 1887. In the cereal rotation, manure doses increased from 1.3 to 4.26 and eventually 4.8 t/ha, respectively. Such increasing requirements are connected with more intensive cropping after the introduction of potatoes and turnips in this rotation. In terms of *monte* surface, these data translate into the following required hectares for every cultivated hectare: 5.8 ha in 1752, 1.3 ha in 1852, and 0.8 ha in 1887. This reduction can be explained by the increasing weight of meadows in the nutrient cycle in Fonsagrada. Surface requirements have been estimated according to livestock bedding, pasture and firewood needs, and express all three needs in every moment.

At the light of these facts, it is necessary to estimate *esquilmo* and manure needs more accurately for other agricultural regions within Galicia and ask ourselves again whether collective tenure could be related with the capacity of fertilization. The biophysical approach might shed some light on this issue. Energy balances would also contribute an interesting approach to the debate.

Definitely, what is important noticing is that *monte* was completely integrated in the agrarian system and cropland depended on it for nutrient replenishment. According to Bouhier, and depending on the region and general soil fertility, between the 50 or the 85% of the agrarian surface should be *monte* in order to maintain its balance with cropland requirements. This is particularly significant in the S. E. regions of Galicia, where *monte* productivity is lower (Bouhier, 2001).

As we have seen, an important amount of land was managed in order to sustain the fertility of soils, which depended tightly on *monte* resources such as gorse, which was the main ingredient of manure. At this respect, farmyard manure fulfils three important tasks: it supplies with all main nutrients (nitrogen, phosphorous, potassium, calcium, magnesium...); improves soil structure in terms of sponginess, soil aeration, and water retention; and corrects soil ph. But more intensive techniques were also used such as the cultivation of leguminous plants in crop rotations, and coexisted with extensive practices such as fallow and *estivadas*. At the light of Bouhier's research, Sobrado includes *estivada* as a fertilizing practice due to the action of the resulting ashes (Sobrado, 2004).

Extensive fertilization techniques such as fallow and, at some extent, *estivadas* as well, impose a lot of pressure and rigidity on the territory and have a high land cost as defined by Guzmán et al. (2011), especially in those areas where land is a scarce resource. In the case of Galicia, fallow was common in most of the territory although it also showed regional differences in its duration and chronology. It was more extended and lasted longer in inner areas of Lugo and Ourense than along the coast of Coruña and Pontevedra. In the inner territories, most of the arable land was cultivated with rye in a biannual rotation with fallow, which progressively disappeared as intensification and new crops advanced (Bouhier, 2001; Saavedra, 1979; Villares, 1982).

Although fertilization in Fonsagrada and generally in the inner territory of Galicia, especially in the 18th century, relied mostly on extensive techniques and on *monte* resources, fertilization included more materials and techniques. The preference for gorse before other shrubs was based on its physiological characteristics: higher production potential, good adaptation to low fertility soils, good response at cuts by generating new shoots that allows using the same plants for several years, and easier decomposition and higher nitrogen content (Sineiro, 1983; Iglesias, 1985). However, in an agrarian logic, almost any vegetal or animal by-product was susceptible of being recycled into manure, compost or applied directly to the soils: domestic and urban residues, leaves, different sorts of shrubs, seaweeds and shells in coastal regions, and, more rarely, marl, clay, lime or other substances that help correct soil acidity. It was also common to cover paths with shrub during the rainy season in order to absorb water and mix up with animal dejections, which would eventually result in an extra provision of manure, although of a lower quality (Bouhier, 2001; Fernández Prieto and Balboa, 2000; Sobrado, 2004). It is common to observe in our case studies that recycling (internal re-uses of materials) was a frequent and inherent practice to agrarian metabolisms. Equally, the general structure of the nutrient cycle in European advanced organic agricultures allows to identify three main components in the management of soil fertility: manured cropland, grass-producing land with more extensive management that provides cropland with nutrients, and livestock, which converts pasture into manure (Lennartsson et al., 2016). This basic structure can be distinguished in both of our case studies and all through the territory of Galicia, where *monte* had an important role as pasture producer, but also as bedding provider for livestock. As we will see, its role in Fonsagrada is increasingly complemented with meadows, which towards the end of the 19th century almost substitute *monte* as nutrient provider for cropland.
However, there were also technical constraints to fertilization which resulted in nutrient losses. Sobrado has described them as technicians from the 18th and 19th centuries had done. Poor practices such as keeping piled manure in the open air for a long time without being covered would result in a loss of nutrients due to the action of sun and rainfall (Sobrado, 2004). On the other hand, Fernández Prieto and Balboa emphasize other technical opinions of the 19th century which express satisfaction with yields and general fertilization levels that optimized natural possibilities. There was also a concern on issues such as storage procedures but technical advice was mainly aimed at improving these practices within an organic metabolism. Technicians would only change towards a more industrial view on fertilization towards the end of the century, when organic conditions started to be seen as a constraint (Fernández Prieto and Balboa, 2000).

Besides, we have pointed out the importance of the Atlantic influence because it is related with soil fertility. As Díaz-Fierros states in his research on fertilization in Galicia, geographical and climatologic aspects determine high leaching levels due to the action of rainfall, but there is also a geological limiting factor in this territory related to soil pH. The combined action of both factors, high rainfall and soil acidity, result in poor and bare soils which require fertilization in order to supply not only nutrients but also organic matter (Díaz-Fierros, 1982).

Moreover, Sobrado has pointed out that manure was not only insufficient but also deficient, especially towards the end of the 19th century, although his sources and data do not seem solid enough for such a statement. García Fernández had mentioned manure scarcity too, and hypothesized the insufficient nutrient replenishment to the soil (García Fernández, 1975: 120). Such facts still need to be validated with further research. On the other hand, Sobrado's description of fertilization practices gives also an idea of adaptation and suitability to the particular agrarian context. These practices were either meant to replenish nutrients and organic matter or to correct soil acidity. Besides, they are also described in relationship to changes within the agrarian system such as intensification and the introduction of new crops, to which fertilization adapted as well. This meant a progressive reduction and latter supression of an extensive fertilization technique such as fallow, as well as the stabling of livestock, which resulted in a higher manure availability that was meant to fulfil the requirements of those new and more exigent crops: maize and, particularly, potatoes (Sobrado, 2004 and 1996). In order to intensify livestock management, its numbers had to be reduced. In the 18th century, Galicia had the largest livestock head within the territories of the Crown of Castile, and even exported bovines to other parts of Castile and Portugal (Bouhier, 2001; Carmona, 2000; Eiras Roel, 1983). The reduction of the livestock head was required in order to get the animals stabled. Thus fertilization practices had a parallel development with intensification and the introduction of new crops (Fernández Prieto and Balboa, 2000; Sobrado, 1996 and 2004), which we can also appreciate in our case studies. Generally in the inner province of Lugo, livestock stabling in order to increase manure production translated in an expansion of meadows and fodder cultivation such as turnips, as concluded by Sobrado for the period 1750-1860 (Sobrado, 1996).

Regarding nutrients, phosphorous has been considered one of the main limiting factors in current Galician agriculture due to the type of soils and the agrarian practices of the region (Gil Sotres and Díaz-Fierros, 1979). This problematic issue had already been pointed out by Muñoz Taboadela in 1965 and would be further researched at the Agrarian Research Centre of Mabegondo (Coruña), where it was concluded that the lack of phosphorous could be even more serious in uncultivated surfaces such as shrubland areas. Fertilization with phosphorus has been proved by Sineiro's research in Mabegondo to regenerate gorse growth, which is more limited under conditions of scarcity of this nutrient, to which gorse is, however, well adapted. Generally speaking, any spontaneous vegetation is conditioned by phosphorous scarcity (Sineiro, 1978). In fact, this surface has been historically characterized by its low fertility due to the intensive use of *monte* as nutrient provider for crops in the past, soil acidity and scarce phosphorus content. This has been confirmed by the good response to phosphorus application performed by previous researchers (González Rodríguez, 1983; Sineiro, 1978). Moreover, phosphates were the first industrial fertilizers to be incorporated in Galician agriculture at the beginning of the 20th century. Fernández Prieto has collected the reviews of coetaneus technicians like Urquijo or Cruz Gallástegui, who explained this need of phosphates as a pre-requisite to mobilize nitrogen mineralization. However, an abusive use of such fertilizers resulted in a reduction of nitrogen content in the soil and decreasing yields towards 1930 (Fernández Prieto, 1992).

This lack of phosphorous replenishment in *monte* must be related with high phosphorus extractions from this surface which are not replenished once most livestock gets stabled towards the end of the 18th century and beginning of the following one. However, our nutrient balances for the case of Fonsagrada do not show phosphorus deficiencies in *monte* during the study period although its stocks do show a decreasing trend.

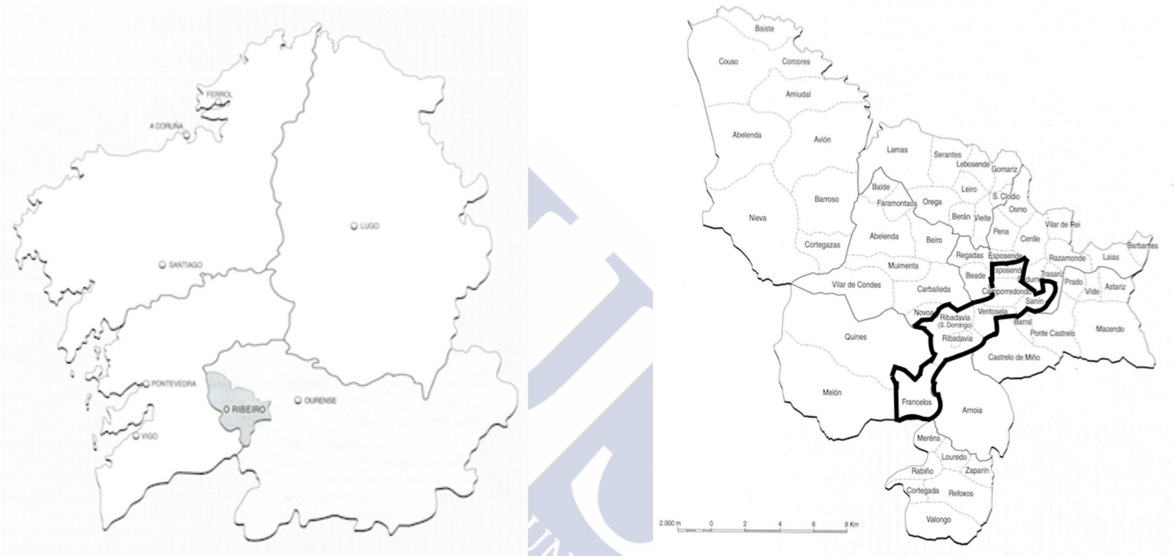
Definitely, as a result of agricultural intensification, and as other authors have hypothesized (Soto, 2006), organic fertilizing techniques must have been insufficient to keep up with nutrient extractions of agriculture due to their high territorial cost (Guzmán et al., 2011), as it occurred in the Mediterranean territory (Tello et al., 2012; Galán, 2015; Infante-Amate, 2014; González de Molina et al., 2015). Inorganic fertilizers were aimed at overcoming this biophysical limit of agriculture. However, their use during the last decades of the 19th century in Galicia was more the exception than the rule (Fernández Prieto, 1992) and soil fertility depended mainly on organic resources in a territory with scarce land for cropping, and poor acidic soils (Gil Sotres and Díaz-Fierros, 1979).

In this research, we focus on the management of soil fertility within an organic metabolism in order to assess its functioning and its limits. Apart from the use of *monte* resources, we also analyze changes in livestock management, manure availability and land uses which were aimed at increasing fertilizer availability for crops, as well as the use of fallow and its progressive supression through the 19th century. The initial hypothesis behind this approach was that sustaining crop yields was conditioned by the limited amount of nutrients that could be transferred from *monte* and more extensive land uses to cropland. Our research contributes some new data at this respect, showing that soil nutrients were quite balanced in the case of cropland in Fonsagrada all through the period but this was achieved at the expense of soil depletion in more extensive land uses. However, further research needs to be done in other case studies with an earlier process of intensification or, as in the case of Ribadavia, with a cash crop specialization.

6.2. Ribadavia: intensification through market specialization

Ribadavia is the historic capital of the Ribeiro region, in the West of the inner province of Ourense, at the foot of the Faro de Avión, Testeiro and Suído Mountains, which lay West and South of the region. The Miño River flows through this region in its central strecth by following a deep tectonic fracture where it collects water from its main tributaries, Avia and Barbantiño rivers. In the last 50 years, the construction of three dumps has completely altered the hydrography of these very enclosed valleys: Albarellos in the Avia River, and Castrelo and Frieira in the Miño. The region of Ribeiro mainly comprises the valleys of these three rivers, which offer the topographic and climatic conditions for vineyard cultivation. Altitude varies between 1,000 m at the peaks and 100 m at the basin. Soils are acidic and mainly composed of granite. Given the abrupt topography of the region and the high risk of erosion, most of the soil is not proper for agriculture, except for the alluvial areas along the riverbanks and slopes that have been terraced for cultivation, mostly with vineyard (Pérez Alberti, 2001).

Map 3. The Region of Ribeiro within Galicia and the location of Ribadavia within the Ribeiro



Maps source: Precedo Ledo, 1999.

The current municipality of Ribadavia has a surface of 25.2 km^2 and is located at the confluence of Miño and Avia rivers, at 112 meters above the sea level and at the edge of the Oceanic climate region, under a strong Mediterranean influence, which can be seen in some of its most characteristic vegetation. Thus, the region benefits from a southern position with less rainfall and higher average temperature than the rest of Galicia. Its location in a river basin gives shelter from the maritime winds that bring rainfall. Temperature inversion is a common phenomenon, and so are fog and frosts, which increased after the building of the dump in the Avia river. Weather is drier and sunnier than in the rest of the territory, with very arid climate and more extreme temperatures: winters are cold and droughts are quite common in summer (Pérez Alberti, 1982). Average annual temperature in the nearby meteorological station of Ourense is of 14ºC, and average annual rainfall reaches up to 2,000 mm at the West side of the mountain ranges but only 800 mm in the Ribeiro region, where there is a precipitation deficit of about 450 mm between the months of April and September, but especially during July and August (Díaz-Fierros, 1971).

This weather is very appropriate for vineyard cultivation, one of the most important crops in the history of Ribeiro. South-oriented slopes are terraced in order to avoid soil erosion and provide the grapes with the most convenient sunshine exposure, also because temperature is higher than in the slopes which are oriented to the North (Pérez Alberti, 1982). This crop expanded mainly during the 14th and 15th centuries due to a higher social demand of wine in Galician villages, thus becoming a monoculture in the Ribeiro until its decline in the 18th century (Huetz de Lemps, 1967). García Fernández puts this vineyard especialization into context by saying that, even though the ecological conditions were not optimal for this crop due to humidity (mainly in automn), it was a human adaptation in order to provide local communities with wine in a time of high demand, and eventually got exported abroad from nearby ports (García Fernández, 1975).

The expansion of vineyard in the region meant the appropriation of shrubland and uncultivated areas, usually by terracing slopes. This long-term process was mainly led by monasteries during the Middle Ages, namely those of Melón and San Clodio in the Ribeiro. These monasteries established land contracts with peasants, which conditioned the agriculture and landscape of the Ribeiro. During the 18th century, wine trade still sustained monasteries economically. However, confiscation laws in 1836 entailed the end of the ecclesiastical control over vineyards (Huetz de Lemps, 1968).

The *foro* was the most common type of contract used for land and labor exploitation in this region, as it was in the whole territory of Galicia (García Acuña, 1995). It is a form of indirect exploitation in which the landlord, usually ecclesiastic members or nobility, assigns land to a family or beneficial owner who would work on it in exchange for a part of the harvest, which could reach up to half of the product, either grape or wine -depending on the particular clauses. The contract had a long-term duration, and regulated other forms of taxation over the land as well as types of crops and the way in which land should be laboured. At the time, vineyard was usually associated with chestnut trees, not only because of their important contribution to the local diet but also as a supply of wood stakes to hold the vines. Cereals such as rye and millet, legumes and linen used to be cultivated in the peripheric areas of the Ribeiro and in those places where conditions were not appropriate for grapevines.

Towards the end of the Middle Ages, secular nobility and liberal professionals became interested in vine growing as well. They contributed to the region specialization by acquiring land for this purpose, and acted as intermediaries by signing *subforo* contracts, thus adding extra charges to the labourers of the land. This lower nobility, the so-called *fidalguía*, grabbed land through this type of sub-contract thus becoming a sort of "*vineyard bourgeoisie*" in the region whose protagonism lasted until the *foro* abolition, towards the first third of 20th century (Huetz de Lemps, 1967 and 1968; Domínguez Castro, 1992).

For all these reasons, the economy of the region was (and still is) highly conditioned by viticulture, which in the past tended to conflict with livestock farming, mostly with bovine, due to the damages of free-ranging animals in vineyards. Monasteries, local authorities and rich farmers, who were the main landlords and had a special interest in the trade of wine, eventually imposed strict regulations to pastureland, since it competed with vineyard surface.

Livestock has therefore historically been very limited in this region, especially sheep and goats (Bouhier, 2001; García Acuña, 1995), as it occurred in other regions with a focus on viticulture in Galicia (Saavedra, 1992c) or for instance in Catalonia (Cussó et al., 2006). Our data confirm this trend as well, and it is coherent with a densely populated territory with low land availability, and a cash crop specialization.

The trade of Ribeiro wine started in the early Middle Ages, being exported to the Cathedral towns of Santiago and Lugo. In the 16th century it was sold in several villages and towns within Galicia, along the Cantabric coast, and even in France, Flanders, Portugal, and especially England, where it reached mainly through the maritime port of Pontevedra during the 16th century, and later on through the one in Vigo. Wars between the reign of Felipe II and England eventually ruined this commercial connection, which did not recover after the treaty of 1611, and even affected trade with Portugal once the English established in Porto after the Portuguese independence from the Crown of Castile in 1640 (Huetz de Lemps, 1968).

Slowly through the 18th century wine trade enters a long and deep crisis with the lost of numerous local and foreign markets due to political conflicts, bad transport conditions within Galicia and the increasing concurrence of other Castilian wines after the train connection with Vigo in 1881, which went through Ribadavia as well. Production then re-oriented towards cheaper and lower quality wines for inner consumption in the region, thus massively leading to the replacement of white vines by red ones. This situation was aggravated by several plagues that caused great damage to the vineyards of the region in the second half of the 19th century: oidium (after 1853), mildew (after 1879), and phylloxera (after 1900), all of them proceeding from America. As a result of such context, it has been pointed out that peasants started to connect with agronomy and industrial agriculture, thus introducing productive innovations (Domínguez Castro, 2001). Sulfur was proved a good remedy against oidium, and was even distriuted by the local government in the province of Ourense in the year 1861, thus helping to overcome the general prejudices that prevented from its use for such purposes, as it was a common remedy for scabies. Equally, copper sulphate also started to spread within the region as a remedy against mildew (Domínguez Castro, 1992). The coetaneous historian Eiján cites the minutes of the Council of Ribadavia from May 5th 1861, where it is said that oidum had been ruining wine harvests for eight consecutive years, thus causing a crisis that would last over a decade, until late in the 1860s (Eiján, 1920).

Both *cartillas* for the second half of the 19th century consign sulfur expenses for vineyard but we have not come accross any records of sulphate. Both products, and the technology and new tasks related with their application were the first industrial inputs that massively spread within the region, thus increasing the costs of wine production. The resulting economic crisis was summed upon the poor harvests of potatoes, cereal and legumes of 1852, and the cholera epidemics of 1856 (Rodríguez Galdo and Dopico, 1978 and 1981).

Eventually, after the phylloxera plagues, local grape varieties were replaced with American ones which were resistant to the insect. The application of sulfur was introduced to fight oidium and mildew and it is accounted for in our sources as a common expense in vineyard plantations during the 19th century. However, these increased costs of production were not favourable in a context of price decline, in which wine adulterations started to be common. In turn, this would also have an impact on exportations, thus resulting in the loss of both foreign and local markets, as well as in new price crisis[59].

This is the context where agrarian unionism originated. Towards the beginning of the 20th century, complex processes took place in Galicia led by the agrarian movement, which achieved land peasant ownership along with deep social, political, economic, and productive changes. This pattern extended through the whole country, and particularly in viticulture regions such as the Ribeiro, where migrant remittances and their progressive socio-political ideas contributed decisively to these transformations. But this analysis exceeds our research targets and chronology, and has already been widely studied (Villares, 1982; Fernández Prieto, 1992; Domínguez Castro, 1992; Núñez Seixas, 1998; Soutelo, 2001).

6.2.1. A vineyard monoculture

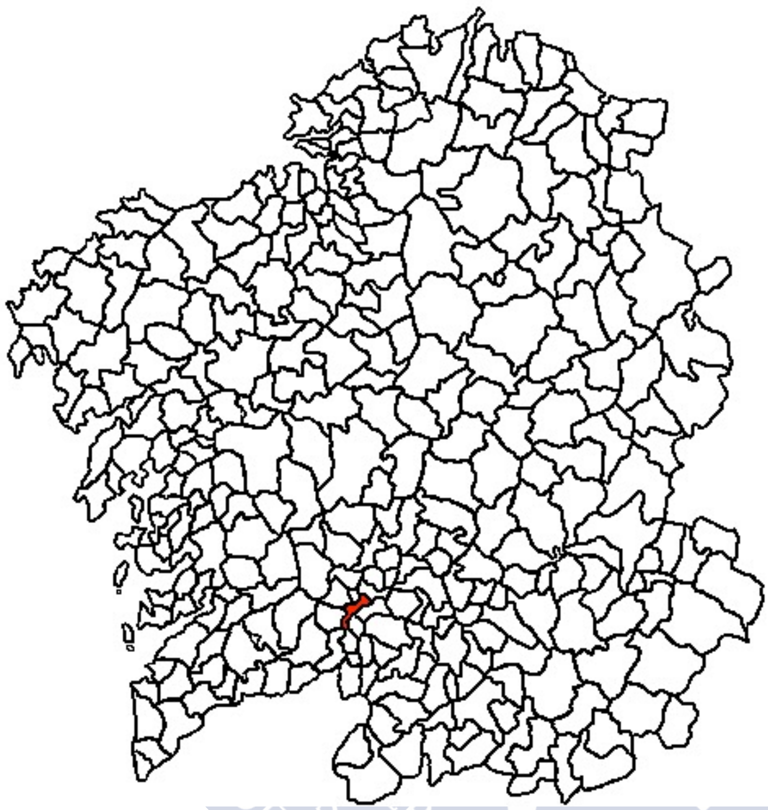
We have already mentioned that Ribadavia belongs to the terraced type of agricultural land organization of the Avia valley, one of the particular patterns that does not fit into the more general trends described by Bouhier (2001). This implies a high degree of land fragmentation, with scarce meadow surface, and very narrow and long fields which can comprehend a whole terrace or *socalco*. The region is also characterized by high population densities, which is at the same time connected with the process of land fragmentation, scarce livestock numbers, and a constrained cropland availability. Vineyards are the most common crop in the region, and they are mostly grown in *cepas* and not in *parras*. *Cepas* are tied to poles and prunned in such a way that they grow towards their sides and close to the ground. *Parras* are prunned to grow in height, thus forming vine arbours (Bouhier, 2001).

We have already described the main different types of documents in our research. Particular data on livestock, agrarian productions, and changes in land use and rotations are from Ensenada's Cadastre in the 18th century, and from *cartillas* in the 19th. The number of parishes that composed the municipality during the study period is uncertain but there are eight of them nowadays: Santo André de Camporredondo, Santiago de Esposende, San Cristovo de Regodeigón, San Domingos de Fóra de Ribadavia, San Domingos de Ribadavia, San Pedro de

[59] For more detail into this process of crisis see Huetz de Lemps (1968) and Domínguez Castro (1992 and 2001).

Sanín, San Paio de Ventosela and Santa María Madalena de Francelos, with a total surface of 25.2 square km[60].

Map 4. The municipality of Ribadavia within Galicia



Map source: http://fr.academic.ru/pictures/frwiki/83/Situacion_Ribadavia.PNG

According to Madoz's dictionary, parish composition in 1855 comprised thirteen parishes, including the four in which the village of Ribadavia had been divided, and other four parishes that were not mentioned in 1752 and which, nowadays, belong to different municipalities or parishes: San Miguel de Carballeda, A Grova, Santo Estevo de Novoa and Santa María de Vilar de Condes. Besides, Francelos had been aggregated to Santa María Madalena, which was one of those four urban parishes (Madoz, 1846-1850, vol XIII: p. 505). Currently, A Grova is part of Sanín.

Since the documents of Ensenada's Cadastre do not clarify the parish composition of Ribadavia at the time, a search was done for parishes and other singular villages in the website where the *Respuestas Generales* (General Replies) are hosted, the Portal of Archivos Españoles (PARES)[61]. Only three of Ribadavia's current parishes have complete information

[60] Information regarding parish composition and surface provided by the *Instituto Galego de Estatística*: http://www.ige.eu/igebdt/esq.jsp?paxina=002001&ruta=nomenclator/nomenclator.jsp and http://ige.eu/igebdt/selector.jsp?COD=77&paxina=001&c=0101001002, respectively.

[61] http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0

on rotations, surfaces and yields in Ensenada's Cadastre: Ribadavia, Camporredondo and Francelos. Other parishes came up as well in this search but their assessments were incomplete in terms of surface and yields and were discarded. Sanín and Ventosela are both allocated to a different jurisdiction, Santo Estevo de Novoa, but also not given surface data. Esposende is mentioned as belonging to Ribadavia but is not assigned with surface either. Besides, Ensenada's Cadastre falls into a lot of territorial contradictions and mistakes for the territory that would ultimately form the province of Ourense, where Ribadavia belongs. This is outstanding when compared to the rest of the terrritory, that would later compose the provinces of Lugo, A Coruña and Pontevedra, with more accurate data (Gallego, 1985), and explains why data are so incomplete and difficult to locate. For this reason, we also obtained the so-called *Comprobaciones* from Simancas archive in Valladolid, elaborated about ten years later (1761-1764) in order to verify and update the previous registries of land property and yields. However, these verifications of Ensenada's Cadastre for Ribadavia are equally incomplete and reproduce mostly all data from the documents of 1752. Again, Ribadavia, Camporredondo, and Francelos are the only parishes with detailed information regarding surface and yields. Other parishes are mentioned as part of the same jurisdiction but their corresponding data are not consigned. However, the document from 1764 seems more accurate, and therefore provided with most of the quantitative data for our analysis. Declared surface for the parish of Ribadavia increases in this new document when compared with the one from 1752, thus going from 259.71 ha to 403.37 ha. Yields do not show relevant differences. However, there are also ambiguities since 0.06 ha of pasture are declared in 1752, which are not mentioned in 1764. We cannot know whether pastureland had disappeared (which is quite unlike) or it was simply not cadastred because of its short surface (most likely). The parish of Sanín is said to have pastureland among its rotations in 1764 but since it is not assigned with surface we cannot register it either, although we take this into account as important qualitative data. Either way, pastureland did not occupy a big proportion of surface in a region with reduced livestock head and a wine-centered economy which excludes and reduces other uses to the minimum (Saavedra, 1992c).

Within the three parishes with complete information in the *Respuestas Generales* from Ensenada's Cadastre (1752) and its correspoding *Comprobaciones* (1764) we discarded Camporredondo in order to simplify the analysis because of its different crop system, which included wheat and/or barley in its main cereal rotations. And, even when at the time Francelos was not yet part of Ribadavia, we have included it because it would later become part of the municipality. Besides, there is some missing data for the parish of Francelos which have been completed with those of Ribadavia: yields for linen seed, distribution of irrigated and non-irrigated crops, yields for chestnut groves, and woodland and shrubland distribution according to the quality of the soil as in Ribadavia, where first quality soils are dedicated to both shrub and wood whereas second and third ones produce only shrub.

As we have just explained, data are disaggregated in parishes in Ensenada's Cadastre but for 1860s and 1880s information is offered at municipal scale by including all parishes but

without specifying them. This introduces problems for scalability and comparison between 1760s and the 19th century, which is only possible in qualitative terms. In the 19th century, rotations seem more uniform according to the cadastral documents. There must have been differences within the different parishes and *aldeas* too but this has not been registered in the sources.
On the other hand, our *cartilla* from 1860 and previous statistical records from 1859 (AHPOu, Facenda, C459/02) collect surface information and yields at municipal scale but the *cartilla* from 1888 does not include surface. Therefore, we have used land use distribution from 1860 as well for 1888, which has been disaggregated according to soil qualities because yields do show these differences. Besides, sources from 1888 mention that vineyard is still cultivated in two different rotations, *cepas* and *parras*, but surface data from 1860 do not disaggregate their surfaces. Therefore, we assigned vineyard surface from this year to *cepas,* the rotation with lower yields. The reason for this decision is that Ensenada's Cadastre assigns a much bigger surface to *cepas*, which occupy only 30 ha before the 198 ha of *parras*. We assume that this proportion was kept through time, thus being the most productive rotation also more labor requiring and therefore assigned with a smaller surface. Besides, with the plagues that affected vineyards in the second half of the 19th century we also assume that yields might have been lower than usual.

In the following sections, we will try to explain how the vineyard monoculture conditioned the process of socio-ecological transition in Ribadavia from the very first stages, since capital permeated the social relationships within the municipality much sooner than, for instance, in Fonsagrada. The intensive and widespread vine cropping dimisished land availability for other uses such as food production or nutrient stock. Thus the nutrient cycle soon became dependent on external importations of fertilizer, but also foodstuff had to be bought outside of the municipality for both humans and livestock.

6.2.2. Population in Ribadavia

Vineyard specialization conditioned not only the socioeconomic features and the habitat of the Ribeiro, but also its demography (Huetz de Lemps, 1967; Saavedra, 1992c; Fernández González and Sandoval Verea, 2011). In the following sections we include previous research on the demography of the region and population data for the study period and the 20th century, when the territory of Galicia follows a very distinctive pattern when compared with the general Spanish trend.

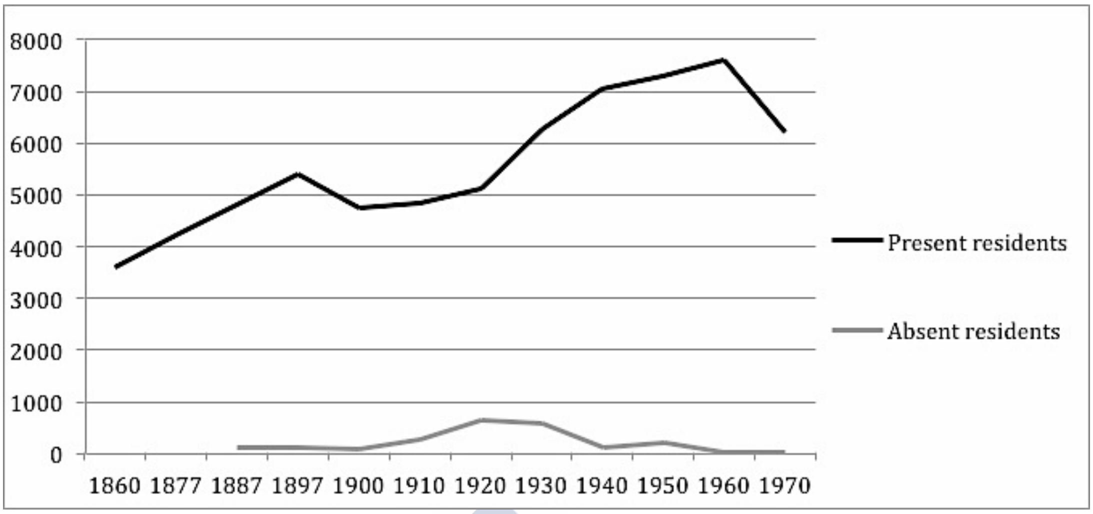
Saavedra studied viticulture economies in the Ancien Regime*,* and concluded that parishes within the Ribeiro of Avia where monoculture is more advanced do not show abrupt variations in the number of neighbors in the long term. On the other hand, parishes with more cereal crops, namely maize, show more dynamic populations. In monoculture parishes, which is the case in most of Ribadavia, demography is tightly linked with wine production, thus population remains mostly stagnant during the 18th century in the Ribeiro, with a relative recovery after 1820s. Demography and wine production were more or less codependent, thus the most remarkable population growth occurred in the Riberio region between the end of the 16th and beginning of the 17th centuries, the golden age of wine production and trade (Saavedra, 1992c: 157-162).

According to Rodríguez Rodríguez, the Ribeiro of Avia, where Ribadavia is located, has a considerably mature demographic model in the Ancien Regime, with a high index of life expentancy and a low proportion of young population which is, however, able to guarantee its reproduction and actually achieves remarkable population increases. Between 1750s and 1825/26, the region increased its population in a 45-50%. The demographic model is self-regulated by means of delaying the age of marriage, especially for women, with high female celibacy rates, and by migration. According to the author, the Ribeiro is unable to absorb all the population excess that it produces, and the demographic model shows signs of exhaustion already by 1820/30s (Rodríguez Rodríguez, 1999).

Fernández Rodríguez (1992a) points out that migration would also be relevant in the late 19th century and, especially, in the first third of the 20th. It is important to notice that this is a region where nuclear family is predominant, thus having an average of 3.9 people per household in several parishes of Ribadavia. Partially, this is due to a relatively high infant mortality, which is related with a poorly varied diet in which meat and milk, but also cereal, are not abundant due to the vineyard especialization of the region (Saavedra, 1992c: 154-157; Rodríguez Rodríguez, 1999).

Our demographic data confirm a high -and increasing- population density in the second half of the 19th century: 158.6 inhabitants per km^2 in 1860: 186.6 in 1877; 212.5 in 1887, and 238.8 in 1897. This high demographic pressure on the territory has also been interpretated as high work force availability, which resulted in cheap wages (Domínguez Castro, 1992). In fact, according to Rodríguez Rodríguez (1999), the Ribeiro of Avia had an long history of intense human occupation and high population densities were the norm already in the Ancien Regime, which was a shared characteristic in viticulture regions.

Graph 1. Ribadavia. Changes in resident population, 1857-1970



Source: population censuses from INEbase for the years 1857, 1860, 1877, 1887, 1897, 1900, 1910, 1920, 1930, 1940, 1950, 1960, 1970 (http://www.ine.es/inebaseweb/libros.do?tntp=71807)[62].

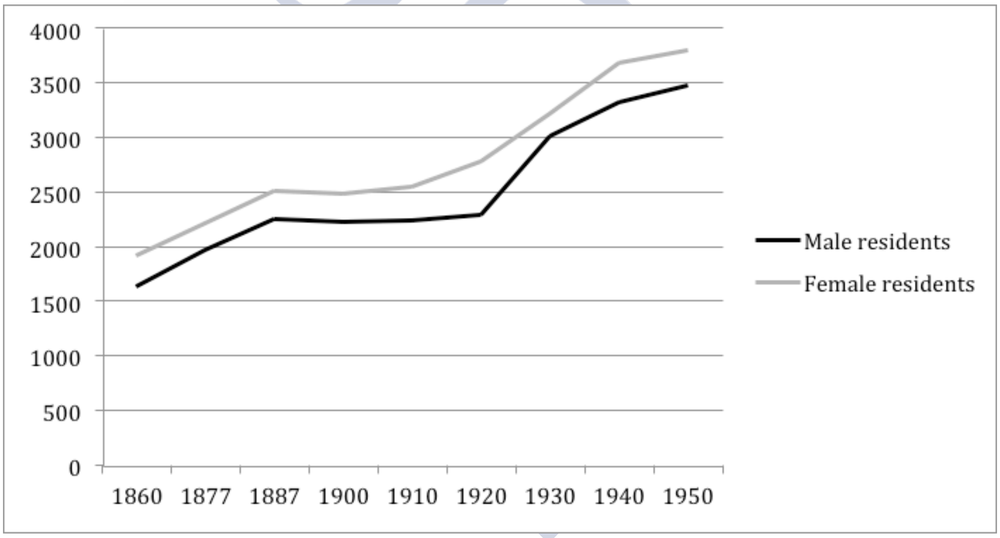
The graph shows an important increase in population between 1857-1900, with a migration trend that matches population losses, especially in the first third of the 20th century and until the 1940s. The evolution in the 20th century is coherent with what has been established regarding the general depopulation and demographic stagnation generally across rural Galicia and, particularly, in the inner provinces of Lugo and Ourense. Such pattern has been connected with a process of deagrarianization, the continued loss of relative weight of agricultural employment, and the absence of other economic activities in rural areas (López Iglesias, 2000). This encouraged the concentration in the Atlantic provinces and, namely, in urban areas, which have younger population than rural ones (Aldrey Vázquez et al., 2000). Population in Galicia increased a 37% between 1900 and 1990, whereas the Spanish average more than duplicated in the same period with an increase of the 111%. The economic inequalities translated in differenciated demographic patterns, which were also evident within the Galician provinces. In fact, between 1900 and 1990, the inner provinces lost population whereas the Atlantic ones increased it. Besides, there is also a general ageing process that also affects rural and inner regions the most, and is connected with the historical phenomenon of migration (Beiras and López, 1999).

Fernández Rodríguez studied migration in the municipality of Ribadavia between 1840-1920, and established three major periods according to the proportion of absent young males detected through military recruitment documents. Between 1855 and 1887 migration is

[62] In this case, we have not accounted for population in 1750/60s because data are too incomplete. The parish of Ribadavia has 402 ecclesiastics but the number of neighbors is not recorded. In Francelos there are 55 secular "neighbors"[62] but ecclesiastics are not specified. This means that any approach we attempted to do with these data would be too far from reality.

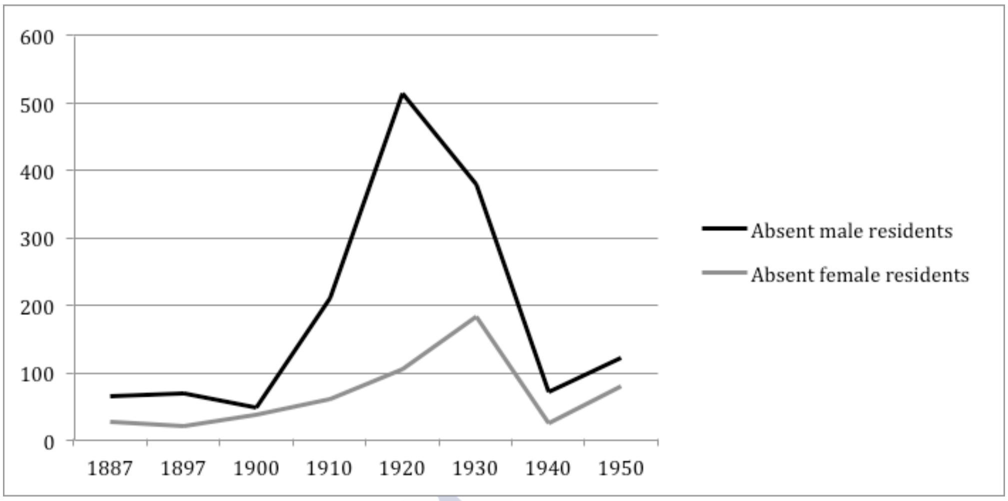
intense, but it would still increase between 1887 and 1920. After this moment, average annual demographic growth indicates a deceleration in the process. According to this author, migration in the 19th century is related with structural factors such as the land tenure system, peasant indebtedness, seasonal "unemployment", land fragmentation due to an egalitarian inheritance system (*"partixas"*), and low land productivity. Thus economic motivations are the main reason for migrating. Due to the fact that economy in the Ribeiro, and particularly in Ribadavia, was based on vine monoculture, harvest losses meant important economic impacts. High population density on a very fragmented land tenure system was the main reason why many young men, and eventually women too, got expelled from Ribadavia, especially after 1830 according to Fernández Rodríguez (1992a) and Rodríguez Rodríguez (1999). The following graphs confirm this deficit of men and an imbalanced sex ratio. The first one shows the evolution of resident population according to sex between 1857 and 1950, and the second informs on the different migrating patterns between men and women during the late 19th century and first half of the 20th. Chronology is determined by data availability in the censuses, which is not uniform.

Graph 2. Ribadavia. Changes in female and male resident population, 1857-1950



Source: population censuses from INEbase for the years 1857, 1860, 1877, 1887, 1900, 1910, 1920, 1930, 1940, 1950, 1960, 1970 (http://www.ine.es/inebaseweb/libros.do?tntp=71807). In this graph, data for the year 1897 were supressed for showing an abnormal evolution in male resident population, which would be of 2,864. In the same year, female residents reach only 2,508. This is likely indicating a problem with the source.

Graph 3. Ribadavia. Male and female absent population, 1887-1950



Source: population censuses from INEbase for the years 1857, 1860, 1877, 1887, 1897, 1900, 1910, 1920, 1930, 1940, 1950, 1960, 1970 (http://www.ine.es/inebaseweb/libros.do?tntp=71807).

Migration was especially numerous after the irruption of oidium and other plagues in the Ribeiro during the period 1853-1862. As a result, demographic growth slowed down. There was a period of recovery after 1864-65, when the oidium crisis was over and migration decreased. After 1884 the mildew plague would soon trigger new crisis, as phylloxera would do again after 1893. Many peasants lost their way of life and migration was the only solution for many Ribadavians, thus resulting in negative demographic growth of 0.07% between 1887-1900. Fernández Rodríguez and Soutelo remark the risks of monoculture, which were evident for the Ribadavia of the second half of the 19th century already (Fernández Rodríguez, 1992a; Soutelo, 2001). On the other hand, such cash crop economy was able to produce and sustain high population densities and, when required, to pay for travel expenses to America.

Fernández Rodríguez also studied the evolution of migration in the neighbor mountainious region of Melón. The pattern described shows a growth in population mainly between 1653-1756/62, a decrease between 1756/62 and 1877, and a slight recovery after 1877 and until 1920. The period when most people leave Melón corresponds with the subsistence crisis of the last third of the 18th century and lasted until 1850 (Fernández Rodríguez, 1992b). Once the crisis of vineyard of the second half of the 19th century are over, Melón starts loosing as much population as before. Being Ribadavia and other places in the Ribeiro a common destination for people from Melón, this certainly refers to a complementarity between the economies and societies of both municipalities: Ribadavia in the valley, Melón on the mountain. The region of Ribeiro offered wage labor possibilities for the inhabitants of the surrounding mountains due to the high labor demand of viticulture in particular moments of the agricultural calendar.

6.2.3. Changes in land use and crop rotations

Most of the land was under *foro* contracts between peasants and nobility. Ecclesiastics were slowly withdrawn from land control after the confiscation laws from the liberal reforms that took place after the 1830s. Low nobility, called *fidalguía*, took advantage of this confiscation process to secure and strenghten their control over land in the Ribeiro, thus abandoning their main role as intermediaries in rent and revenue income. The process also allowed bourgeois sectors to access land and conform a sort of agrarian bourgoisie. All of them had interest in the commercialization of wine. Peasants, on the other hand, only see their control over land progressively granted at the beginning of the 20th. This social class depended on landlords for their main income as labourers in the fields. Such tasks were always wine related, as the economy in Ribadavia functioned around this sector. Cereal crops seldom required labourers (Domínguez Castro, 1992).

As explained before, the *Comprobaciones* of Ensenada's Cadastre and *cartillas* from the 19th century provided with quantitative and qualitative information on land uses, yields and crop rotations, as well as livestock numbers. Ensenada's Cadastre is incomplete, since not all parishes have surface nor yields data. Besides, their reliability regarding surface declarations is quite biased for the parish of Ribadavia according to López-Pardo (1999), who concludes that the main concealment is also in *monte* areas. Regarding data for the 19th century, the *cartilla* from 1888 does not contain surface data, but other statistical documents from the same decade reproduce those of 1860. This probably indicates that cropland had already reached its maximum extent. We have used the same surface distribution available for 1860 in both years.

On the other hand, information for 1764 is still more incomplete since only two parishes are reflected in the final data. Total surface cadastred in this year for both parishes of Ribadavia and Francelos reaches 403.37 ha. We have used these data for comparison in terms of distribution of agrarian surface, but not in absolute terms since most of the municipality is not cadastred (current surface of the whole municipality is 25.2 km^2). According to Saavedra (2007), cadastred surface in the province of Ourense in 1752 is usually about the 21.6% of total current surface. From this percentage, 13.5% would correspond to cropland surface.

All in all, our most complete year is 1860, which is analyzed with more detail. For a more structured description of the agroecosystem, we use the following categories, which correspond with the main crop rotations in Ribadavia:

- Vegetable gardens
- Cereal rotations
- Vineyard
- Chestnut groves (*soutos*)
- *Monte*

Besides, according to documents that contained information for the elaboration of the *cartilla* of 1888[63], there were also pastureland and fertilized meadows. Ensenada's Cadastre from 1752 mentioned meadows as well. However, we do not have any surface data for any of these rotations. In the *cartilla*, meadows are said to be irrigated, and fertilized with manure. A document from 1875[64] specifies that artificial meadows do not exist in the municipality, but there are "*prados naturales*" (natural meadows), which only produce in autumn and winter. Fodder is then cut and dried in July. Neither yields nor surface are specified.

As mentioned before, the cash crop monoculture of vines conditioned the distribution of land uses in the region, reducing most of them to the minimum in order to spread vineyard as much as possible within the very constrained limits of the valley. This implies a reduced livestock head as well, which was fed on crops and pasture from *monte* areas.

In the following graphs we can see cropland distribution in Ribadavia in 1764 and 1860. Data are not comparable in absolute terms because, as mentioned before, surface from 1764 refers only to two parishes whereas in 1860 the whole municipality is included. However, distribution in relative terms does not change much. We have excluded *monte* in this comparison because data are misleading, either because of its scarcity in the parishes of Ribadavia and Francelos, the more urban ones, or due to the concealment of its surface in Ensenada's cadastre, where it represents only the 23% of total declared surface. In 1860, it amounts to the 56% of the total agrarian surface of the municipality. Both percentages are considerably low but match, however, the distinctive pattern of *monte* appropriation in those regions with an earlier process of agricultural intensification and higher land productivity (Bouhier, 2001; Pérez García, 2000; Soto, 2006).

Vegetable gardens occupy the 2% of cropland surface in the parishes of Francelos and Ribadavia in 1764, and the 3% in 1860 at municipal scale. And the same happens with vineyard, that remains in very similar relative percentages: 76% of the total of cropped surface in 1764, and 71% in 1860. The monoculture vocation is clear and, in fact, this crop reaches an average of the 80% of total cropland in the Ribeiro of Avia (López-Pardo, 1999). Apart from vegetable gardens, cereal and chestnut rotations are the main foodstuff suppliers. Their relative distribution is not very much altered either. Cereal rotations occupy the 19% of the cultivated surface in the two parishes in 1764, and the 24% in 1860. Finally, chestnuts occupy the 3% and 2%, respectively.

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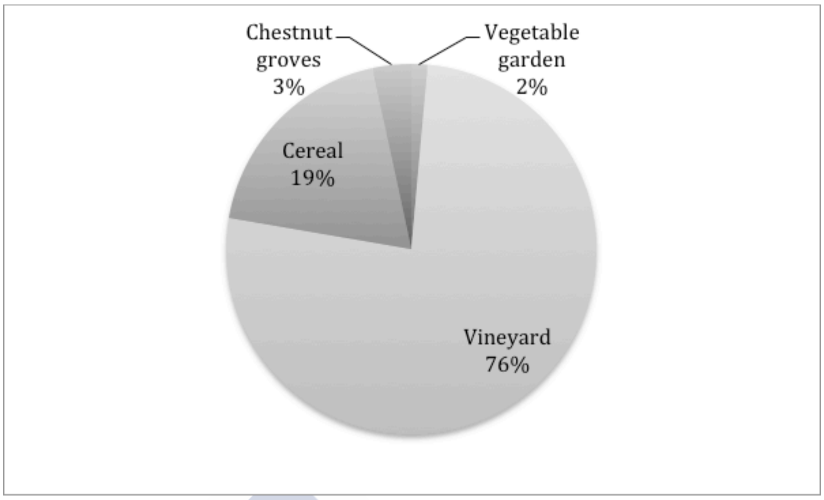
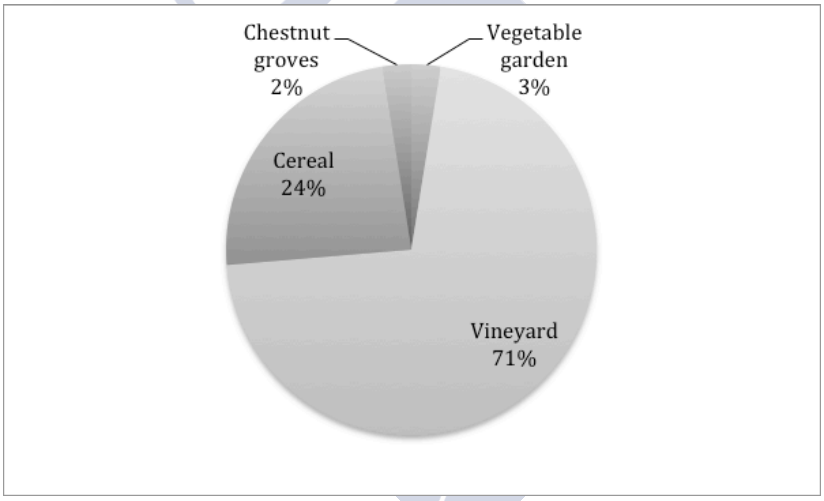
[63] "*Datos para la cartilla evaluatoria*", AHPOu, Facenda, C459-05.
[64] "*Interrogatorio para reunir datos a fin de redactar una memoria sobre el estado de la agricultura en esta provincia de Ourense*", August 27th, 1875, AHPOu, Facenda, C459-04.

Graph 4. Ribadavia. Cropland distribution in 1764 (parishes of Francelos and Ribadavia, %)



Source: Ensenada's Cadastre, *Comprobaciones* of Ribadavia, 1764, AGS, DGR, 1RE, 1129_01.

Graph 5. Ribadavia. Cropland distribution in 1860 (municipality of Ribadavia, %)



Source: *cartilla* from Ribadavia, 1860, AHPOu, Facenda, C459/03.

Chart 1. Ribadavia. Distribution of agrarian surface in 1860 (ha)

	Surface
Vegetable gardens	22.76
Vineyard	637.67
Cereal	213.68
Chestnut groves	22.35
Monte	1,147.77
Total	**2,044.23**

Source: *cartilla* from Ribadavia, 1860, AHPOu, Facenda, C459/03.

About 500 ha are missing in this land registry from 1860 if compared with the current surface of the municipality of Ribadavia. We cannot know what the exact surface was at the time, but we have used the current one as a proxy reference. Besides, the previous comparison in land distribution between 1764 and 1860 validates our data in relative terms since vine cultivation in the region had reached its peak already in the Middle Ages, and land distribution remains more or less in similar percentages in both moments of the 19th century. As suggested by Saavedra (1992c), vineyard could have not expanded much after the end of the 18th century, which means that, even if surface is not accurate in absolute terms, data are still coherent regarding the previous analysis by Huetz de Lemps (1967). However, according to the interrogatory from 1887 titled *La crisis agrícola y pecuaria*, vineyard surface in 1888 had increased considerably in the previous ten years in order to palliate the effects of the *oidium* crisis, which had been present since 1858 and remained untreated until 1868, when sulfur was distributed (Ministerio de Fomento, 1887, vol. II: 368). But this is not contradictory with the previous fact since there had been more variations in vineyard surface according to pest related crisis.

On the other hand, in his history of Ribadavia, first published in 1920, Eiján refers to a document from 1838 by the Council of Ribadavia[65], which also speaks about the monoculture situation in Ribadavia and, generally, in the whole region of the Ribeiro, and explicitely mentions the lack of *esquilmos* or shrubs that are used as fertilizers (Eiján, 1981). The cash crop monoculture seems to have led to an imbalanced land use in Ribadavia, which was mostly evident when the wine harvest failed and the scarce production of local food became more evident.

Vegetable gardens

Our data for yields are from the *cartilla* from 1888, which consigns average productions in kg/ha. We present these yields in the following chart, including residues as well, which have been estimated according to converters in Guzmán et al. (2014).

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[65] *Libro de acuerdos* of the Council of Ribadavia, minutes from March 8th 1838, as cited by the author (Eiján, 1981: 595-596).

Chart 2. Ribadavia. Yields in vegetable gardens in 1888 (kg/ha, dry matter)

	Crop	Crop and residues
Lettuce	102.54	217.53
Potatoes	727.22	996.32
Green Beens	87.14	539.96
Cabbage	168.13	506.02
Onions	89.12	159.25
Tomatoes	15.40	45.75
Pepper	7.10	10.53
DE t/year	27.24	56.35
Total DE (t/ha)	**1.2**	**2.48**

Source: *cartilla* of Ribadavia, 1888, AHPOu, Facenda, C459/10. Residue conversion factors from Guzmán et al., 2014 (standard deviation).

According to the expansion patterns of new crops (from the S.W. coast towards the North and inner regions through river valleys), we are not certain whether potatoes and beans were cultivated in Ribadavia as far back as 1764, but they are not mentioned in Ensenada's Cadastre. Rodríguez Galdo and Dopico collect data related to potato expansion in a map, according to which the *Partido Judicial*[66] of Ribadavia would have potatoes in 21 to 40% of its parishes towards 1826-29. The crop would expand considerably after this moment, thus having a 50% more of parishes cultivating potatoes within Ribadavia in 1840s, as collected in Madoz's Dictionary[67]. Unfortunately, there are not accurate informations on this expansion, which was limited by technical constraints such as irrigation and manure scarcity. According to Rodríguez Galdo and Dopico (1981), potatoes would only be planted in Ribadavia in temperate summers but not in very hot years when draught would stop them from growing. Besides, these authors have observed that the expansion of potatoes was more difficult through regions with a specialization in vineyard cultivation.

However, considering the reduced garden surface at the time and the fact that specific yields are not available for either 1764 nor 1860, we have applied the yields from 1888 to all years and analyzed results as a mere illustration of a trend in domestic extraction, as shown in the following chart.

[66] Judicial District refers to a territorial unit that groups municipalities under the same judicial jurisdiction.
[67] "*Productos: trigo, maíz, patatas, hortaliza, legumbres, lino, frutas y mucho vino tinto y blanco"* (Madoz, 1846-1850, Vol. XIII: p. 505).

Chart 3. Ribadavia. Land productivity in vegetable gardens: 1764, 1860 and 1888 (dry matter, residues included)

	Ha	DE (t/year)	DE (t/ha)
1764*	4.22	14.30	3.39
1860	22.76	56.35	2.48
1888	22.76	56.35	2.48

Source: Ensenada's Cadastre, *Comprobaciones,* 1764, AGS, DGR, 1RE, 1129_01; *Interrogatorio sobre la producción agrícola* in Ribadavia, 1859, AHPOu, Facenda, C459/01; and *cartilla* of Ribadavia, 1888, AHPOu, Facenda, C459/10. Residue conversion factors are from Guzmán et al. (2014).

*If we had we excluded potatoes in 1764, yields in vegetable garden would be of 2.34 t/ha (dry matter), that is to say a total annual Domestic Extraction of 9.89 t instead of 14.30 t.

Yields are disaggregated according to soil qualities in the *cartilla* from 1888. We have used these data in order to estimate garden production in 1764 and 1860 according to surface distribution. Since surface from 1860 has been extrapolated to 1888, extractions remain the same for both years. In 1764 vegetables were only cultivated in first and second quality soils, therefore yields are slightly higher. Yields of green beens are available in both land registries from 1860 and 1888. For 1860 a conversion factor from *arrobas*[68] to kg has been applied, showing yields of 862, 575 and 503 kg/ha (fresh matter), according to soil quality. In 1888, a statistical document on prices assigns green beens with yields of 860, 840 and 800 kg/ha (fresh matter). However we have used the yields proceeding from the *cartilla* from 1860 for all three periods in order to maintain the inner coherence of the data.

This intensive cropping in Ribadavia would certainly increase the demand of manure and, very likely, fertility problems in the soil appeared as well. However, according to Domínguez Castro (1992), industrial fertilizers are not generally applied in gardens in this region until 1930s, and are usually related with the expansion of potatoes, which are not massively consumed before the second half of the 19th century.

Besides, some vegetables were cultivated between the lines of vines. This fact is confirmed by our sources, both cartillas from 1860 and 1888, but crops are not specified. Domínguez Castro (1992) mentions potatoes but clarifies that this crop association was more common among poor peasants who could not afford to dedicate land exclusively to vegetables.

We cannot describe intensification in terms of land productivity or crop association in vegetable gardens because it is impossible to know whether there was an increase in production per surface unit with the available sources, nor which particular crops were cultivated. However, the possibility of intensification in this rotation seems very likely as well considering the whole picture of the agroecosystem and the increasing demographic pressure all through the study period.

[68] Traditional weight measure.

If compared with garden productivity in Fonsagrada in the decade of 1880s, which reaches 0.84 t/ha (dry matter) before the 2.48 t/ha in Ribadavia, both data are coherent with the two main patterns of intensification described by historiography, as explained before.

Cereal rotations

There are several cereal crops in Ribadavia, with a higher diversity of crops in the mid-18th century than later in the 19th. We hypothesize that this is not only due to the intensification process and its prioritization of maize regarding its higher yields, but also to problems with the sources. In the 19th century, statistics operate at municipal scale, not at parish level, which could have resulted in a simplification of reality. In fact, wheat is mentioned in documents of the 1880s but not assigned with surface. The annual rye rotation appears all through the period, wheat is only detailed in 1860, and maize is mentioned in 1760s in association with rye or rye/linen, and later on in the 19th century in a specific rotation with beans and fodder, which occupies far more surface than rye in any of the moments. In 1764 there are two rotations that are not mentioned any longer in the sources as the century moves on and maize takes over land and replaces crops in pre-existing rotations. One is an irrigated biannual rotation without fallow, which includes linen/maize in the first year, and rye/maize in the second. The other is an irrigated annual rotation of rye and maize. Linen is one of the crops that is progressively displaced through the 19th century. However it is still mentioned in the interrogatory from 1857[69], which informs that linen is sowed in the month of March in the same land in which maize is planted, thus harvesting both products at the same time. This document also mentions the cultivation of beans and sweet peas. The simplification in rotations and the progressive disappearance of millet and wheat along with the expansion of maize have also been concluded for this particular case by García Acuña (1995), who studied *foro* contracts in the county of Ribadavia in the 16th, 17th and 18th centuries. Besides, as it generally occurred in Galicia, linen textil products started to be replaced by imported cotton manufactures, mainly from England since the beginning of the century (also through contraband), and from Catalonia as well after the 1870s. Besides, the linen that was used by rural industry in Galicia started to be increasingly imported from the Baltic regions after 1800, which contributed to its supression from the fields. Changes in customs policies affected imports of these raw materials and, eventually, the loss of the Spanish colonial market, among other factors, had a considerable impact on the crisis of this rural industry, which had gone into obvious decline after the middle of the 19th century (Carmona, 1990).

In 1764, rotations are described as being adapted to each specific soil quality, thus best soils have the most intensive cropping, with up to two harvests a year within a biannual rotation,

[69] *"Interrogatorio sobre la producción agrícola con aplicación a las subsistencias y a la industria"*, 1857, AHPOu, Facenda, C459/04.

whereas poor soils are cultivated in annual rotations with just one harvest per year. In 1860 and 1888, all rotations are cultivated in all three types of soil qualities. The intensity of cropping in this region is very remarkable, especially when compared to the Mediterranean Spain, where the introduction of mixed farming was very constrained by water and nutrient scarcity (Fernández Prieto and Soto, 2010; González de Molina, 2010a).

The following charts collect data on land productivity of cereal rotations and their changes through the study period according to the quality of the soil (first, second or third) and whether they are irrigated or not. The first one details all the different rotations that sources describe for 1764, with their surfaces and Domestic Extraction in t/ha of dry matter.

Chart 4. Ribadavia. Cereal rotations in 1764 (parishes of Ribadavia and Francelos): surface and productivity (dry matter, by-products included)

	Soil 1 (irrigated)		Soil 2 (irrigated)	Soil 3 (non-irrigated)
	1st year	2nd year	Annual rotation	Annual rotation
Summer crop	Maize	Maize	Maize	
Winter crop	Linen	Rye	Rye	Rye
Surface (ha)	35.99		16.11	4.85
DE (t/ha)	4.51		3.34	1.01

Source: Ensenada's Cadastre, *Comprobaciones*, AGS, DGR, 1RE, 1129_01.

For the estimation of average yields in the irrigated biannual rotation of linen/maize and rye/maize without fallow, surface has been divided by two. This rotation only takes place in first quality soils with a total of 35.99 ha and an average productivity of 4,511 kg/ha, which result in a total Domestic Extraction of 162.37 t/year (dry matter). In the first year, linen yields 465.62 kg/ha of fibre and 209.86 kg/ha of grain. The source refers that grain yields in a short proportion and needs to be imported for sowing it back again. After linen, in the first year, maize is planted, which yields 1,260.79 kg/ha of grain and 2,061.74 kg/ha of straw. In the second year, rye yields 1,081.42 kg/ha of grain and 2,281.35 kg/ha of straw, and maize yields 630.40 kg/ha of grain and 1,030.87 kg/ha of straw.

The irrigated annual maize/rye rotation without fallow is only cultivated in second quality soils, with 16.11 ha, average productivity of 3.34 t/ha, and a total Domestic Extraction of 53.85 t/year. Rye yields 540.70 kg/ha of grain and 1,140.68 kg/ha of straw, and maize 630.40 kg/ha of grain and 1,030.87 kg/ha of straw. These two first rotations progressively turn into an annual one which combines maize, beans, and fodder in the 19th century. The introduction of leguminous crops had been previously connected with increases in land productivity, both within the historiography on English agriculture (Chorley, 1981; Allen, 2004), and within research on Galician agrarian history (Bouhier, 2001; Soto, 2006). The cultivation of legumes would result in a progressive nitrogen accumulation in the soil, which would lead to an increase in land productivity in the long term. Chorley (1981) even denies that manure were so relevant in the process of agricultural intensification due to nitrogen losses in the process of production, but this must have been different in our case, where manure was elaborated with a leguminous plant with a high content in nitrogen (Iglesias Pérez, 1985). Definitely, the author concludes that changes in the pattern of cropping such as the introduction of fallow crops (namely potatoes), were only possible by means of an increase in nitrogen availability, which had been previously supplied by legumes.

According to Bouhier, maize is never cultivated by itself, but along with beans and even cabbages on the sides of the fields. Once maize is harvested, or even before in most of the cases, fodder is sowed between the rows of maize, thus having two harvests a year (Bouhier, 2001). On the other hand, Bouhier (2001) and Soto (2006) have remarked the role of fodder as foodstuff provider for livestock, which played an essential role in manure production all through the intensification process, thus strengthening the integration of *monte,* cropland and animal husbandry. The pattern of maize introduction in Galicia through the 17th and 19th centuries goes from South to North and from the coast to the inner regions, mainly along the river valleys. Along with its introduction, other crops progressively disappear, namely linen and, especially millet which, having a similar cycle to the new crop, marked the geographical pattern of expansion for maize, being more common along the Atlantic regions than in the inner ones (Saavedra, 1990). In the South Atlantic coast, maize is associated with fodder in a very intensive rotation that supplies foodstuff for both humans and livestock (Bouhier, 2001). The same type of crop association can be found in Ribadavia, where millet had been the main cereal before the introduction of maize. Such pattern has been generally described in regions with a vine spezialization, where the new crop mitigated the impact of wine crisis (Saavedra, 1990). The following chart reflects the above-mentioned changes in crop association and its corresponding productivity. In the estimates for 1860 and 1888 we have used average yields of all three soil classes, which have been weighted by surface.

Chart 5. Ribadavia. Introduction of the maize-fodder rotation: changes in crop associations, surface (ha), and land productivity in 1764, 1860, and 1888 (dry matter, by-products included)

	1764		**1860**	**1888**
	1st year	2nd year	1st year (irrigated)	1st year (irrigated)
Summer crop	Maize	Maize	Maize and beans	Maize and beans
Winter crop	Linen	Rye	Green fodder	Green fodder
Surface (ha)	35.99		163.61	163.61
DE (t/ha)	4.51		8.31	7.58

Source: Ensenada's Cadastre, *Comprobaciones*, AGS, DGR, 1RE, 1129_01; *cartillas* of Ribadavia from 1860 and 1888: AHPOu, Facenda, C459/03 and C459/06, respectively.

Surface changes cannot be properly assessed since surface in 1764, as we have already explained, corresponds only to two parishes, whereas data for the rest of the period refer to the whole municipality, and specific land distribution data are not available for 1888. The most interesting fact within these changes is the increase of land productivity between 1764 and 1860, even when in the 19th century this rotation also takes place in second and third quality soils. Productivity in 1860 is almost twice of that from 1764. But according to the *cartilla* from 1888, land productivity would be lower than in the previous moment. This points out at a very likely exhaustion of the intensification process, especially considering that the maize/beans/fodder rotation, which is annual and irrigated, is the most intensive one and should be the first to show the symptoms. This rotation is mentioned in both *cartillas* from 1860 and 1888. Its surface is in both cases that of 1860, as indicated before, but its productivity decreases in 1888, going from 8.31 t/ha in 1860 to 7.58 t/ha (dry matter). Total domestic extraction achieves 1,359 t and 1,239 t annually, respectively. Since data for fodder yields are not available in the sources and we have used the same yields for both fodder and beans in 1860 and 1888, we cannot be more precise about the decrease in land productivity. However, the *cartillas* show this trend clearly with maize: its average grain yield decreases from 2,076.58 kg/ha to 1,797.46 kg/ha (dry matter). Yields of maize are specified in other document from 1888 called *Propuesta de tipos medios*[70] and are very similar to the ones we have taken from the *cartilla*, which makes our data more reliable since this other document did not have a fiscal purpose and is not so likely to be deceitful. However, we have not used such type of source because it is usually less complete than *cartillas* and lacks seriality. This document consists of a list of productions and their prices in the municipality. It collects yields of 33, 29 and 27 hl/ha for maize grain, according to soil quality, which is equal to 2,392, 2,102, and 1,957 kg/ha (fresh matter), respectively. The data in the *cartilla* from the same year, consigned in kg/ha, are very close to these numbers: 2,320; 2,030 and 1,885 kg/ha (fresh matter).

There might have been variations within the other crops when compared with yields from 1860 too but data are not available. Besides, yields for beans are only consigned in our land registry of 1888, and fodder ones have been taken from *La ganadería en España* (Ministerio de Agricultura, 1892). These same data for beans and fodder have been applied to both years, 1888 and 1860, and the estimation of average yields gives evidence of a decreasing trend in the productivity of this rotation.

The following chart collects data of the rye rotation, which is the only one that steadily increases its productivity through the period. Rye is cultivated in a non-irrigated annual rotation without fallow, and is maintained like this all through the period with an ongoing increase in land productivity which goes from 1 t/ha in 1764 to 3.27 t/ha in 1860, and 4.36 t/ha in 1888 (dry matter). This is certainly connected with its less intensive cropping, which must have still left some margin for further intensification while the more intensive rotations were already showing symptoms of exhaustion.

[70] AHPOu, Facenda, C459/8.

Chart 6. Ribadavia. Changes in the rye rotation: surface (ha) and land productivity in 1764, 1860, and 1888 (dry matter, by-products included)

	1764	1860	1888
Surface (ha)	4.85	16.16	16.16
DE (t/ha)	1.01	3.27	4.36

Source: Ensenada's Cadastre, *Comprobaciones*, AGS, DGR, 1RE, 1129_01; *cartillas* of Ribadavia from 1860 and 1888: AHPOu, Facenda, C459/03 and C459/06, respectively.

Wheat is only assigned with surface and yields in our sources from 1860. However, it could have been present in 1760s as well, and it is also mentioned in statistic documents from 1888, which allows to think that it was cultivated in that moment too, which is also likely regarding informations on wheat cultivation collected in a report from 1875 (CSAIC, 1981: 369) and its role as rent-paying cereal[71]. However, the interrogatory conducted in 1880s in order to investigate the causes of the general agricultural crisis in Spain informs that wheat was not cropped in Ribadavia. Its short proportion when compared with other crops must have led to its elimination from municipal sources, although we cannot know whether it was in fact cultivated or not. In 1860, its surface achieves 33.89 ha and yields 2,156 kg/ha of grain (dry matter). Land productivity in this rotation achieves 6.19 t/ha (dry matter), which result in a Domestic Extraction of 209.93 t/year (dry matter).

Taking all these rotations into account and their average productivity, we have estimated total average Domestic Extraction in cereal cropland for every year as shown in the following chart. These estimates are based on average annual yields which include by-products in order to assess land productivity. Wheat is not accounted for in estimates for 1888. Had we done so, Domestic Extraction would have increased to 1,520 t, but overal productivity would have decreased to 7.11 t/ha (dry matter).

Chart 7. Ribadavia. Average land productivity and Domestic Extraction in cereal rotations: 1764, 1860, 1888 (dry matter, by-products included)

	Surface (ha)	T/year	T/ha
1764	56.96	220.97	3.88
1860	213.68	1,622.28	7.59
1888	179.78	1,310.62	7.29

Source: Ensenada's Cadastre, *Comprobaciones*, AGS, DGR, 1RE, 1129_01; *cartillas* from 1860 and 1888: AHPOu, Facenda, C459/03 and C459/06, respectively.

[71] Because *foro* rents were usually payed in wheat, it was compulsory for peasants to grow some, and the initial landlords opposition to the introduction of new crops was not only due to the fact that they were not getting any rent from them, but also because the space for their taxated products was being reduced (Rodríguez Galdo and Dopico, 1981). Besides, rye was better adapted to acidic soils (Shiel, 2006b) and had a shorter cycle, which made it a safer harvest compared to wheat, and was therefore the main crop in the inner regions of Galicia, as we can see especially in the case of Fonsagrada (García Fernández, 1975; Saavedra, 1979).

The increase in productivity between 1764 and 1860 is, in fact, very remarkable. This can only be explained by the simplification of rotations and the introduction of a more yielding crop such as maize, which is conveniently associated with beans. Besides, fodder is also introduced in the rotation and allows to integrate livestock husbandry with agrarian practices. The intensification of mixed farming, which had started long ago in this region, is responsible for this huge increase of productivity. The interrogatory by the CSAIC[72] from the year 1875 informs on a very intensive cropping in the region in relation with a high population density. The report points out at this particular rotation of maize associated with legumes, done in the month of April, which allowed a turnip harvest during the winter as well once maize and beans were collected at the end of the summer (CSAIC, 1981). We have no references in our sources to turnips nor to the specific type of fodder cultivated in the maize rotation but, according to Bouhier, *ferraña*[73] was common in the region (Bouhier, 2001: 680). The statistic report on livestock for the year 1891 also mentions this type of fodder, which is said to be composed of rye or barley, and occasionally also oats (Ministerio de Agricultura, 1892, vol. IV: 208). On the other hand, even when these magnitudes give a good evidence of of a productivity increase, we must also notice that sources for 1760s might have been more distorted not just because only two parishes are included but also because Ensenada's Cadastre must have been more unreliable than the *cartillas* of the 19th century for this case study.

Finally, since changes in the associated crops in each rotation make it impossible to compare them through the period, we have also estimated productivity according to soil quality. The following graph shows changes in land productivity in cereal rotations according to this parameter. "Cereal 1" refers to first quality soils and includes the biannual rotation of maize/linen and maize/rye in 1764, irrigated maize in 1860 and 1888, and non-irrigated wheat in 1860. "Cereal 2" refers to second quality soils and includes rye/maize in 1764, maize and rye rotations in 1860 and 1888, and wheat in 1860. "Cereal 3" refers to productivity in third quality soils and includes only rye in all three moments. Rye in 1860 and 1888 is not cultivated in first quality soils, which were dedicated to the most intensive rotations.

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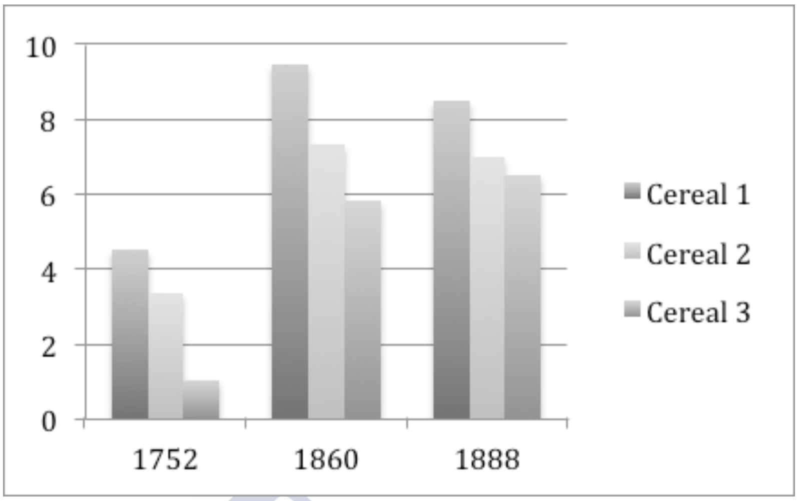
[72] Consejo Superior de Agricultura, Industria y Comercio, "Breve noticia sobre el estado actual de la agricultura y ganadería de la provincia de Orense", in *Revista Galega de Estudios Agrarios,* Servizo de Publicacións da Xunta de Galicia, 1981, n. 5, pp. 349-376.

[73] *Ferraña* is a type of fodder which is usually composed of rye (Soto, 2006: 88).

Graph 6. Ribadavia. Land productivity according to soil quality in cereal rotations in 1764, 1860, and 1888 (t/ha dry matter)



Source: Ensenada's Cadastre, *Comprobaciones*, AGS, DGR, 1RE, 1129_01; *cartillas* from 1860 and 1888: AHPOu, Facenda, C459/03 and C459/06, respectively.

This graph clearly shows that productivity increased remarkably between 1764 and 1860, but then decreased towards the end of the period in first and second quality soils, which were the most intensely cultivated so far. Rye was only cultivated in third quality soils in a annual rotation without fallow, which certainly allowed for a further intensification by 1888 and explains why this is the only rotation with an ongoing increase in its productivity. The general decreasing trend gives evidence of the exhaustion of the intensification process, although nutrient balances would be required in order to assess this issue.

Eventually, regarding fallow, there is a document from 1875[74] which states that this practice no longer exists in the municipality, and that some soils produce up to two harvests a year. However, there are also not mentions to fallow in Ensenada's Cadastre, and rotations as described in this section do not include fallow in any of the moments. This is very characteristic of the most intensely cultivated areas of Galicia within the coastal regions, and particularly along the southeast coast. Therefore, this particular case study can be considered as representative of that agricultural pattern as described by Pérez García (1982).

Vineyard

We have already mentioned that Ribadavia and most of the Ribeiro region are a vineyard monoculture already in the Middle Ages. According to our data, this rotation occupies the 71% of cultivated surface in the whole municipality in 1860, which is the 31% of the total

[74] "*Interrogatorio para reunir datos a fin de redactar una memoria sobre el estado de la agricultura en esta provincia de Ourense*", August 27th, 1875, AHPOu, Facenda, C459-04.

agroecosystem. The remaining percentages correspond to vegetable gardens and cereal rotations (12%), and *monte* (57%). Regarding the manure requirements of this monoculture and the intensive cropping of the region, this ratio of *monte*-cropland might not have been enough to replenish soil fertility in a satisfactory way. However, this is so far just a hypothesis which can only be validated with the construction of nutrient balances.

In this section we will show all available data to describe the agroecosystem, which will be useful for the future elaboration of balances. The following chart presents vineyard surface and yields. Let us remind that the surface datum for 1764 includes only two parishes, whereas the one for 1860 and 1888 refers to the whole municipality.

Chart 8. Ribadavia. Surface (ha) and land productivity in vineyard (dry matter): 1764, 1860, 1888

	Surface (ha)	(DE t/year)	DE (t/ha)
1764	229.37	398.97	1.74
1860	637.67	1,530.17	2.40
1888	637.67	1,548.44	2.43

Source: Ensenada's Cadastre, *Comprobaciones*, AGS, DGR, 1RE, 1129_01; *cartillas* from 1860 and 1888: AHPOu, Facenda, C459/03 and C459/06, respectively.

Dometic Extraction includes vine shoots and grapes. Again, specific surface data are not available for 1888, but yields are from the *cartilla* of this year. Domestic extraction in 1764 is an average datum obtained from two different values, which correspond to the rotations that we explained before: *parras* and *cepas*. Yields are higher in *parras* than in *cepas* (2,218 kg/ha before 1,665 kg/ha, dry matter)[75] because in the case of *cepas*, other crops and fodder were cultivated in between the lines of vines, which we have not been able to account for and had an impact on grape production too. Because *parras* give shade, intercropping was not possible and grape yields were therefore higher than in *cepas*. These differences are described in the draft of a *cartilla* from the beginning of 1880s[76].

Our *cartillas* from 1860 and 1888 do not specify both types of vineyard, and yields and surface are given as if it there was only one vineyard rotation, although the one from 1888 does mention the fact that there are other crops as well. However, a document from 1888[77] distinguishes both rotations again, showing higher yields in the case of *parras*, although without surface assignation. In order to mantain the coherence with data from 1860 we have only used the yields and surface specified in the *cartilla* from 1888. This is also the most conservative option. Had we disaggregated yields from *parras* and *cepas* in both years, domestic extraction would have been higher.

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[75] These yields include vine shoots and leaves.
[76] "*Datos para la cartilla evaluatoria*", AHPOu, Facenda, C459/05.
[77] *"Propuesta de tipos medios"*, 1888, AHPOu, Facenda, C459/08 and C455/11.

Our data from 1764 for Ribadavia show average yields of 14.48 hl/ha of wine in *cepas*[78] (which occupy 198.53 ha), and 26.32 hl/ha for *parras*[79] (30.84 ha), the proportion of which is low in the region both according to previous research (Huetz de Lemps; 1967; Saavedra, 1992c, López-Pardo, 1999) and to our own data, which show that only a 13% of declared vineyard surface is occupied by *parras* in the parishes of Francelos and Ribadavia[80]. Average yields when considering both *cepas* and *parras* is 16 hl/ha. However, in our estimations on productivity in 1764 we weighted each yield by its corresponding surface.

Huetz de Lemps (1967) consigns yields between 20 to 27 hl/ha in the Ribeiro of Avia towards the middle of the 18th century by using Ensenada's Cadastre. In the case of Ribadavia, the author consigns average yields of 20 hl/ha according to a total production of 10.744 hl in 530 ha. This research is based on the *Respuestas Particulares*[81] to Ensenada's cadastre, which are currently lost to the *Arquivo Histórico Provincial* in Ourense. Bouhier also records average yields between 20-24 hl/ha in the Ribeiro of Avia. De Juana and Limia Gardón (1980) offer similar average yields for Ribadavia, between 22-23 hl/ha. García-Lombardero (1973) reminds that these data should be taken as maximum thresholds since they refer to the most productive areas. Bouhier collects much higher yields for other parishes of the region and, especially, for *parras* (up to the double), just as our data show. There is, however, an important difference between Bouhier's data and ours. Since this author consulted the *Respuestas Generales* and we used the *Comprobaciones*, total surface data are higher in our study. On the other hand, this allows to see that declarations on *parras* and first quality vineyards were proportionally higher in the *Respuestas Generales* than in the *Comprobaciones*. This is coherent with the main type of fraud in Ensenada's Cadastre, as we have already explained, which means that our yields are slightly lower than they should be, thus offering a more conservative value.

Pérez García (1982) compared average yields from Ensenada's Cadastre and ecclesiastical wealth records from the mid 18th century in coastal areas of Pontevedra. The former would reach 13.88 hl/ha whereas the latter would be of 44.73 hl/ha. While Ensenada's Cadastre data are prone to information concealment, these ecclesiastics documents are suspicious of the opposite, thus trying to reach the minimun required wealth in order to be admitted in the seminary. However, according to this author, Ensenada's Cadastre would not be a valid source for wine yields in regions with high productivity.

Saavedra (1992c) studied wine production in the Ribeiro with price and tithe series from San Clodio abbey and concluded that production levels from the last third of the 17th century would not be reached again. Yields were particularly high between 1680-1739 but show a

[78] 29.5 hl/ha; 14.77 hl/ha, and 11 hl/ha in first, second and third quality soils, respectively.
[79] 33 hl/ha in first quality soils, and 18.5 hl/ha in second ones. *Parras* are not cultivated in third quality soils.
[80] According to the *Respuestas Generales*, this proportion would be different: 13.8 % of vineyard in Ribadavia would be occupied with *parras* whereas in Francelos this percentage increased up to the 26% (Bouhier, 2001).
[81] Reports that collect land uses and yields by individual.

general decrease ever since despite a mild recovery between 1760-1809, which was probably related the switch from white to red vines after the lost of foreign markets and the inner reorientation in commercialization. From the beginning of the 19th century, production keeps falling to very low levels, and the same can be observed in nearby locations such as Banga, Gomariz and Moldes (Saavedra, 1992c). Definitely, Saavedra confirms a decreasing trend in vineyard yields in the Ribeiro de Avia since the middle of the 18th century, with an important crisis after the beginning of the eighteen hundreds. Before such a negative juncture, the author outlines a relative increase in cereal production. However, we need to include Saavedra's remarks when considering vineyard productions. The author states that long-term fluctuations are more likely due to changes in surface than to changes in yields since vineyards were more limited than, for instance, cereal rotations when considering increases in productivity. On the other hand, Bouhier affirms that vineyard productivity did increase between a forth to a third between the middle of the 18th century and the end of the 19th (Bouhier, 2001). Our data are not very conclusive at this respect but seem to support Bouhier's conclusion as well, although with a shorter margin of increase (0.125%).

López-Pardo studied wine yields specifically for the Ribeiro of Avia, and concluded that average yields of wine reached 20 hl/ha as well, and specifies 17.1 hl/ha for *cepas* and 31.9 hl/ha for *parras*. The author concluded that average yields as declared for the parish of Ribadavia in 1752 are not reliable when compared with other ecclesiastic and notarial documents, since they only reach 9 hl/ha before the 25.4 hl/ha of ecclesiastic records or the most extreme 38 hl/ha from other nearby parishes which are, however, well over the average. Data from the *Comprobaciones* seem more accurate than data from 1752, although our average yield is of 16 hl/ha before the 23 hl/ha that López-Pardo assigns to the parish of Ribadavia or the average of 27.1 hl/ha for the whole Ribeiro of Avia. López-Pardo also concludes that this region's main concealment in Ensenada's Cadastre affects surface the most (up to a 60%), whereas yields are not so far from those of private documents, as it had been concluded by Pérez García for Pontevedra (López-Pardo, 1999).

Our average wine yields for 1764 are much lower than those of ecclesiastic wealth declarations collected by Pérez García for Pontevedra for the same period, and also lower than those of Huetz de Lemps for the whole municipality. Eventually, we opted for the most conservative option, which is also relatively coherent regarding the above indicated remarks. Wine yields as consigned in the *cartilla* of 1860 are considerably higher: 30.21 hl/ha. Other statistical documents from 1888[82] show even higher average yields than Pérez García's but we refused to use them in order to maintain the internal coherence of the *cartillas*, also because yields at this time were certainly affected by the mildew plague (Huetz de Lemps, 1967). Finally, data from Domínguez Castro's research (1992) on two family households in Ribadavia show similar yields for the middle of this century: 29.5 hl/ha in the period 1834-

[82] *Propuesta de tipos medios,* 1888, AHPOu, Facenda, C459/08.

1844; 28.1 hl/ha in 1863-1872; 51 hl/ha in 1873-1882; 39.1 hl/ha in 1883-1892; 39.6 hl/ha in 1893-1902 and 37.7 hl/ha in 1905-1909.

Eventually, we chose the conservative option regarding yields and therefore land productivity. Our data allow to track agricultural intensification and, eventually, when applying nutrient balances to these data, we would obtain lower nutrient extractions than the actual ones, but in proportion to inputs, which are partially available in the *cartillas*. The actual situation must have been more critical for nutrients than our eventual results would show. In the next section we will briefly comment on fertility management in vineyard rotations.

Vineyard fertilization

Firstly, it is important to consider the particular nutrient requirements of vineyard, which will be relevant for constructing the balances in the future. Nitrogen is particularly necessary for flowering and has a certain capacity to increase vineyard fertility. However, nitrogen requirements in this type of crop are relatively low and current studies do not see a proportional relation between grape yields and nitrogen supply. However, this must have been very different in the past when intercropping was a common practice in vineyards, at least in this case study and generally in the Ribeiro of Avia. According to Hernáez, phosphorus is also not necessary in big amounts, although its balance with other nutrients is essential for the correct assimilation of other elements. Potassium is more relevant for vines due to its role in the chlorophyllic function, which determines carbon assimilation by leaves and the volume of the harvest, alcohol level and other important aspects related with wine. Regular supplies of organic matter are also important (Hernáez Mañas, 1993). This is coherent with the use of green manure in the Ribeiro, and confirms the deep knowledge that peasants developed of their territory over the course of centuries.

Together with vegetable gardens and cereal, vineyards receive most of the manure in the region of Ribeiro. Our sources for the 18th century do not offer any data on manure doses. The *cartilla* of 1860 mentions that, in order to maintain the vineyars in good state, 20 baskets of manure must be applied every 10 vines, that is 2 baskets per vine. Unfortunately, we do not have a converter for the weight of a basket of manure, although it could be easily estimated. This fertilizing practice was aimed at "renovating"[83] the plants by digging a *"pozo"* (well) around them, thus burying the old plant and leaving young shoots out. This hole was then filled with manure and both leaves and pruned shoots. This was done to weak vines, or sistematically once every ten to fifteen years to each plant (CSAIC, 1981; Domínguez Castro, 1992). The interrogatory on the agrarian crisis of 1876 carried out in the province of Ourense reveals that this kind of management resulted in a disorderly planting pattern which was,

[83] "*Renovar"* in the sources.

besides, overpopulated with vines twice or even three times beyond the advisable. This report also mentiones that pine needles were used as fertilizer in vines as well (CSAIC, 1981).

Our *cartilla* from 1888 consigns manure expenses in carts. We have used a converter from *La ganadería en España* (Ministerio de Agricultura, 1892), which establishes that a cart of manure in Ourense weighs 550 kg. Therefore, in vineyards with intercropping manure would be applied as follows, according to soil quality: 5,280 kg/ha in first quality; 4,400 kg/ha in second, and 2,640 kg/ha in third. In the "*Propuesta de tipos medios*", the document on prizes from 1888[84], these amounts are given in kg/ha and also especified for the vineyard rotation without intercropping. The first would receive 6,000; 7,000 and 7,600 kg/ha respectively, being the most manured those of better qualities; and the second rotation, without intercropping, would receive still more manure: 8,600; 9,000 and 10,200 kg/ha, being the most manured those of worse quality. These data do not seem reliable because, even if it seems logic that vineyards for only wine receive better care and therefore more manure, the proportion in application according to soil quality should follow the same criteria.

Apart from being the essential ingredient of manure, gorse was also used in other two additional ways, both of them by burying the plant itself, either as green manure when gorse was buried right after being cut and collected, or after having fermented on piles but not with animal excreta. This was particularly common in vineyards that were close to *monte* areas (CSAIC, 1981). Since such practice required a lot of labor, it was only undertaken every five or eight years (García Fernández, 1975; Domínguez Castro, 1992). Domínguez Castro, who studied two prominent households[85] in Casaldereito (Cenlle, Ribadavia), mentions the use of 76 carts of manure in one particular vineyard in the year 1872, which would mean 33.7 carts/ha. This author also explains that both leaves and vine shoots were used as manure, as well as small branches and leaves from the bushes and trees used for preparing the stakes to tie the vines. Besides, once grapes are pressed, the resulting pomace can also be used as fertilizer for vineyards. According to this author, pomace returns potassium to the soil, which is necessary for the ripening cycle of the grapes. Its acidity was balanced with quicklime, at least in the case study of Domínguez Castro (1992 and 2001).

Regarding manure availability, Bouhier and Domínguez Castro mention that the amount of fertilizer produced with available shrub and livestock within Ribadavia was not enough for all the cropped surface and prime matter such as gorse was imported into Ribadavia at least at the beginning of the 20th century and until the 1940s, both in the Ribeiro of Avia and Ourense (Bouhier, 2001; Domínguez Castro, 1992).
There are other qualitative information that remark manure scarcity in prior moments, but not only. De Juana and Limia Gardón (1980) mention sources to which we did not have access

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[84] AHPOu, Facenda, C459/08.
[85] Meruéndano and Pardo, bourgeois and nobility members, respectively, with political and economic protagonism in the region. See Domínguez Castro, 1992.

that inform on the importation of cereal from Amoeiro into Ribadavia at least since the 1880s. This village was between 25-30 km away from Ribadavia. The interrogatory *La crisis agrícola y pecuaria* also refers to food imports in 1880s (Ministerio de Fomento, 1887, vol. II, p. 368). Besides, in his memoirs, the doctor Rodríguez Troncoso, born in A Cañiza[86] in 1926, refers to gorse purchases near where he lived with destination to the Ribeiro too:

> *"Back in the day, in the three or four first decades of the 20th century, and maybe even before, there were families that transported carts of gorse to sell in the Ribeiro (Leiro, Francelos and Castrelo), at about three leagues away. The buyers buried it between the grapevines as manure[87]"* (Rodríguez Troncoso, 2004: 165).

The chronicler Meruéndano Arias (1981) refers to a common fact within the Ribeiro of Avia during the 16th and 17th centuries at least, which consisted in marrying people from the surrounding mountains. Thus renowned families had properties outside of Ribadavia which served as a complement to their vineyard economy.

Moreover, Domínguez Castro (1992) has documented purchases of gorse, manure and hay in the 19th century by the one of the two family households of his research, although the origin of such products is not indicated. These families were among the wealthiest in the region, and most of the small peasants could probably not afford such imports. This gives evidence that inequality is tightly connected with sustainability since access to fertilizers and animal foodstuff was conditioned by an uneven access to natural resources, which must have led to over-exploitation (González de Molina and Guzmán, 2006; González de Molina and Toledo, 2011 and 2014).

Even if Meruéndano Arias does not offer enough reliability and most of the authors refer to the 20th century, they allow to think that importations of gorse into the region were linked with vineyard monoculture and, therefore, must have been a common practice at least since the last decades of the 19th century. The same applies to food imports, as mentioned by de Juana and Limia, who show that long distance transport was not exclusive of the 20th century.
However, despite an apparent lack of manure, inorganic fertilizers do not seem to have easily spread through the region, at least according to Domínguez Castro (1992: 194), Fernández Prieto (1992) and Soutelo (2001). Domínguez Castro emphasizes the idea that peasants preferred to use their own manure.

[86] In the province of Pontevedra, his *aldea* within A Cañiza could have been between 10 to 20 km away from Ribadavia.
[87] Own translation.

Chestnut groves

The harvest of chestnuts indicated the beginning of the agricultural calendar in the Ribeiro region, thus being more determinant than vineyards at this respect (Domínguez Castro, 1992). More or less between 1875 and 1880, the expansion of an infestation from Portugal, which was caused by two fungi, *Phytophthora cinnamoni* and *Phytophtora cambivora*, resulted in the disappearance of most chestnuts in Galicia, except for the South of the province of Lugo and the Eastern mountains of Galicia (Bouhier, 2001). In the following chart we collect surface and Domestic Extraction data of chestnut groves in Ribadavia through the study period.

Chart 9. Ribadavia. Surface (ha) and land productivity in chestnut groves (dry matter): 1764, 1860, 1888

	Surface	ED (t)	ED t/ha
1764	10.08	36.21	3.59
1860	22.35	147.12	6.58
1888	22.35	138.93	6.21

Source: Ensenada's Cadastre, *Comprobaciones*, AGS, DGR, 1RE, 1129_01; *cartillas* of Ribadavia from 1860 and 1888: AHPOu, Facenda, C459/03 and C459/06, respectively.

We have accounted all main products that were extracted from these groves: chetnuts, wood, and firewood. Average yields of chestnuts in dry matter are: 359 kg/ha in 1764; 2,026 kg/ha in 1860, and 1,660 kg/ha in 1888. Data for 1764 must be underestimated because productivity is too low, especially taking into account that plagues had not yet affected *soutos* and that Ensenada's Cadastre specifies yields of chestnuts altogether with those of wood. Since such yields were not disaggregated we used the original datum as only for chestnut and estimated wood production differently, as well as firewood. These data have been obtained as indicated in the case of Fonsagrada (see Appendix 1 for more detail).

On the other hand, the slight reduction of productivity between 1860 and 1888 is certainly related with the above-mentioned plague because most of other crop yields are similar in both *cartillas*, which means that fraud is not likely to be the reason behind this decrease. However, over-exploitation of resources such as wood, firewood and perhaps even leaves, which are used in Fonsagrada as fertilizer material, could also be the behind a long-term process of nutrient mining in this rotation, especially considering the high demand of wood stakes for the vines. The region was well-known for its wood resources at least in the 18th and 19th centuries, although pines were the most common species for such extraction (de Juana and Limia, 1980; Meruéndano, 1981).

Monte

Ensenada's Cadastre and both *cartillas* make a clear distinction between "*monte alto*" (woodland) and "*monte baxo*" (shrubland). According to statistical documents from the early 1880s[88], the main difference is the extraction of wood in the first ones, which are said to provide with pasture for livestock as well, whereas the second would only produce *esquilmo* (livestock bedding) and pasture. Both of them seem to be subject to either common or individual property. A document from 1875 points out that *montes* are common property[89], and that the State did not own any *monte* surface in the municipality. However, according to the Grupo dos Comúns, *monte* in Ribadavia was mostly property of the council, thus being *monte de propios*[90] (GEPC, 2004: 124). In fact, Ensenada's Cadastre, in the reply to question number 23 of the general interrogatory, 232 *ferrados* are declared as *montes de propios*, which is equivalent to 14.59 ha. This surface has been summed up to the rest of declared *monte* surface. We have not considered the juridical situation of *montes* in our study but this would be interesting when studying the inequality in its appropriation since this type of property requires the payment of a fee in exchange for its use. This would imply that less households could benefit from its resources. However, these legal differenciations do not affect the biophysical analysis at the scale of agroecosystem.

In 1764, the two parishes of Ribadavia and Francelos declare a total of 403.47 ha, of which 102.84 correspond to *monte*. From these 102.84 ha, 15.13 are woodland, which is appropriated every two years for wood; 27.45 ha are shrubland, which is harvested every six years, and the remaining 45.67 ha of shrubland are harvested every nine years, plus 14.59 ha of *montes de propios* that were mostly used as shrubland. In 1860, a total of 1,147.77 ha are cadastred as *monte* in the municipality, 694.01 of which correspond to woodland and 453.76 to shrubland. Intermission in harvesting is not specified any more, which could be a symptom of intensification in *monte* appropriation. The increase in *monte* surface between both moments is mainly explained by the limits of the sources from 1764, which cadastred only two parishes, whereas data in 1860 refer to the whole municipality. However, comparison in relative terms shows something interesting regarding the proportion between cropland and *monte*.

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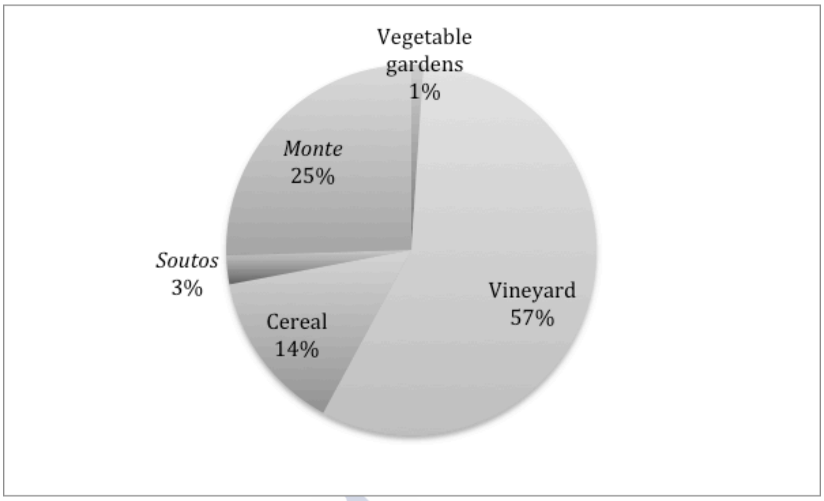
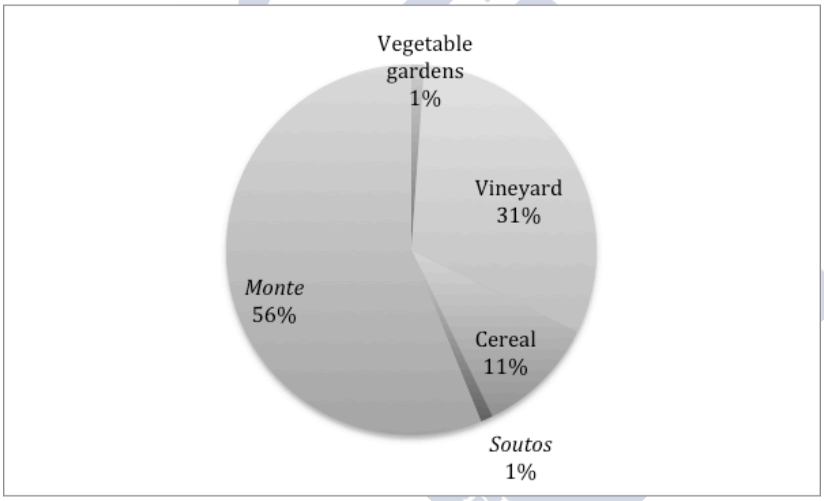
[88] "*Datos para la cartilla evaluatoria*", AHPOu, Facenda, C459-05.
[89] *"comunales de los pueblos o sus vecinos"* (*Interrogatorio para reunir datos a fin de redactar una memoria sobre el estado de la agricultura en esta provincia de Orense*, August 27th, 1875, AHPOu, Facenda, C459/04).
[90] Such legal status was uncommon in Galicia. For more detail see Bouhier (2001: 780-781) or Balboa (1990: 52-53).

Graph 7. Ribadavia (parishes of Ribadavia and Francelos). Distribution of agrarian surface in 1764



Source: Ensenada's Cadastre, *Comprobaciones*, AGS, DGR, 1RE, 1129_01.

Graph 8. Ribadavia (municipality). Distribution of agrarian surface in 1860



Source: *cartilla* from 1860, AHPOu, Facenda, C459/03.

In 1764, these two parishes would only have a 25% of *monte* surface regarding a 75% of cropland, out of which a 57% was vineyard. This ratio must be distorted either due to undeclared *monte* surface, which was the most common fraud in Ensenada's Cadastre (Saavedra, 2001), or because Ribadavia is a more urban village and is very constrained by the river limits, where vines are cultivated, and might have less access to *monte* than the rest of the parishes. Either way, the proportion changes considerably in 1860, when a 56% of *monte* corresponds to the 43% of cropland. This ratio seems more balanced and is closer to the limits that Bouhier observed in regions with a very intensive agriculture, where *monte* resources were equally intensely exploited in the 19th century (Bouhier, 2001). These limits do not mean, however, sustainability.

Monte provided essential raw materials, mainly in the form of *esquilmo* (shrub), and in the case of wine economies such as the Ribadavian, it provided with other specific services as well. In 1850s, Madoz's Dictionary states:

> *"The land is generally of good quality: it comprehends some common montes, of which many are private property; oaks, pines, gorse, heather and other shrubs are cultivated on them, there are also small chestnut groves"* [91], (Madoz, 1846-1850, vol XIII: p. 505).

Pine trees were planted to produce stakes for tying the vineyards. Chestnuts and oaks provided wood for barrels or wine presses, as well as firewood to distill liquors, etc. Wood from chestnuts and oaks was very appreciated for making barrels and other recipients and appliances related with the production of wine (Domínguez Castro, 1992 and 2001).

However, one of its most important tasks as nutrient provider for cropland seems to have been scarce, as indicated before. This would mean that the nutrient cycle could not be closed with the available resources at agroecosystem scale and part of the fertilizer and foodstuff had to be bought in surrounding areas, and not only for livestock but also for people, as reflected in Madoz's Dictionary for the 1840s: *"Imports of clothing and necessary foodstuff"*[92] (Madoz, 1846-1850, Vol. XIII: p. 505).

Livestock

Our livestock data for Ribadavia are not reliable enough as to be very conclusive in our analysis. We do not have any complete data for 1752 nor 1764 since the parish of Ribadavia is missing livestock data for secular population and Francelos is missing data for ecclesiastics. According to the available information in *Censo ganadero de la Corona de Castilla*, there would be at least 42 bovines, 62 pigs and 3 sheep (INE, 1996). For the year 1860, the closer available livestock data are collected in a statistical interrogatory from 1857[93]. These numbers seem more accurate than those of the *cartilla*, which are much lower and do not include sheep nor goats, which used to spend their live on *monte* areas and were therefore more easily concealed in declarations. However, this interrogatory records less than half of the pigs in the *cartilla* from 1860, which is not coherent either because pigs are a basic component of peasants' economy and even poor families had at least one. Therefore, as a test, we have used the livestock census from 1865 and extrapolated its density and livestock head composition data at the scale of Partido Judicial to the municipality of Ribadavia. Some facts indicate that

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[91] *"El terreno en lo general es de buena calidad: comprende algunos montes comunes, habiendo muchos de propiedad particular; en todo sellos se crían robles, pinos, tojos, retama y otras matas, encontrándose también pequeños sotos de castaños"*, own translation from original text.
[92] Own translation from original text: "*importación de géneros de vestir y comestibles precisos*".
[93] "*Interrogatorio para la formación de la estadística pecuaria"*, in *"Noticias estadísticas. Producción agrícola con aplicación a las subsistencias y a la industria. 1857"*, AHPOu, Facenda, C459-04.

this estimation is not completely satisfactory either: cattle numbers are too high, whereas mules should probably be higher regarding both the rest of data and the labor requirements of a vineyard monoculture on terraced slopes. Finally, the *cartilla* from 1888 does not record livestock data at all. In the following chart we present all available information for livestock during the study period.

Chart 10. Available livestock data for Ribadavia in 1764, 1857, 1860, 1865, and 1876

	1764	1857	1860	1865	1876
Cows	42	200	132	527	140
Horses	0	10	6	14	30
Mules	0	40	40	20	6
Donkeys	0	8	6	8	6
Pigs	62	140	300	410	400
Sheep	3	60	*	276	20
Goats	0	20	*	55	10

Source: Ensenada's Cadastre, *Comprobaciones*, AGS, DGR, 1RE, 1129_01; *Producción agrícola, con aplicación a las subsistencias y a la industria,* 1857, AHPOu, Facenda, C459/04; *cartilla* from 1860, AHPOu, Facenda, C459/03; Livestock census from 1865 (JGE, 1868); *Interrogatorio para reunir datos para redactar una memoria sobre el estado de la agricultura en la provincia*, 1876, AHPOu, Facenda, C459/04.
*Sheep and goats are not mentioned in sources of 1860.
** Data for 1764 include only the two parishes of Ribadavia and Francelos. The rest of the data refer to the whole municipality.

Chart 11. Ribadavia. Livestock Units and density in 1764, 1857, 1860, 1865, and 1876

	1764	1857	1860	1865	1876
Cows	25.2	120	79.2	316.2	84
Horses	0	6	3.6	8.4	18
Mules	0	24	24	12	3.6
Donkeys	0	2.4	1.8	2.4	1.8
Pigs	7.44	16.8	36	49.2	48
Sheep	0.15	3	0	13.8	1
Goats	0	1.2	0	3.3	0.6
Total	32.79	173.4	144.6	405.3	157
LU-500 kg/km^2	**1.46**	**7.71**	**6.43**	**18.01**	**6.98**

Source: Ensenada's Cadastre, *Comprobaciones*, AGS, DGR, 1RE, 1129_01; *Producción agrícola, con aplicación a las subsistencias y a la industria,* 1857, AHPOu, Facenda, C459/04; *cartilla* from 1860, AHPOu, Facenda, C459/03; Livestock census from 1865 (JGE, 1868); *Interrogatorio para reunir datos para redactar una memoria sobre el estado de la agricultura en la provincia*, 1876, AHPOu, Facenda, C459/04.

Livestock density from 1764 cannot be accepted for the whole municipality. Data refer to only two parishes, one of which is the capital and therefore more urban and less suitable for livestock farming. Besides, these data are incomplete since part of the registries are lost, as especified in the source (INE, 1996). This is just an approximation and refers to a minimum availability. However, data from 1857, 1860, and 1876 are close to 7 LU-500 kg/km^2. This value is very close to livestock densities in Mediterranean cases with a pattern of specialization on woody crops, for instance Sentmenat (Barcelona), with 7.25 LU-500 kg/km^2 in 1865 (Tello et al., 2012), and Andalusian cases like Montefrío, with 7.73 LU-500 kg/km^2 in 1852; Baena, with 7.64 LU-500 kg/km^2 in 1858; or Santa Fe, with 11.8 LU-500 kg/km^2 in 1858 (González de Molina et al., 2010). But despite the Mediterranean-like climate, and according to the rotations we described before, mixed farming was more developed in Ribadavia than in Andalusian or Catalonian cases, where both water and nutrients were more limiting for the expansion of particularly intensive crop associations and imposed a higher land cost to biomass production (González de Molina et al., 2010; Fernández Prieto and Soto, 2010). Therefore such values do not seem coherent for the case of Ribadavia, where livestock densities should be higher regarding a bigger capability to sustain livestock within a mixed farming management.

On the other hand, sources and previous research give evidence of scarce livestock in the region. As explained before, according to Saavedra (1992c) and Domínguez Castro (1992), livestock was subsidiary to the main economic activity of wine production. This means that livestock was required as manure producer and in agricultural tasks and transport, but also that meadow surface was constrained by the expansion of vineyard and available land for sustaining livestock was scarce. This explains the need and the importance of incorporating fodder in the maize rotation, which is common in regions with very intensive agriculture in the Galicia of the 18th and 19th centuries (Bouhier, 2001; Soto, 2006).

Domínguez Castro also verifies hay imports in one of the households of his research, although we do not know whether it proceeded from within Ribadavia or outside its municipal boundaries. Since this household was amongst the wealthiest in the region, both options were possible. If the hay were from within Ribadavia, it would be related with an inequal internal resource distribution: not every household could afford to have livestock because its feeding required a big investment both in terms of land and money. When coming from outside, unsustainability would be exported to the mountains surrounding Ribadavia, where grass was available. It was also in the mountains where livestock could be more easily sustained due to abundant food resources such as *monte* pasture and natural meadows, and was, therefore, more numerous than in the valleys (CSAIC, 1981). According to this mountain/valley pattern and the vineyard monoculture, livestock head must have been reduced, and imports of food or fertilizers seem the most likely option, although it does not exclude inner commerce as well.

On the other hand, Madoz mentions mainly bovine, swine, and sheep cattle for the Ribadavia of the 1840s, but in low numbers:

> *"there is bovine and sheep livestock in short numbers, partridge and rabbit hunt, trouts, lampreys, eels, salmons, allis shads and other fish (...). The 10th of every month there is a fair*

and a regular market on Saturdays; cloths, cattle and pigs are sold in the first"[94] (Madoz, 1846-1850, vol. XIII: 505).

Only bovine cattle and pigs would be aimed for the market. This livestock was mainly held in aparc*ería* contracts, which was the most common type of contract in the region of Ribeiro, and namely for cows and pigs. This is a form of share-farming contract which establishes that the moneylender pays for the animal and the peasant looks after it while benefitting from milk, manure, and transport. When the brought up animal and offspring are sold, money is then shared in halves between the peasant and the moneylender, as well as losses if that were the case. With pigs, most adult animals are slaughtered instead of sold. In this case, meat is not shared in half: the moneylender takes only one third but of the best quality. Moneylenders are usually livestock dealers in local markets, and some of them are peasants themselves. For most peasants, it was the only way to have access to livestock, which was necessary for labor as well as an important part of diet (Domínguez, 1992). This means that access to livestock was unequal and, therefore, labor force, manure, milk, and meat were distributed accordingly. *La crisis agrícola y pecuaria* describes livestock numbers in Ribadavia as "*insignificant*" (Ministerio de Fomento, 1887, vol. II: 370), which is obviously an exaggeration but expresses the local perception of its scarcity.

Besides, this reduced livestock head has also been related with fertilizer scarcity. García-Lombardero (1973: 55) cites a document from 1776[95] where the *Junta del Reino* from Galicia complains about the expansion of vineyard towards the higher and colder parts of the valley, thus displacing animals and resulting in poor harvests and food scarcity as well. However, the petition of pulling out such vines was not accepted in order not to go against peasants' interests. This is important because it remarks the importance of peasant agency at modeling the regional economy, which was based on a cash crop and by the end of the 19th century had externalized food production and, very likely, fertilizer supply too.

6.2.4. Wine specialization as the triggering factor for nutrient imports

Even though nutrient balances would allow more accuracy regarding soil fertility, we have mentioned evidences of the importation of both food and fertilizers in the Ribeiro towards the end of the 19th century and, especially, at the beginning of the 20th century. Our data are also coherent with such a fact considering that *monte* surface occupied only a 56% of the total agrarian surface in 1860. This percentage seems too low considering the high degree of agricultural intensification and the requirements of a monoculture economy in a region with

[94] Own translation from original text: *"se cría ganado vacuno y lanar en corto número; caza de perdices y conejos; y pesca de truchas, lampreas, anguilas, salmones, sábalos y otros peces (...). El 10 de cada mes se celebra una feria y un mercado todos los sábados; en la primera se venden paños, ganado vacuno y de cerda".*

[95] Madrid, May 4th, 1776, Archivo Histórico Nacional. Consejos. Leg. 886, núm. 10.

reduced land availability. On the other hand, as we can see in the following chart, land productivity does not decrease considerably between 1860 and 1888 despite the infestations that affected vineyards after 1850s.

Chart 12. Ribadavia. Agrarian surface and land productivity in 1764, 1860, and 1888 (dry matter, by-products included)

	Fertilized cropland* (ha)	Monte (ha)	Monte ha / Cropland ha	DE (t)	DE (t/ha)
1764	290.55	88.25	0.30	634.39	2.18
1860	874.11	1,147.77	1.31	3,209.27	3.67
1888	840.21	1,147.77	1.37	2,914.95	3.47

Source: Source: Ensenada's Cadastre, *Comprobaciones*, AGS, DGR, 1RE, 1129_01; *cartillas* of Ribadavia from 1860 and 1888, AHPOu, Facenda, C459/03 and C459/10, respectively.

*Vegetable gardens, cereal rotations, and vineyard.

The very low proportion of *monte* and cropland in 1764 is only due to biased and incomplete data from Ensenada's Cadastre. Data for the rest of the period are within the limits established by Bouhier for average farming practices in Galicia, which goes from 1 to 2 ha of *monte* for every cropped hectare, and corresponds *theoretically* to a 33-50% of cultivated land. The author suggests that such a "*balanced*" proportion could be valid already for the end of the 18th century, having an ancient origin (Bouhier, 2001: 862-863). However, these estimations are based on evidence from a period when industrial fertilizers had been incorporated in agriculture, and have not taken into account agronomic considerations. Nutrient balances would clarify this issue since the range of possibilities is too wide as to be accurate regarding nutrient replenishment, especially in such a particular agroecosystem.

On the other hand, land productivity in cropland increases considerably between 1764 and 1860, but seems to remain stagnant in 1888, if not already in decline. Wine yields do not show important variations (2.40 and 2.43 t/ha dry matter in 1860 and 1888, respectively, which can be explained by the recovery of the vines after the fungal infestations. Cereal rotations also show a slight decrease (from 7.59 to 7.29 t/ha). Such reductions are not significative and could easily be within the margin of error related to our sources. However, they show a clear trend of stagnation. Our main hypothesis in the case of Ribadavia is that vineyard specialization and agricultural intensification trigger a process of nutrient mining, of which locals were aware and aimed to solve by initially importing nutrients from nearby areas. The following chart shows an aproximation to manure needs and requirements in 1860. Manure availability has been estimated with livestock numbers from 1865. We have already explained that data from this census do not seem coherent, but in this case we want to point out that even with such high levels of livestock density (18 LU-500 kg/km^2), manure was still scarce in the agroecosystem[96].

[96] The amounts of manure produced by each animal species have been obtained with converters from both livestock reports by the JCA (Ministerio de Agricultura, 1892 and Ministerio de Fomento, 1920). In the case of

Chart 13. Ribadavia. Manure requirements and availability according to the *cartilla* from 1860 (fresh matter)

	Tons
Required manure	7,176
Available manure	3,291
Fertilizer supply	45.9%

Source: *cartilla* of Ribadavia from 1860, AHPOu, Facenda, C459/03, and *Censo de la ganadería de España* from 1865 (JGE, 1868).

In this aproximation we consider only local fertilizer availability, and assume that all of the *esquilmo* would be used as livestock bedding for manure production. This means that only a 45.9 % of manure requirements would be satisfied in all three fertilized rotations: vegetable gardens, cereal rotations, and vineyard. Such option is unfeasible because sources clearly indicate that the application of green manure to vineyards was a common practice. This means that not all the *esquilmo* could be used to produce this amount of manure. This exercise is aimed at showing that, according to declarations in the *cartilla* from 1860, manure production and crop requirements with estimated livestock head from 1865 is clearly insufficient, even when livestock data are clearly higher than other sources from the second half of the 19th century indicate for Ribadavia. Therefore, we hypothesize that this agroecosystem was highly dependent on nutrient supplies from outside its boundaries. For a more accurate aproximation we should estimate biophysical requirements of plants and Net Primary Production in both cropland and *monte*.

As a result of the protagonism of vineyard, surface for other crops and *monte* was scarce, and both food and fertilizers had to be imported into the municipality. *La crisis agrícola y pecuaria* (Ministerio de Fomento, 1887, vol. II, p. 368) informs of the frequent importation of cereal regarding the low local production in Ribadavia. However, the mountains around the Ribeiro, where vines were not cropped, used to be more self-sufficient and provided the valley with their surplus harvest (Domínguez Castro, 1992). Madoz's dictionary also mentions food imports (1846-1850, vol. XIII: 504). Eventually, as detailed before, Domínguez Castro (1992) refers to gorse, manure and hay imports in his case studies of Ribadavia, and Rodríguez Troncoso (2004) informs of frequent shrub imports to the region of the Ribeiro at the beginning of the 20th century at least.

The inequality between Ribadavia's agroecosystem and its surrounding territory was determined by the dualism valley/mountain at many levels, as it is obvious, but also by social

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goats and sheep, data are from the province of A Coruña instead of Ourense. Manure requirements have been estimated according to declared amounts in the *cartilla* from 1860 and using a converter of 25 kg for each basket (*cesta*) of manure. This datum has been estimated according to manure doses in carts as declared in the *cartilla* from 1888. A converter from cart into kg (550 kg) is available in Ministerio de Agricultura, 1892. All other data regarding productions and land use are from the *cartillas* of 1860 and 1888.

class within the municipality, which conditioned the access to basic resources. All in all, the vineyard monoculture economy of Ribadavia and generally in the Ribeiro seems to have subordinated surrounding agroecosystems (usually in mountainious areas) in order to close both its nutrient and energy cycles. Labourers from nearby villages found economic opportunities in wine related tasks such as harvesting, digging[97] or prunning (Domínguez Castro, 1992), but food and fertilizer imports were also required according to both sources and our aproximative estimations on manure availability. The agroecosystem was highly dependent on external inputs and the result was that the agroecosystem was exporting the unsustainability of its agricultural pattern of intensification and monoculture to surrounding areas. Inequality in the access to resources seems to have played an important role in unsustainability within Ribadavia's agroecosystem but this remains a hypothesis so far.

6.3. Fonsagrada: "extensification of intensification"

Agriculture in the region of Fonsagrada during the second half of the 18th century has already been described as a mixture of both intensive and extensive elements (Saavedra, 1979). First quality soils are cultivated yearly without fallow and *cortiñas* include biannual rotations with cereal and turnips. However, this is a minor surface considering that most of cropland is left fallow for one year between crops. Besides, the system of *estivadas* requires indeed a huge amount of *monte* surface, which is left fallow between 20 to 50 years. Therefore, the concept of "*intensification of extensification*"[98] is very appropriate to describe what happens between this moment and the end of the 19th century. Cropland has been intensified in cultivation, fallow has been supressed and even *estivadas* take place on the same piece of land with a higher frequency, in an average of twenty years. But at the same time, the extensification element is present when we compare surface evolution, which increases for all of the rotations.

Livestock plays a very important role in the process and experiences paralel and adaptative changes. The extensive component in livestock management looses protagonism through the first century of the period. In 1752, livestock depends mainly on *monte* and is not held in stables. Along with the intensification process, as manure demand increases in order to sustain cropland intensification, livestock abandons *monte* progressively, gets stabled and starts to be mainly fed on meadows, fodder, and turnips. Livestock head is considerably reduced in order for it to be stabled and produce manure near cropland areas. As we will see in the corresponding section, livestock numbers are reduced by half between 1752 and 1855. Because cattle turn into a market product (apart from its labor contribution), it gets better

[97] This task was done twice, the first time in the early spring and the second in May, June or July.
[98] This concept was suggested by González de Molina in personal communication at the World Environmental History Conference held in Guimarães, 2014.

looked after. A livestock head as that of 1752 could not be managed in such an intensive way as it would later be since it would overtake the agroecosystem's capacity to sustain it.

From an agronomic perspective, this leads to wonder about the environmental consequences of such a process. In recent times, multidisciplinary research has approached regions in Spain, Austria and the US from this viewpoint. The shared hypothesis in all these case studies pointed at nutrient mining processes and soil exhaustion in European agricultures towards the end of the 19th century, as it was eventually confirmed. At the light of these results, several members of the SFS project proposed that the so-called "*crisis agraria finisecular*"[99] in Europe could be re-interpretated under the biophysical approach by analyzing the management of soil fertility in the European continent and the colonial territories in America and Australia. The latter belong to a frontier agriculture based on the fast consumption of long-term accumulated nutrients which provided high yields with little labor investment while, at the same time, the old continent was starting to experience the exhaustion of its long-term intensification process in spite of the development of land management practices which were aimed at sustaining soil fertility, which resulted in higher land and labor costs (Cunfer and Krausmann, 2009; Garrabou et al., 2010; González de Molina et al., 2010; Infante-Amate, 2014).

Through the following sections, we will analyze available data in the case of Fonsagrada. Final results are coherent with the pattern of agricultural exhaustion in Europe towards the end of the 19th century. The agroecosystem of Fonsagrada shows nutrient imbalances at least by 1880s, which is connected with an increasingly bigger cropland surface and land scarcity in order to sustain its soil fertility after a paralel process of agricultural intensification.

6.3.1. An extensive territory

Fonsagrada is a municipality in the inner province of Lugo with a surface of 438.5 square kilometers[100]. It is located in the oriental mountains of Galicia, in the eastern centre of the province of Lugo, on the West of Asturias. Two river basins frame this municipality: the Eo's on the West and the Navia's on the East. Other two minor rivers divide the area in between from North to South: the Rodil, which flows into the Eo river, and the Lamas-Villabol, which flows into the Navia river. Both of them end up in the Cantabric Sea. The average height in the municipality is between 700 and 800 meters above the sea level (López Fernández et al., 1987).

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[99] In Spanish historiography, the agrarian crisis that took place towards the end of the 19th century is usually referred to as the "*end-of-the-century crisis*".
[100] http://ige.eu/igebdt/selector.jsp?COD=77&paxina=001&c=0101001002, consulted in October 2011.

The eastern mountains of Lugo are a nexus with the Cantabric Mountains, thus forming a bio-geographic frontier with the rest of the inner territory of Lugo (Terra Chá, Sarria-Lemos) where winds from the coast are stopped. Oceanic climate is predominant although in transition with continental influence. Annual average precipitacion ranges between 1,750 and 2,100 mm, and there would not be any drought month (Giménez de Azcárate, 1993). Winters are cold and snow is common, as frosts are in a large part of the year. Thermopluviometric conditions favour certain weathering processes which do not modify the chemistry of soil in a high degree (Pérez Alberti, 1982; Martínez Cortizas et al., 1999). Average annual rainfall in the nearby meteorological station of Pedrafita reaches 1,900 mm with an annual precipitation deficit of 122 mm between the months of June-August. Mean annual temperature is 8.3 ºC. We have used these average data for the construction of nutrient balances[101] (Díaz-Fierros, 1979).

In this region, geological materials are mainly slate, schist, calcareous rocks and quaternary sediments of alluvial origin. Most of these materials are rocks that are difficult to alter, which added to the mountanious character of the area and the effects of erosion, result in shallow soils with frequent rock outcrops. Leptosols and Cambisols are common, and also Regosols in sedimentary areas such as valleys or river basins, where soils are more diverse and present different depths and degrees of evolution. According to Macías et al. (2001), the main limitations to agrarian uses in the soils of this region are those of physical nature: steep slopes, soil shallowness and compaction, stoniness, erosion risks when associated to scarce vegetation cover, etc[102]. Since the 1970s, an important part of the shrubland surface has been turned into pastureland in order to take profit of this type of soils in a cattle-orientated region. Traditional land use in mountainious regions is charecterized by agro-silvo-pastoral integration, with the corresponding adaptations to the diverse ecological environments and a definitive configuration towards the Middle Ages. The bottoms of valleys receive soluble elements from the upper lands, apart from manure, and are intensely cultivated. Human habitat is concentrated on sunny slopes or at the bottom of the valleys. Vegetable gardens are spread among the houses and surrounding the villages. Next to them, we find the *soutos* (chestnut groves) and *labradío* (cropland). After these surfaces, further away from the village, there is *monte,* mostly shrubland or uncultivated land which serves as nutrient reserve for cropland. Such surface is regularly burned in order to regenerate shrubland production and pastureland. Meadows are located at the floor of the valleys and along water streams. Shade, humid and far away slopes suffer less human pressure, thus preserving original forest (Guitián, 1993).

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[101] These data belong to the termopluviometric station at Pedrafita do Cebreiro, a mountain village with similar geographical and climatic conditions as Fonsagrada and within 50 km from this case study. There are two weather stations in Fonsagrada, O Xipro and Alto do Cerredo, but they have only functioned since 2007 and 2011, respectively. We preferred Díaz-Fierros' data because this author offers average values of the period 1931-1960. We must notice, however, that this station is situated at about 300 m higher than the average height in Fonsagrada.

[102] For more detail on soils, see Pérez Alberti (1982 and 1995) and Macías et al. (2001).

According to Bouhier, Fonsagrada belongs to the Oriental territory of *agras,* a type of agricultural land organization which receives different names depending on the region (*chousa, veiga, vilar, estivo, barbeito,* etc.). Generally, *agra* refers to an *aldea'*s cropland that is organized in enclosed fields which, at the same time, are internally divided in smaller plots of different holders who develop a collective work discipline.

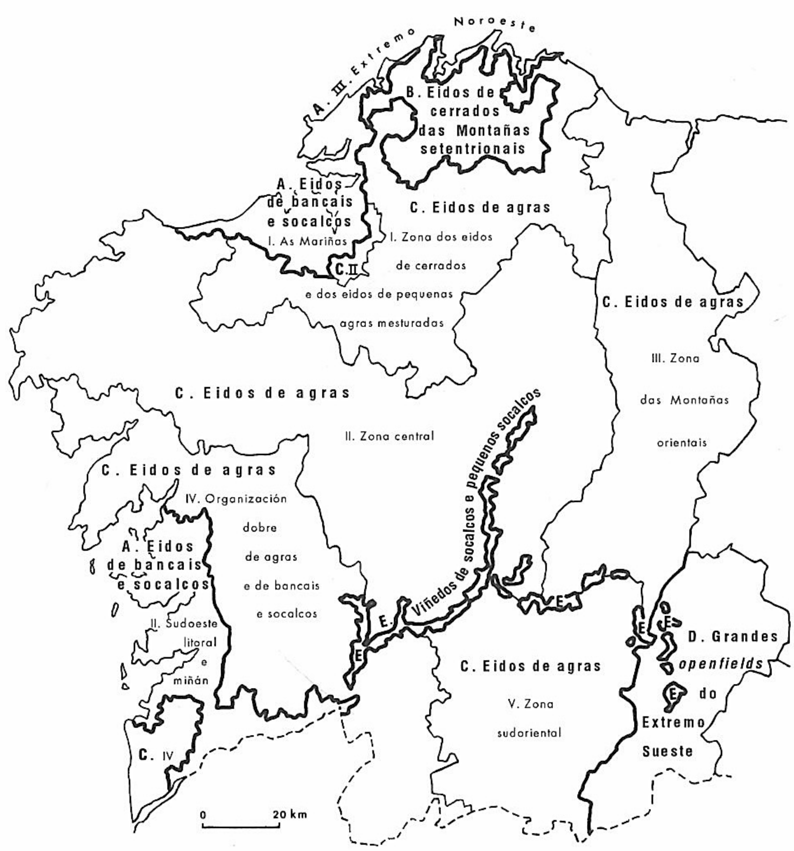
Illustration 4. *Agra* enclosed by a fence in the municipality of Cervantes

Source: Bouhier, 2001, vol. I: 369. Unknown year, ca. 1960/70s.

The following map of Galicia shows different types of land organization, of which *agras* are the most extended. Section C., called "*Eidos de agras* - II. *Zona das Montañas Orientais*"[103] in the map is where Fonsagrada belongs, particularly in the central sector.

[103] *Agra'*s fields – II. Region of the Eastern Mountains (own translation).

Map 5. Distribution of the main types of agrarian organization in Galicia



Source: Bouhier, 2001, vol. I: 103.

In order to better understand what an *agra* looks like, we include the following illustration as an example. The sketch shows the structure of a particular *agra* in an *aldea* in the surroundings of Santiago de Compostela, in the province of Coruña.

Illustration 5. Structure of an *agra* in an *aldea* in O Pino, A Coruña

Source: Bouhier, 2001, vol. I: 337. Legend: 1. Built spaces - 2. Cropland - 3. Gorse plots – 4. Low gradients within the *agra* – 5. General enclosure of the *agra* – 6. Limits of open plots – 7. Open paths.

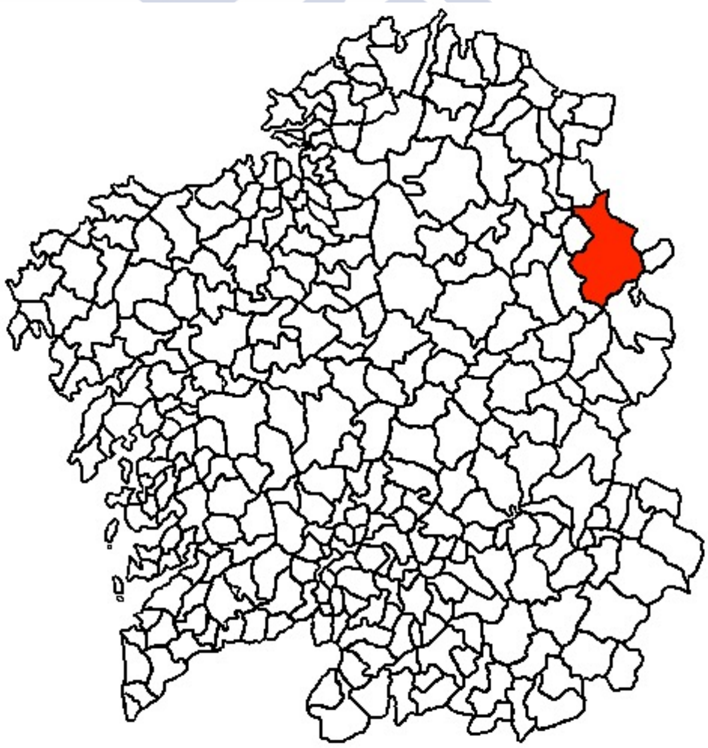
The central sector Bouhier comprehends a mountainious region which goes from Meira/Fonsagrada to Incio/Pedrafita, where cropland fields are not very large and have tended to be individualized although, traditionally, labor used to be collectively organized. Parishes are large and *aldeas* are scarce and isolated from one another, and usually located on not very deep slopes. The agrarian structure as analyzed by Bouhier in the 1970s was mostly composed of *cortiñas*, which used to be *agras* that switched to uninterrupted cropping, and meadows. Through our study, we will see how these *cortiñas* were initially not so common, since they served as experimentation fields for intensification (Bouhier, 2001).

However, in such an extense territory, homogenization has clear limits. As Saavedra has pointed out, a rugged terrain like this shows sharp differences even between adjacent parishes. An average height of about 1,000 meters above the sea level results in deep valleys and steep slopes which are not appropriate for cultivation. The main harvests consist of rye and chestnuts in the 18th century. Vines and maize can be cultivated in some valleys, which are more densely populated, like the parishes of Baos or Suarna for instance. On the opposite, parishes located at higher altitudes have less diversified crops and a bigger livestock head, like Bastida or Fonfría, for instance (Saavedra, 1979). However, we will try to focus on cultivated land as declared in the sources, which is a simplified picture of all the parishes that compose Fonsagrada. Surfaces which were not appropriate for cultivation were either not declared or registered as "uncultivated". Besides, the sources themselves already proceeded to standardize the terrain in order to tax its productions, mainly in the 19th century. We are aware of the limits of this approach, which has been determined by the method but, on the other hand, it offers a very useful interpretative tool.

Surface and parish composition in the sources of Fonsagrada

In order to consider a homogeneous territory we assume that Fonsagrada has always had the same surface as today (43,850 ha), which has served to estimate undeclared surface in the three moments we analyze. Parish composition suffered alterations through the study period and surface must have changed accordingly, but sources do not offer such information.

Map 6. The current municipality of Fonsagrada within the territory of Galicia



Map source: http://www.codigopostal.org/images/imagen-de-fonsagrada-3.jpg

For 1752 we have used data as presented in Ensenada's Cadastre, with 31 parishes[104] and a total of 7,918.12 ha of declared surface. According to Saavedra, an average of 25.9% of land was cadastred in 1752 in Lugo over the current surface of the province. Cropland would correspond with a 10.3% of the total current surface of the province (Saavedra, 2007). According to our data, total cadastred land in 1752 reaches almost 7,900 ha, which is about the 18% of the current municipal surface.
Our sources for the 19th century offer aggregated data at municipal scale. Madoz's dictionary accounts for a total of thirty parishes and the part of other two in 1850s (Madoz, 1846-1850, vol. VIII: 126), which is almost the same composition as in 1752. Declared surface in the documents of the 19th century never reaches the current datum but is much closer than that of 1752: 38,205 ha in 1852, and 43,565 ha in 1887. These latter surfaces include estimates regarding total *estivada* surface that are based on yearly cultivated surface as declared in the sources, as we will see. Undeclared surface usually corresponds to *monte* and land which was not appropriate for cultivation, as it has been established by historiography. Besides, *monte* was usually under collective property, which also explains why most of this surface was not cadastred (Saavedra, 2011; Bouhier, 2001; Villares, 1982). This is also coherent with our data since the expansion of cropland and *estivadas* was certainly done over *monte* surface, with an expansion over new areas which were less apropriate for cultivation.

Data on urban and oakwoods surface are missing in the sources of the 19th century and we used those of 1752: 86.42 and 105 ha, respectively. Considering the inheritance system, which aimed at preserving the household unit undivided, and an extended family structure with up to three generations under the same roof, new constructions were not easily accomplished in this region. However, as a result of the intense demographic growth, nupciality restrictions relaxed and some new houses were funded between 1770-1830 (Sobrado, 1996; Saavedra, 1979, 1992b, and 2008), thus urban surface must have increased as well.

6.3.2. Population in Fonsagrada

It is necessary to approach demography in quantitative terms, not only for a complete presentation of the territory of Fonsagrada, but also to show how we obtained this variable for the biophysical analysis of the agroecosystem. However, we will also introduce the characteristic demographic traits of the region during the 18th and 19th centuries. This will allow to better understand changes in human pressure over the territory.

[104] A complete list of the 29 current parishes is available in the Nomenclator of Galicia: http://www.ige.eu/igebdt/esq.jsp?paxina=002001&ruta=nomenclator/nomenclator.jsp

Eiras Roel (1996) includes the municipality of Fonsagrada in a common pattern of the inner Lugo which he names after the municipality of Samos (Lugo). This model, constructed with data from Floridablanca's Census (1787), shows signs of an ageing society, with a considerable average life expectancy. Population growth is not remarkable in general terms since there is a strict regulation through the control of marriages with high celibacy rates and, secondly, by migration too, although this phenomenon is not as intense as in other regions. Average age at the moment of marriage is quite delayed when compared with other demographic models, thus controlling reproduction and natality rates as well. According to this author, this model has an average family composition is of 4.74 members although, for the particular case of mountainious areas such as Fonsagrada, this average increases up to 6 according to Saavedra (2003). Such demographic model is related with low population densities and an agrarian system which is based on biennal rotations with fallow, and therefore requires quite extensive farm units to sustain family reproduction. Thus the inheritance system, which relies on the first-born son, is also adapted to this requirement of avoiding household fragmentation, and is related with the strenght and consolidation of the family house and with high celibacy rates. A more detailed qualitative analysis of demography in Fonsagrada for the period 1750-1860 can be found in Saavedra, 1979 and 2008. Even when this author offers population numbers for the whole region of Burón, which means that the parish of Negueira de Muñiz is also included, we use his data since parish composition would still change and Negueira was part of Fonsagrada until the territorial reform of 1835. Besides, the demographic trend within the whole region has little variations. Due to the nature of our sources and the changing parish composition of the municipality through the study period population numbers, especially until 1860s, are accurate enough although not exact.

Censuses from 1857 and 1887 offer data at municipal scale but for 1752 we have used Saavedra's datum, who collected it from the *Vecindario* of Ensenada's Cadastre, and also provides that of Floridablanca's census of 1787 and another one for 1826[105]. For the rest of the period, we have used INEbase population censuses at municipal scale, as we will detail in the corresponding section. Their reliability for this region has also been assessed by Saavedra (1979).

The following graph collects population data regarding different criteria as used in the original census. *De facto* population refers to the total number of people that were present at the moment when the headcount was done. When passers-by are specified, we have deducted them from this number in order to obtain a more accurate number of inhabitants. *De jure* population refers to the whole population that was entitled to live in the municipality.

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[105] For this year, Saavedra refers that two parishes are missing in the original source, Minaño's Dictionary. Thus he estimates total population to be around 15,000 people (Saavedra, 1979: 16). We leave the datum as in the original source because the region of Burón comprises a bigger territory than just Fonsagrada, and the fact that Negueira's population is included serves as balance for the missing data.

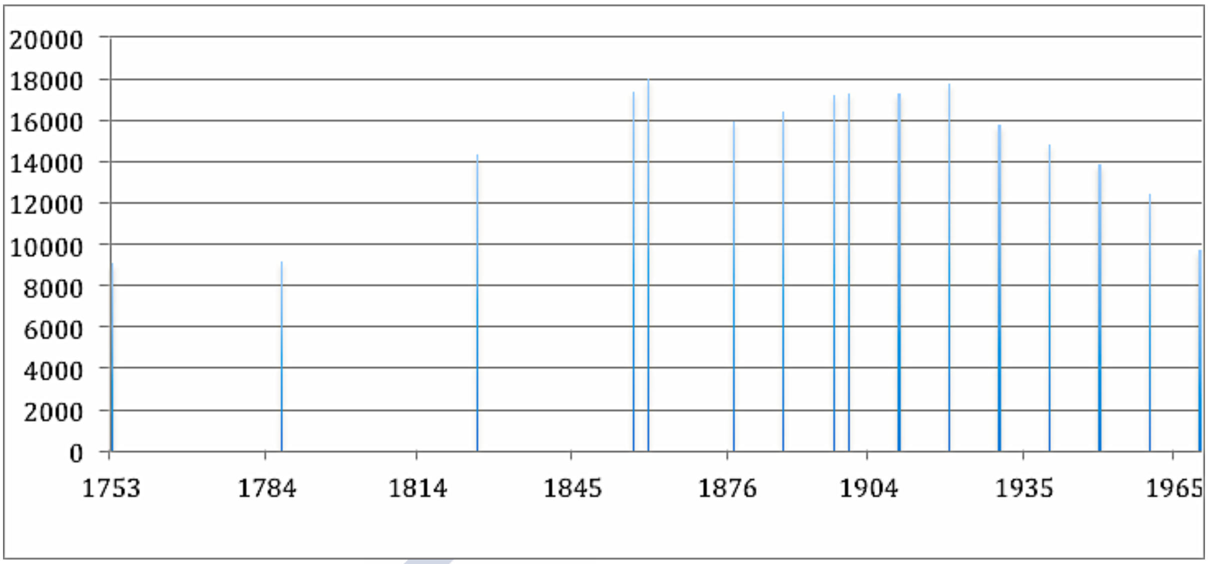
Chart 14. Fonsagrada. Population data, 1753-1970 (number of inhabitants)

	De facto population without passers-by	Total *de facto* population	*De jure* population
1753	9,099	-	-
1787	9,187	-	-
1826	14,289	-	-
1857	17,368	17,401	-
1860	18,014	18,018	-
1877	15,903	15,908	-
1887	16,419	16,419	-
1897	17,163	17,172	17,201
1900	17,294	17,302	17,448
1910	17,307	17,321	19,219
1920	17,744	17,750	19,861
1930	15,792	15,807	17,896
1940	14,824	14,832	15,455
1950	13,857	13,925	14,584
1960	12,423	12,423	13,090
1970	9,744	9,744	10,326

Source: data from Saavedra (1979) for 1752, 1878, and 1826, and INEbase population censuses for the rest of the period (http://www.ine.es/inebaseweb/libros.do?tntp=71807).

According to data from the first column of this chart, population density in the years of our study would be the following: 20.8; 39.7; and 37.4 inhabitants per square km in 1752, 1857, and 1887, respectively. The increase from the first moment to 1857, which is the datum we have taken for 1852, is indicative of the qualitative and quantitative changes performed in agrarian production. Population duplicates over this first century of the study period. The decrease in 1887 is a sympton of the expulsion of population which had been intensified after 1850s, when migration started to be definitive with the popularization of America as a destination. About a century later, population numbers are again similar to those of the 1750s, thus showing a typical demographic pattern in Galicia with an ageing society and demographic stagnation (Beiras and López, 1999).

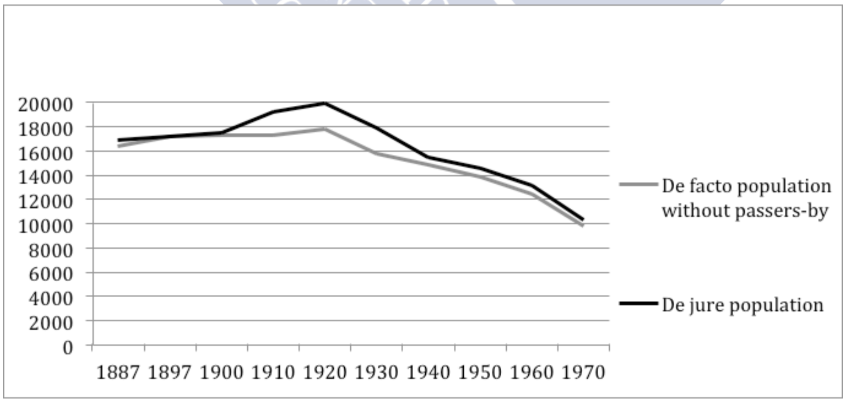
Graph 9. Fonsagrada. *De facto* population (without passers-by): 1752-1970



Source: data from Saavedra (1979) for 1752, 1878, and 1826, and INEbase population censuses for the rest of the period (http://www.ine.es/inebaseweb/libros.do?tntp=71807).

Saavedra's data allow to see how population remained stagnant between 1753 and 1787. As a contrast, the period 1878-1826 would be the most dynamic one, which continued until 1857 although at a lower pace. This population growth is connected with the introduction of potatoes in the region after the agrarian crisis of the last third of the 18th century, which forced peasants to start consuming this tuber despite their initial rejection (Saavedra, 1979).

Graph 10. Fonsagrada. Changes in *de facto* and *de jure* population: 1897-1970



Source: INEbase population censuses (http://www.ine.es/inebaseweb/libros.do?tntp=71807).

Graph 11 shows a common phenomenon within Galicia. We can only offer data from 1887 on because previous censuses did not collect *de jure* population data. The difference between the number of people entitled to live in Fonsagrada and the number of people who actually lived there, refers to absent people, either temporary or definitely. Definitive migration affected Fonsagrada as well, but mainly after 1850s and still more intensely in the first third of the 20th century and from then on, as the graph reflects. During the 18th century, the municipality was mainly composed of peasants, who represented about the 90% of the total population, and migration rates were much lower than the average in the rest of the territory of Galicia. The reasons for this reduced impact on mortality rates is explained by Saavedra in connection with an abundant and considerably diversified diet, which was based on rye, turnips (even for humans), chestnuts, and on a big livestock head that provided high meat availability. Between 1860 and 1910, the municipality would loose about 7,000 inhabitants to migration, thus resulting in deep demographic stagnation (Saavedra, 1979).

6.3.3. Changes in land use patterns and crop rotations: the First Wave of the Socio-Ecological Transition in Fonsagrada

The following sections deal with land uses and land productivity in Fonsagrada's agroecosystem. During the period 1750s-1890s, we can observe evidence of changes that have usually been associated with the so-called First Agricultural Revolution. In our case, as specified in the corresponding section, we refer to these changes as the First Wave of the Socio-Ecological Transition, thus indicating that it was just the beginning of a long-term process that would not conclude until later on in the 20th century with the incorporation of fossil fuels in agriculture. The Second Wave, which mainly refers to the use of inorganic fertilizers, can be identified in Fonsagrada and, generally, in the whole territory of Galicia, after the beginning of the 20th century although with different rythms (Fernández Prieto, 1992; Soto, 2006). Right before that moment, changes are related with an optimization of agrarian production within organic limits. And this is were we have put our focus.

Changes in surface, rotations and yields

In the case of Fonsagrada, and in most inner regions of Lugo, changes related with the First Wave of the SET were first experimented in *cortiñas*, which are enclosed plots with intensive management that Saavedra has documented at least in the 13th century. Legumes are cultivated in *cortiñas* at the time, and in the 16th and 17th centuries every *aldea* dedicates its own space to *cortiñas*, where turnips, linen, millet and other crops are cultivated. Manure is abundantly applied to these orchards, which produce at least one harvest a year. According to their intensive management, *cortiñas* are similar to vegetable gardens, and also used to be near the houses (Saavedra, 1979; López Fernández et al., 1987; Bouhier, 2001).

However, it is difficult to track changes in *cortiñas* with detail, especially regarding surface. In Ensenada's Cadastre data are not very specific about this type of rotation and its surface, and they do not appear any more in the sources for the 19th century. Thus we have excluded *cortiñas* from the balances, which could be feasable for some parishes in 1752.

In the aggregated analysis we consider only the main rotations, which are the ones we operated with in the nutrient balances and have detailed surface and yields information. Some other rotations such as wheat, oats or maize are very important in qualitative terms but are assigned with either a very small surface that is not representative of the agroecosystem, as in 1752, or not even assigned with surface data at all in the 19th century. For this reason we have excluded them from the aggregated scale and the nutrient balances as well, although they have been included in a more detailed description and general analysis due to their agronomic significance.

For a more structured description of the agroecosystem, we have considered the following rotations:

- Vegetable gardens
  - *Cortiñas*
- Cereal rotation (includes also potatoes and turnips in the 19th century)
- Meadows: both irrigated and non irrigated
- Chestnut groves (*soutos*)
- Vineyard
- Woodland
- *Monte*
  - *Estivada*: this rotation takes place on *monte* surface

According to Saavedra, the agrarian system as we know it in 1750s had already been conformed over a century ago, with mentions of rye, oats, spelt, millet, barley and legumes in *foro* contracts of the 13th century, although, except for rye, all of them were probably cultivated in *cortiñas* and vegetable gardens. The most common and abundant rotation all through the period, as it is the usual in the region, is rye: either in a biannual rotation with fallow or, progressively through the 19th century in association with potatoes and turnips, and without fallow. During the thirteen to fourteen months of fallow, pasture regenerates and livestock grazes on it. In the 19th century more meadows are created to balance the loss of pasture in fallow areas. According to Saavedra, meadows are not common back in the 17th century, and livestock is mainly sustained on *monte*. Chestnuts are also a fundamental resource, and wood is exported through the rivers, by floating the trunks down the valley towards near ports like Ribadeo or Navia (López Fernández et al., 1987).

Vegetable gardens and *cortiñas* are under annual production, which explains their reduced proportion within cropland. The cereal rotation at this moment produced only rye in Fonsagrada, which is one of the most basic foodstuff all through the study period. From this moment on, cropland surface would increase, at least until 1880s, as shown in the following chart.

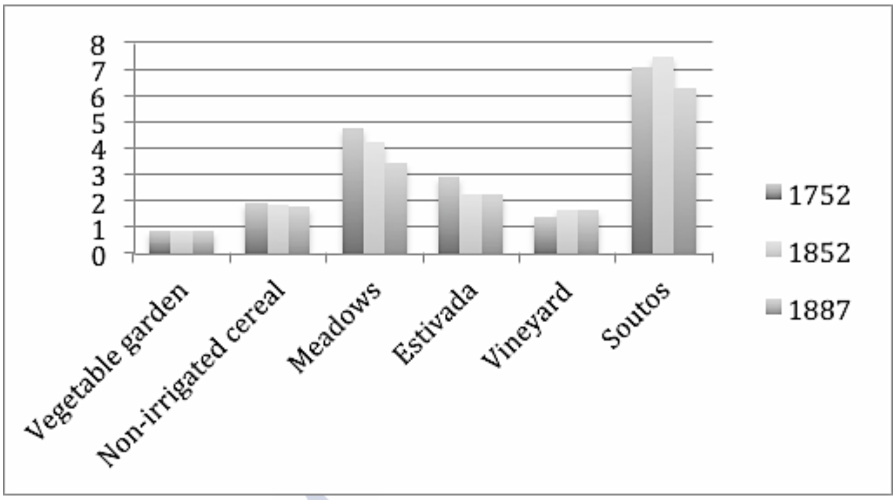
Chart 15. Fonsagrada. Cultivated surface in 1752, 1852, and 1887 (ha)

	1752	1852	1887
Vegetable garden	*33	101	69
Non-irrigated cereal rotation	1,603	3,041	3,379
Meadows	238	1,068	4,318
Vineyard	5	24	897
Soutos	124	213	608
Estivada (yearly cropped surface)	101	910	1,194
Total	**2,105**	**5,359**	**10,465**

Source: *Respuestas Generales* of Ensenada's Cadastre (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0), and *cartilla* from 1852 and agricultural stastics from 1887, APHL, Facenda, C14491.
*Includes *cortiñas*.

These data are mostly coherent with the general hypothesis that other authors had formulated for Galicia, according to which cropland surface would mainly increase between 1750-1850, and would from then on stagnate (Carmona, 1990). However, according to our data, the end of such process in Fonsagrada must have occurred after 1880/90s since the non-irrigated rotation still increased about 338 ha between 1852 and 1887, although its relative weight is more reduced when considering the whole expansion of cropland surface. Vegetable gardens do decrease between both moments but this must be related with the reduction of population after the beginning of a process of definite migration. Vineyard and chestnut groves must have been considerably under-estimated in 1752, however their increase between 1852 and 1887 is also very remarkable. Besides, yearly *estivada* surface, which provided an extra cereal crop, also shows a progressive increase through the period: 101 ha in 1752; 910 ha in 1852, and 1,194 ha in 1887. Finally, the biggest increase is that of meadows with 238 ha, 1,068 ha, and 4,318 ha, respectively. This is coherent with the livestock specialization trend that was common in the province of Lugo (Villares, 1982). At the end of the period, meadows surface is bigger than the cereal rotation, which used to be the most extense, and replaces *monte* surface as the main nutrient provider. In the following graph, we collect average productivity data for these different rotations.

Graph 11. Fonsagrada. Cropland productivity in 1752, 1852, and 1887 (t/ha, dry matter)



Sources: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *cartillas* of Fonsagrada from 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively, and agricultural stastics from 1887, APHL, Facenda, C14491.

The graph shows a decreasing trend and stagnation of land productivity in most rotations. In fact, overall productivity in cropland remains more or less the same all through the period although with a slight and progressive increase: 2.55 t/ha in 1752; 2.57 t/h in 1852, and 2.76 t/ha in 1887. However, we must note that the same yields have been applied to some rotations in all three moments and differences in productivity are mostly related with changes in the quality of cultivated soils. In the case of meadows, the decreasing trend can be explained by a bigger proportion of non-irrigated ones, which have lower yields. In vegetable gardens we have also applied the same yields all through the period and variations are only related with a different distribution of soil qualities. The decrease in the productivity of *soutos* in 1887 is mainly explained by the fact that first quality soils disappear from the declarations of this year and surface increases considerably in the other two qualities. In this case, yields are specific for 1752 but in the 19th century we applied chestnut yields from the neighbor village of Rendar[106] for both moments. Productivity is so high in *soutos* because wood and firewood extractions are included. Chestnut yields vary between 596 kg/ha in 1752, 880 kg/ha in 1852, and 623 kg/ha in 1887 (dry matter). The incidence of pests in the case of *soutos* and nutrient problems generally in all rotations could have also influenced this trend, especially in meadows, which have the most imbalanced levels of nutrients, as we will see. Changes in vineyard, are remarkable but mostly related with a different soil quality distribution. There is an initial increase of productivity from 1.34 t/ha to 1.62 t/ha between 1752 and 1852, which is accompanied with a slight surface expansion, and a later increase to 1.66 t/ha in 1887 as surface also expands hugely, especially in first soil quality.

[106] *Cartilla* from Rendar, 1852, APHL, Facenda, C14491.

Definitely, the most reliable data that indicate an exhaustion of the intensification pattern are those related with the non-irrigated cereal rotation and *estivadas*. In both cases, there is a decrease in productivity already between 1752 and 1852, even when it is not abrupt. These are the main rotations when it comes to food provision and the most intensively managed after vegetable gardens and *cortiñas*, which emphasizes the impact of their changes.

The non-irrigated cereal rotation includes only rye in 1752, mostly in a biannual rotation with fallow, and rye, potatoes, and turnips in 1852 and 1887 but without fallow. This is the most significant example of the intensification process in Fonsagrada. Net production in this rotation duplicates at the end of the period also in relation with a considerable expansion of its surface, but shows a decreasing trend in productivity from the beginning, which is certainly connected with this process of more intensive cropping and a higher level of extractions. This strategy drained nutrients from other surfaces by means of livestock conversion, mainly from *monte* at the beginning of the period and, increasingly, from meadows too. The process of nutrient mining is evident in the decreasing productivity of *estivadas*, which were also intensified all through the period by reducing the years of fallow between crops, apart from a remarkable expansion of their cultivated surface. The extensive component of this agroecosystem is also behind this decreasing productivity due to the expansion of the agricultural frontier over more inappropriate land for cultivation.

Finally, it is important to consider that our sources have reliability concerns. As explained in the corresponding section, fiscal sources used to conceal information in two main ways. Firstly, by under-declaring productions, and secondly, by reducing the surface of first quality soils and declaring more surface in second and third quality ones. We cannot assess this issue more accurately in this case but a combination of both frauds seems likely. This does not invalidate the conclusion of a general decrease and stagnation of land productivity towards the end of the study period, which is evident and also coherent in the long term according to nutrient balances. In fact, if more first quality soils and higher yields were declared, nutrient mining would still be more severe due to higher levels of biomass extraction. Our data show therefore conservative results, both in land productivity and nutrient balances.

Eventually, it is worth noting that most of the land in Fonsagrada was directly owned by nobility, mainly local *fidalguía,* who represented about the 80% of landtenants[107], before a 20% of ecclesiastics, and were also peasants in a 95% of the cases since less of the 5% of them could be considered wealthy and afford to pay labourers to work their land. Ecclesiastics represented about the 1% of population in 1787, and proceeded mainly from *fidalguía*. Thus, according to Saavedra, *subforo* contracts were not common in the region, which resulted in a relative lower rent pressure over peasants when compared with most of Galicia, where

[107] According to Ensenada's Cadastre, *fidalguía* could have been about a 15% of society. However, Saavedra questions the reliability of this datum since, according to the census of 1787, *fidalgos* represented a higher proportion of the population of Burón.

fidalgos had acted as intermediaries between ecclesiastics and peasants, thus contributing to a higher rent burden. Since most of the population was connected with agricultural activities, it is necessary to establish a certain differentiation according to access to land, livestock, and either active or passive rents. As a result, small peasants were the most numerous within Fonsagrada, representing up to the 83.6% of the agrarian population in 1750s. They had lower access to land (1.12 ha average), their livestock was abundant but most of it was under *aparcería* contracts, and many were in debt. However, Saavedra concludes that their socioeconomic situation had improved by the end of the century considering the consequences of the introduction of potatoes, and especially by the middle of the 19th century (Saavedra, 1979).

Regarding livestock tenure, *aparcería* contracts were the most common form of access to livestock by peasants in Fonsagrada, especially with the most marketable species such as bovine. This author studied seven parishes within the municipality of Fonsagrada and concluded that the 35% of bovine cattle was under *aparcería*. According to this contract, ¾ of each animal would belong to the owner, and ¼ to the peasant, apart from milk and manure. The same conditions applied in the case of calves, goats or sheep. Oxen, pigs and horses were shared in halves. According to Saavedra, market was not alien to the feudal production mode but only upper classes took advantage of such activities, being *aparcería* contracts one of their preferred businesses. Peasants benefited from the milk, labor, and manure of animals under *aparcería* but only from ¼ of the market revenue. It was namely the *fidalguía* members who took the most out of this contract (Saavedra, 1979: 53-54, 81).

Irrigated cropland: vegetable gardens and *cortiñas*

Garden crops are missing in sources except for surface data and some of the vegetables that are cultivated. Crops in vegetable gardens and their yields have been extracted from the *cartilla* of the neighbor municipality of Castroverde for the year 1888. This *cartilla* specifies different yields according to soil class. In the following chart we show average yields for every crop.

Chart 16. Castroverde. Yields in vegetable garden crops (dry matter, by-products not included), 1888

	kg/ha
Collards	480.27
Lettuce	29.00
Cabbage	58.47
Onions	33.92
Green beens	32.65

Source: *cartilla* from Castroverde, 1888, AHPL, Facenda, C14459.

These data have been applied to all the years we are studying, except for green beans, which we assume were not present in 1752. Therefore we are unable to describe this rotation accurately in Fonsagrada except for its surface changes.

In order to obtain annual Domestic Extraction in vegetable gardens in Fonsagrada and compare it along the study period, we have applied disaggregated yields from Castroverde to Fonsagrada's surface according to soil qualities. The following chart collects surface and domestic extraction with by-products, which have been estimated according to converters from Guzmán et al., 2014.

Chart 17. Fonsagrada. Vegetable garden surface (ha) and Domestic Extraction (dry matter, by-products included) in 1752, 1852, 1887

	Surface (ha)				Domestic Extraction	
	Soil 1	**Soil 2**	**Soil 3**	**Total surface**	**T/year**	**T/ha**
1752	4.81	4.95	3.98	13.73	**11.29**	0.82
1852	20.27	30.41	50.69	101.37	**81.99**	0.81
1887	15.67	22.65	31.15	69.47	**57.39**	0.83

Source: *Respuestas Generales* from Ensenada's Cadastre, 1752 (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *cartilla* from Castroverde, 1888, AHPL, Facenda, C14459; *cartillas* of Fonsagrada from 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively, and agricultural stastics from 1887, APHL, Facenda, C14491.

Variations in the surface and total Domestic Extraction of this rotation must be directly connected with the evolution of population, especially considering that DE is an indicator of demographic pressure. We do not have data between 1752 and 1852 to approach this issue more precise but, so far, both magnitudes seem to increase and then decrease according to the changes in population numbers. Thus DE in 1752 reaches 11 tons and matches a reduced population of about 9,000 people. This population has doubled by 1852, when annual DE reaches almost the 82 tons a year. In 1887 surface has been reduced in 31.9 ha when compared with 1852, and so has DE, decreasing to about 57 annual tons.

Fonsagrada's population started to decrease after 1860, with a slight recovery after 1877 but with stagnation mostly until the end of the century, and never reaching previous numbers in inhabitants again. We hypothesize that this stabilization between 1880s and 1920s is related with a new equilibrium within land uses and a more balanced management regarding soil fertility. This could be related with the introduction of industrial fertilizers, which allow to save land and labor since nutrients can be replenished with a lower use of meadow and *monte* resources and less manure production, but also with the fact that demographic pressure over the territory had decreased due to migration. Enventually, after the decade of 1920, the population decline is constant until today. In fact, the province of Lugo would be the most affected by depopulation after the 1950s, with the lowest population densities of all four provinces[108] and, along with Ourense, with the lowest percentage of the contribution to total Galician population (López Iglesias and Pérez Fra, 2004).

Regarding *cortiñas*, their most remarkable expansion had not yet quite started in the 18th century (Sobrado, 2001). However, even though their surface is reduced in Fonsagrada when compared with other types of cropland, *cortiñas* are very relevant in qualitative terms as experimental fields for intensification and the introduction of new crops (Bouhier, 2001). Therefore the situation in 1752 was a lot more diverse than sources would show in the 19th century, which probably left out minor rotations as well. We have not taken them into account in the aggregated analysis because their assigned surface is irrelevant within the agroecosystem and is only disaggregated in 1752. Their anecdotal presence in our sources reveals, however, an ongoing process of intensification that we see almost completed by 1852. In this year, other three rotations are mentioned but not even assigned with surface data: wheat, maize, and oats. We have excluded them from the aggregated analysis as well since it is impossible to compare them through the period due to scarce data in the sources.

According to Ensenada's cadastre, oat was cultivated in the manor (*couto*) of Padrón and the parish of Carballido. In the case of Padrón, it was part of a two year *estivada* rotation with rye[109]. Barley is mentioned in Seoane and in the manor of Lamas de Moreira, and wheat in Carballido, Seoane, Neiro and the manor of Lamas de Moreira. In this manor there was also maize, linen and millet, which are not mentioned in any of the other parishes, and the two last ones are not even assigned with surface nor yields data. Maize is the new crop which would eventually replace millet in Galician fields. It was not common to cultivate maize in the inner regions of Lugo, especially at the time of Ensenada's Cadastre, when it grew in some valleys where the weather conditions were less severe. It occupied first quality soils and it usually alternated with wheat, as it is the case in Fonsagrada (Pérez García, 1978; Saavedra, 1979; Sobrado, 2001).

On the other hand, linen would slowly disappear along with the introduction of foreign industrial textil products. Unfortunately, we cannot be more specific about its cultivation in Fonsagrada through the period we are considering. As referred by Saavedra, linen

[108] 52.9 cap/km2 in the province of Lugo, 68 in Ourense; 122.3 in Coruña, and 159.7 in Pontevedra in 1950; and 36.3 cap/km2 in the province of Lugo; 46.5 in Ourense, 137.9 in Coruña, and 201.1 in Pontevedra in 2001. Between 1950 and 2001, the coastal provinces of Coruña and Pontevedra would increase their population in a 12.8% and a 26.5%, respecetively, whereas Lugo and Ourense would lose more than the 30%, resulting in a bigger imbalance in the distribution of population and a further displacement of population towards the more Atlantic regions. The situation would be much more aggravated in rural areas, with ageing population and highly negative vegetative balances. The roots of such demographic stagnation and rural depopulation are, according to López Iglesias and Pérez Fra, in the drop of rural employment and in the belated and abrupt deagrarianization of society. Generally through the territory, higher rates of depopulation match earlier protagonism of agricultural activities. The underdevelopment of other economic activities did not offer other employment opportunities (López Iglesias, 2000; López Iglesias and Pérez Fra, 2004: 36-37).

[109] See the corresponding section on *estivadas* for more detail about this rotation.

manufactures were partially oriented to the markets in Castile, where they were taken by temporary migrants who worked on the wheat harvest. These labourers would also bring linen fibre back to Fonsagrada due to its local scarcity in order to satisfy the external demand. After the crisis of these exportations towards 1820/30s, linen manufactures would be limited to self-consumption. These economic exchanges with Castile would be in the origin of cattle exportation from Fonsagrada to this region too (Saavedra, 1979 and 1991; López Fernández et al., 1987: 96-99). Regarding oats, spelt, wheat, millet, barley and legumes, Saavedra has described them as minor crops within a context of rye predominance, and would therefore be cultivated either in vegetable gardens or in *cortiñas*. The author documented all of them in the region of Burón in the 13th century at least (Saavedra, 1990). Our data, and namely Ensenada's cadastre, seem to confirm such pattern. This source sometimes specifies which crops are part of *cortiñas* rotations. As shown in the following chart, their yields as declared in the cadastre are not higher than the average rye cultivation at the moment, wich has a productivity of 3.76 t/ha (dry matter, by-products included), but this is under a biannual rotation with fallow and *cortiñas* are cultivated annually and usually provide more than one crop a year, which sets a relevant qualitative difference.

Chart 18. Fonsagrada. Surface (ha), Domestic Extraction, and land productivity in *cortiñas* in 1752 (dry matter, by-products included)

		Surface	DE (t)	DE (t/ha)
Cortiñas	Annual rye rotation without fallow	1.41	3.97	2.82
	Biannual rotation rye/turnips	0.43	0.91	2.12
	Biannual rotation wheat/barley	0.14	0.52	3.72
Other rotations	a) Biannual rotation rye and maize*	8	23.25	2.91
	b) Biannual rotation wheat and maize*	8	25.00	3.13

Source: *Respuestas Generales* from Ensenada's Cadastre, 1752 (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0).

* a) and b) refer to one rotation only, in Lamas de Moreira, but as the source indicates it has two options in the first year, when either rye or wheat is cultivated. In the second year, maize is always cropped.

Turnips are documented in *cortiñas* in several places in 1752: in the parishes of Carballido, Seoane and the manor of Padrón. In Seoane, turnips are cultivated in a two year rotation with rye in second and third quality soils in *cortiñas*. Yields are specified in carts, which makes it difficult to determine their productivity. Therefore we have used turnip yields from the *La ganadería en España* (Ministerio de Agricultura, 1892) for all the years in our study. In the case of Padrón, it is clearly specified that it was a voluntary crop[110]. This relates to the spread of new crops in the region along with livestock stabling and demographic growth. Maize, turnips and potatoes are completely integrated in the agroecosystem by 1852.

[110] Ensenada's Cadastre, 1752, Fonsagrada, Padrón (*couto*), sheet 11,274.

In the previous chart we include "Other rotations" as well. This refers to the case of Lamas de Moreira, where there is a biannual rotation of either rye or wheat in the first year and maize in the second that is not mentioned within *cortiñas* in Ensenada's Cadastre. However, taking its crops and yields into account it is very likely a *cortiñas* rotation as well.

Main crops in this type of rotation used to be linen and turnips, but *cortiñas* were generally the experimental fields for agrarian intensification where new plants and crop associations were tested before expanding to bigger surfaces within the agroecosystem. Linen disappears progressively along with domestic industry due to the importation of fabrics from textil industries in Cataluña (Saavedra, 1979). Turnips served both for human and animal feeding and were common in the inner regions of Lugo, where livestock had also a bigger presence. Beans were common in this type of surface and other cereal crops such as millet, rye or wheat were also cultivated in *cortiñas* and harvested as fodder. Wheat was used only to pay the rents since clima and poor soils of the region where very limitant for its cultivation. Since rye was better adapted to these conditions, it was wider spread and represented the main component in peasants' diet (Sobrado, 2001). Turnips were also firstly introduced in *cortiñas*. They are one of the main crops in 1852 and were already present in 1752 in Santa María de Carballido, San Xoán de Seoane, and in the manors[111] of Lamas de Moreira and Padrón, although almost in an anecdotal way:

> *"...even though other seeds such as turnip, barley, millet and flax are cropped within this boundary, it is only in a small portion and indifferent to taxation since the already declared ones are the most common: wheat, rye, and mayze, as it corresponds to the substance and nature of the soil"* (Catastro de Ensenada, Fonsagrada, couto Lamas de Moreira, sheet 7607)[112]

Due to their reduced surface and multifunctionality, quantitative data on *cortiñas* are usually not specified in sources. This type of cultivated surface could not expand much as it required irrigation, a lot more manure than an average cereal rotation, and was therefore also more exigent in labor. *Cortiñas* also existed in the rest of the territory and adapted to the characteristics of the agroecosystem. For instance, along the Atlantic coast they were usually planted with vineyards (García Fernández, 1975; Bouhier, 2001).

It would be of interest to build the nutrient balances of these *cortiñas* rotations through time but, unfortunately, surface and yield informations are missing in the rest of our sources.

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[111] In Fonsagrada there are also two parishes called Santa María de Lamas de Moreira and San Xoán de Padrón. They did not belong together in 1752 but we assume that they were both eventually reunited under the same adscription of their corresponding parishes. According to Ensenada's Cadastre, the manors of Padrón and Lamas along with the parishes of San Xoán de Seoane and Santa María de Carballido seem to have developed the most dynamic and diverse agricultural practices within Fonsagrada. They all declare new crops such as mayze and turnips, even though in small amounts, and they still keep flax and millet, which would generally disappear from the agraricultural landscape along the 19th century.

[112] Own translation from orginal text: "*...aunque en el término se cogen también las semillas de nabos, cebada, mixo menudo y lino son cortas porciones e indiferente en los llevadores por practicar más comúnmente las que llevan declarado de trigo, centeno y maíz como correspondientes a la sustancia y fondo de la propia tierra*".

However, balances only for 1752 would offer important information and the task should be considered in future research, as well as the connection of such results with demographic data at parish and manor scale in the above-mentioned cases.

Non-irrigated cereal rotation

This is one of the main rotations of the region, where rye is cultivated, and where we can better appreciate the intensification process. Fallow disappears progressively between 1752 and 1852, cultivated surface grows, new crops are introduced, and total annual Domestic Extraction increases too.

Chart 19. Fonsagrada. Surface in non-irrigated rotation in 1752, 1852, and 1887 (ha)

	Soil quality	Rotation years	Crops	Surface
1752	Soil 1	1	Rye	333
	Soil 2	2	Rye/fallow	588
	Soil 3	2	Rye/fallow	682
			Total surface	**1,603**
1852	Soil 1	2	Rye/potatoes+turnips	325
	Soil 2	2	Rye/potatoes+turnips	961
	Soil 3	2	Rye/potatoes+turnips	1,755
			Total surface	**3,041**
1887	Soil 1	2	Rye/potatoes+turnips	485
	Soil 2	2	Rye/potatoes+turnips	897
	Soil 3	2	Rye/potatoes+turnips	1,997
			Total surface	***3,379**

Sources: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively, and agricultural stastics from 1887, APHL, Facenda, C14491.

* In 1887 potatoes and turnips are assigned a bigger surface than rye. Accorgind to the corresponding surface distribution in the sources (statistics from 1887, APHL, Facenda, C14491), rye is cultivated in 1,551.94 ha whereas potatoes and turnips are assigned with the remaining 1,827.11 ha. This differences have been taken into account when estimating average land productivity and domestic extraction with yields data from the *cartilla* of Fonsagrada from 1852 (APHL, Facenda, C14491).

First of all, we want to outline the complete disappearance of fallow between 1750s and 1850s. In 1752, the 20.75% of the surface of this rotation was declared as first quality soil and was cultivated annually. The remaining 79.25% could not produce without a year of fallow. Saavedra researched the region of Burón by analyzing crop rotations in detail in seven of its parishes, which all belong to Fonsagrada, and similarly concluded that the 23.6% was cultivated annually in 1752. Besides, this author mentions that first quality soils in 1752 could certainly produce more than one harvest a year, and mentions maize, turnips, and linen, which were typical *cortiñas* crops. Thus, the situation must have been more complex than the cadastre reflects, since a bigger part of first quality soils could actually be vegetable gardens or *cortiñas*. Besides, this author detects intensification signs already towards the end of the 18th century, with a higher presence of turnips and potatoes, which were introduced in the rotation with rye. Maize was occasionally present as well (Saavedra, 1979).

By 1852, fallow is no longer mentioned in the sources and this rotation has became biannual. Rye is cropped in the first year, and alternated with both potatoes and turnips in the second one. Once rye is harvested in July, then turnips are sown in late August or September. These tubers are harvested in February and, later on, potatoes are planted. After potatoes are removed from the land, rye is sown again. This crop association is not exclusive of Fonsagrada since this scheme was common in the inner region of the province (Sobrado, 1996 and 2001; Saavedra, 1979; Bouhier, 2001). It is important to mention that in 1887 more surface is cultivated with potatoes and turnips than with rye in the case of Fonsagrada. Besides, in 1852 other three rotations are mentioned but not even assigned with surface data: wheat, maize and oats. As explained before, we have excluded them from the aggregated analysis as well since it is impossible to compare them along the period.

The introduction of potato is associated with the supression of fallow but also with changes in both techniques and tools. The cultivation of this tuber requires deeper tillage and is more exigent in terms of nutrients than rye, thus increasing the demand of manure. Fertilizer is applied when potatoes are planted, and then less exigent crops would also take advantage of it. This means that manure was not applied yearly but only with potatoes (Sobrado, 2004).

Historiography relates the introduction of potatoes in Fonsagrada and the eastern regions of the province of Lugo with the agrarian crisis of 1768-69, which helped overcome the feeling of rejection towards this tuber. It had been cultivated since the 17th century, but only in an experimental and anecdotal way. Up to this hunger crisis, potatoes had only been used as animal feedstuff but with the consequences of the agrarian crisis and given the fact that this crop provided big harvests in small surfaces, it progressively became part of the polyculture system, thus feeding both people and livestock (Saavedra, 1979). According to Rodríguez Galdo and Dopico (1981), towards the end of the decade of 1830 potatoes were present in the 81-100% of the parishes of Fonsagrada, thus being completely consolidated in the region.

Obviously, all these changes allowed Domestic Extraction to increase, thus feeding an increasing population. However, with a high extensive component, land productivity in this rotation did not increase but, on the contrary, remained more or less stagnant.

Chart 20. Fonsagrada. Average productivity and annual Domestic Extraction in non-irrigated cereal rotation (dry matter): 1752, 1852, 1887

	1752	1852	1887
Rye grain (kg/ha)	852	589	587
Rye straw (kg/ha)	1,798	1,243	1,238
Potato tuber (kg/ha)	Not cultivated	656	666
Potato leaves (kg/ha)	-	405	411
Turnip root (kg/ha)	Not cultivated	619	630
Turnip leaves (kg/ha)	-	1,237	1,261
Total DE (t/year dry matter)	**3,012**	**5,488**	**6,034**
DE (t/ha dry matter)	**1.88**	**1.80**	**1.79**

Sources: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively, and agricultural stastics of 1887, APHL, Facenda, C14491.

In his research on the region of Burón, Saavedra concludes that yields as declared in Ensenada's Cadastre are considerably accurate. In this chart we have disaggregated by-products, which allows to assess global productivity of the agroecosystem by considering other useful productions such as straw that are usually not accounted for. We have estimated these yields in kg/ha of dry matter for more comparability. Unfortunately, we do not yet have similar research within Galicia to set a comparison. Available data so far have mainly compared grain yields, which are obviously decreasing, but the authors had not considered the rest of productions included in the same rotation nor the scale of the whole rotation itself.

In the case of Fonsagrada, productivity in the non-irrigated rotation remains stagnant all through the period. On the contrary, previous studies, which had focused only in the yields of the main products such as grain, potatoes and turnips separatedly, emphasized the yield decrease. This is evident in our data as well if we only take rye grain into account, but this decrease from about 850 kg/ha to 590 kg/ha (dry matter) is the coherent result of including more crops in the same rotation. Land productivity does not change much but Domestic Extraction in total tons of dry matter duplicates at the end of the period. It is important to consider that both potatoes and turnips have a high humid content, thus the increase in productivity is not evident when data are presented in dry matter. Most historiographical research so far had considered crops isolated from their rotations, especially when this was done according to provincial statistics, which disaggregated agrarian production by crop.

For instance, Pérez García indicates average yields for rye grain of 13-14 hl/ha (834 kg/ha dry matter) in regions with rye predominance towards the middle of the 18th century (Pérez García, 1982), and Dopico points out that rye grain yields no more than 12 hl/ha (741 kg/ha dry matter) at the end of the 19th century (Dopico, 2000). However, these authors do not account for the other crops that accompanied the rye harvest in a more complex rotation, namely potatoes and turnips, which are cultivated on the same soil in a biannual rotation. Considering all three crops into account and estimating an annual average yield shows that land productivity, at least in the case of Fonsagrada, remained more or less stable and, although with a decreasing trend, this is not as abrupt as when considering the main products alone.

This partial analysis has been used by other authors as well in order to prove that yields were decreasing generally in Galicia towards the end of the 19th century, thus affirming its backward character. See for instance Carmona's analysis on agricultural changes in the second chapter of his research on rural industries in Galicia (Carmona, 1990: 29-63). Our data do show this exhaustion of the intensification process towards the end of the century, but the situation is not as critical as depicted according to previous research, wich focused only on part of the agrarian productivity. The rotation scale had not usually been taken into account in previous research on Galician agrarian history except for Soto Fernández, who introduced it as a relevant parameter when dealing with land productivity. And it is also essential in order to accurately assess the impact of cropping on soil fertility (Soto, 2006).

Besides, we need to consider that declarations in fiscal sources used to conceal part of the wealth, both in yields and surface. As explained in the sources section, fraud regarding yields was not as common as reducing the surface of first quality soils, which used to be declared as second quality ones. If this were the case in Fonsagrada, our results on land productivity would be distorted, mostly in the 19th century when cropland surface reached its highest levels. We cannot be more precise at this respect but it is important to keep this in mind because even when stagnation seems obvious according to our data, the decrease in average land productivity could have been even less abrupt.

Meadows

Our data show that meadows did not use to be a relevant part of the agrarian system in Fonsagrada until the late 18th and early 19th centuries. At this respect, Saavedra has pointed out the importance of new crops with higher yields, namely potatoes, which allowed for more land availability by reducing the role of grains in the diet (Saavedra, 1994).

We assume that meadows are not fertilized because our sources do not mention such a fact. And taking their fiscal nature into account, it seems likely that manure was actually not applied since it is an expense and fiscal records prove reliable when it comes to the declaration of that sort of goods, which actually tend to be over-represented. However, it was common for meadows to be fertilized at the time in some regions in the inner Galicia, which shows that management adapted in order to compensate for the nutrient transfer from this surface into cropland. As the 19th century draws on, nutrient deficits arise in the agroecosystem. In fact, nutrient balances show problems in meadows all through the period. Nitrogen and potassium are not fully replenished to the soils in none of the moments of our study, as we will see.

Meadows in Fonsagrada are either irrigated or non-irrigated. Their uses and yields differ but are not clearly specified in the sources. According to both *cartillas,* irrigated meadows used to be cut twice a year, and non-irrigated ones were only used for grazing. Yields are unclear since they are only consigned in carts and most of the times grass is only assigned monetary value. Therefore we have used production values from the corresponging *Avance* (Ministerio de Agricultura, 1905), which are 6.75 t/ha in irrigated meadows and 2.88 t/ha in non-irrigated ones (dry matter). Sources are more specific when it comes to surface declaration. These data have been collected in the following chart along with estimated domestic extraction through the study period according to the above-mentioned yields.

Chart 21. Fonsagrada. Meadow surface (ha) and Domestic Extraction (dry matter): 1752, 1852, 1887

	Meadows	Surface (ha)	DE (t/year)
1752	Irrigated	115	774
	Non-irrigated	123	355
	Total	**238**	**1,129**
1852	Irrigated	456	2,769
	Non-irrigated	612	1,756
	Total	**1,068**	**4,525**
1887	Irrigated	939	5,393
	Non-irrigated	3,379	9,452
	Total	**4,318**	**14,847**

Sources: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively; agricultural stastics of 1887, APHL, Facenda, C14491, and Ministerio de Agricultura (1905).

The most striking fact is the surface increase of this rotation, which goes from 238 ha in 1752, to 1,068 a century later, and would still grow four-fold within the following thirty-five years. This is the territorial imprint of livestock stabling, which must have caused a dramatic change in the landscape. In 1752, most of livestock head was sustained on *monte* resources. One century later, bovine livestock must have been completely stabled, or at least we have assumed so in order to estimate manure availability at its maximum, which was already required at the time. The further increase in meadow surface is related with an increase in livestock numbers as well, as we will see in the corresponding section.

This trend is part of the configuration of an agroecosystem with a bovine specialization within an organic metabolism where livestock fulfiled a number of functions that went beyond the mere commercialization, since they were used for labor, milk, and transport before being sold. On the other hand, land availability made it possible for livestock to get stabled and fed *in* *situ*. However, nutrient balances will show how these changes within the agroecosystem affected soil fertility, since nutrients started to be extracted mainly from meadows, and not as much from *monte*, but without an equivalent nutrient return to the soil which *monte* received from animals when grazing or, in a different way, with *estivadas*. Animal excreta was not being deposited on the spot, but in stables, and was then taken to cropland but not to meadows, or at least not by now according to our sources. Our main hypothesis is that this reorganization of the agroecosistemic functionning is in the origin of nutrient imbalances since, eventually.

Chestnut groves (*soutos*)

Chestnuts had an important presence in peasants diet, but these cultivated forests also provided firewood, wood and pasture, especially for pigs, goats and sheep (Bouhier, 2001). The following chart collects data on surface and land productivity of this rotation.

Chart 22. Fonsagrada. Chestnut groves: surface, average yields and Domestic Extraction in 1752, 1852 and 1887 (dry matter, by-products included)

	1752	1852	1887
Chestnut (kg/ha)	596	880	623
Wood (kg/ha)	3,085	3,149	2,360
Firewood (kg/ha)	790	800	652
Pasture	1,600	1,600	1,600
Total DE (t/year)	752	1,370	3,182
Surface (ha)	**124**	**213**	**608**
DE (t/ha)	**6.07**	**6.43**	**5.23**

Sources: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively; *cartilla* from Rendar, 1852, APHL, Facenda, C14491; and agricultural stastics from 1887, APHL, Facenda, C14491.

The *cartilla* from Rendar, a village 100 km away from Fonsagrada, offers chestnut yields according to soil quality for the year 1852 which we have applied to Fonsagrada in both moments in the 19th century because data from the original *cartillas* were too low. Changes in productivity are mostly related with a different soil quality distribution, which is specified in the following chart.

Chart 23. Fonsagrada. Disaggregated surface (ha) in chestnut groves: 1752, 1852, 1887

	Soil 1	Soil 2	Soil 3	Total
1752	34	39	51	**124**
1852	61	71	81	**213**
1887	0	211	397	**608**

Sources: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *cartilla* of Fonsagrada, 1852, APHL, Facenda, C14491, and agricultural stastics from 1887, APHL, Facenda, C14491.

Firewood yields are from the *cartilla* of Castroverde (1888), which are also proportional to soil quality. Wood production has been estimated according to current specialized literature that also distinguishes soil qualities, of which we have taken the lowest values (Cabrera and Ochoa, 1997). It strikes us that there are no first soil quality groves in 1887. We can not know whether this is a mistake of the source or an intended concealment of surface. The possibility of a plague affecting only first quality groves seems unlikely. However, chestnut scarcity after these plagues also helped to progressively switch towards potato cultivation and consumption. However, the common trend in non-fertilized rotations such as *estivadas* and meadows is to decrease in yields as a consequence of soil exhaustion due to a long-term process of nutrient mining, which can also be applied to *soutos*. Besides, in the case of this rotation, part of the leaves were removed from the groves and used as livestock bedding, thus reducing the possibilities of natural nutrient replenishment through humus formation in the soil (Pfeiffer, 2004). This has not been incorporated in our estimates regarding productivity but has been taken into account for nutrient balances, which show net losses of nitrogen in this rotation. Besides, this is another example of how extensification ends up in diminishing returns due to the expansion over more inappropriate soils for cultivation.

Vineyard

This is not a common rotation in Fonsagrada due to its climatic requirements. Thus it was only cultivated in certain valleys with a proper orientation. In 1752 vines are mentioned in three parishes: Monteseiro, Sena, and Vilabol. The surface of this rotation increased all through the period and sources do not include it among the fertilized ones. Therefore we have not accounted for manure inputs in the elaboration of nutrient balances in vineyard. The following chart offers information on surface and land productivity in the three moments of our study.

Chart 24. Fonsagrada. Vineyard surface (ha), yields and land productivity (dry matter): 1752, 1852, 1887

	1752	**1852**	**1887**
Grapes (kg/ha)	88	215	233
Vine shoots (kg/ha)	566	566	566
Leaves (kg/ha)	574.34	574	574
Pomace	111	269	292
DE (t/year)	7.15	39.52	1,494
DE (t/ha)	**1.34**	**1.62**	**1.66**
Surface (ha)	**5.34**	**24.33**	**897.27**

Sources: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively, and agricultural stastics from 1887, APHL, Facenda, C14491.

Productivity increases between 1752 and 1887, although it remains within the same magnitude between the two last moments of the period. Yields for 1880's are missing in the sources of this decade, therefore we used those of 1852. Differences are related with a different distribution of soil qualities. Vineyards were not fertilized, and had considerable environmental limits to its cultivation in this mountainious region. It is stricking that sources of 1887 consign such a big surface for vineyard. We cannot know whether this is a mistake.

Woodland

Only cadastred in 1752 as oakwoods, we assume that this surface remains the same during the whole period, that is to say a total of 104.5 ha, of which 8.92 ha are first quality soils; 79.63 ha second quality, and 15.95 ha third quality. At least in the 18th century, these hectares seemed to correspond to the so-called *devesas reais*, which were enclosed wood surfaces that belonged to the State and were mainly composed of oaks in order to supply wood for the construction of navy ships. Such forests were, however, not abundant within Galicia (Balboa, 1990; Rey Castelao, 1995). Besides, this surface could have decreased through the study period regarding the process of mortmain abolition and the resulting deforestation of expanding agricultural and farming practices. According to the *Clasificación general de montes de utilidad pública* (Ministerio de Fomento, 1859)[113], in Fonsagrada only 32.68 ha were of state ownership towards the middle of the 19th century. But even when not all the woodland surface belonged to the State, we assume that the type of vegetation should have not changed a lot since it is mentioned in our sources that these woods used to be far away

[113] Its general reliability within Galicia has been stablished by Balboa (1990), especially considering those surfaces which belonged to the State.

from the villages, which made their exploitation difficult[114]. Even if the informers in our sources exaggerated, if we consider the huge uncultivated surface in Fonsagrada at the time we do not think woodland would have been completely chopped down. Therefore, we have considered that these 104 ha were still be populated with oaks at the end of the period.

We have accounted for a few important extractions in this surface: wood, pasture, and acorns. This results in a productivity of 8.66 t/ha (dry matter) all through the period, which is important in order to estimate nutrient balances because these extractions were not compensated with fertilizers. On the other hand, this wood complemented extractions from *soutos* as well, and acorns were an important complement in pigs nutrition.

Monte

In the case of Fonsagrada, the access to *monte* resources is determined by descent or lineage. These are called *montes de varas* and are characteristic of the northern half of Galicia, whereas *montes en man común*, where access is determined by neighborhood, are predominant in the southern half. Co-owners in *montes de varas* can actually sell their plots and, apart from the common appropiation of pasture or firewood, most other uses were individual (Bouhier, 2001; Saavedra, 1982; Balboa, 1990).

As mentioned before, *monte* satisfied a number of needs that referred to three main aspects in Galician agroecosystems: firewood, pasture, and bedding for stabled livestock, thus being a nutrient supplier for cropland. Pasture in this category does not refer to artificial meadows but to the multifunctional role of shrubland areas, where it was common for animals to live and/or graze. This pasture was composed of both spontaneous plants and those shrubs that were planted in *estivadas*, namely gorse but also heathers. Thus *monte* was mainly composed of shrubland, and has been interpretated both as "*support*" (Bouhier, 2001) and "*motor*" (Soto, 2006) of the agrarian system. According to Bouhier, the diverse functions of *monte* would remain the same during the intensification process, apart from a progressive decline of *estivadas*. According to Soto, changes in the appropriation of *monte* are the pre-conditions of intensification. Nutrient balances help explain what occurred in Fonsagrada, where *monte* appropriation adapted to changes in the management of soil fertility and lost protagonism before the expansion of meadows, which became the main nutrient suppliers for cropland at the end of the study period.

[114] *Respuestas Generales*, Ensenada's Cadastre, 1752, http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0; *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively, and agricultural statistics from 1887, APHL, Facenda, C14491.

Finally, Cardesín (1992) and Saavedra (1994) have also pointed out the essential role of commons, and namely of *monte,* as basic resource provider for poor peasants, who depended tightly on these areas for their subsistence. This also included hunting, fishing, and mainly wild harvesting since the first two activities used to be affected by feudal privilege. *Rebusque*[115]*, espigueo*[116] or the common appropriation of *rastrojeras*[117] were also part of the common pool resources but they usually took place in the *agras*. *Espigueo* was also practiced after *estivadas*.

In Fonsagrada, open and enclosed *monte* areas used to have the same kind of uses, except for the fact that *estivadas* mostly took place in enclosed ones, which generally had a more intensive exploitation, as historiography has confirmed. The distribution of *estivada* surface was done according to the individual property rights of each co-owner (García Fernández, 1975; Bouhier, 2001; Balboa, 1900; Cardesín, 1992; Pérez García, 2000; Soto, 2006). Other *monte* surfaces were declared as "unuseful" because they were either too rocky or steep for *estivadas* or regular appropriation, but could also provide some shrub or pasture.

Usually considered improductive by the administration, *monte*, and particularly shrubland surface, were not properly accounted for in fiscal sources. It was also easy to deceive the authorities, technicians or civil servants who ellaborated the cadastre and alike documents since they were either foreign and had no idea how the agrarian system worked, or local authorities who usually benefited their comunities. For all these reasons, *monte* surface was the most easily and frequently conceived or simply ignored in this kind of sources. Its main function as a nutrient provider for cropland is not obvious to those who are alien to the particular agroecosystem. Thus its huge value went unnoticed by the tax administration and even forest technical engineers. Apparently, it was mere uncultivated land which yielded nothing. This perception would later be in the origin of a political and pseudo-technical narrative geared to turn shrubland into "productive" surface through forestry. As a result, conflicts over this resource increased in Galicia since the late 19th century (Balboa, 1990).

For the same reason that its surface was not properly accounted for, yields of extracted products in *monte* are also very imprecise and given in carts or monetary value, or simply ignored. We have estimated average *monte* productivity in 8,968.22 kg/ha of fresh matter or 5 t/ha of dry matter. This datum has been estimated according to expert knowledge in the field (Sineiro, 1982; Egunjobi, 1971; Hernández Robredo, 1936) and to biophysical conditions and extractions in form of firewood, livestock bedding and pasture. The average datum of firewood extraction has been taken from the *cartilla* of Castroverde (1888), which assigns the following values according to soil quality: 4,325; 3,100; and 1,897 kg/ha (fresh matter).

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[115] After the grape harvest, small racemes left behind were open for common appropriation (Sobrado, 1999).
[116] With the same logic of the *rebusque*, *espigueo* refers to the *espigas* (ears) of grain crops left after the harvest, which were also a common resource in the inner province of Lugo (Sobrado, 1999).
[117] Stubble fields were common in its use after the cereal harvest during spring and summer (Sobrado, 1999).

In the following chart we present changes in *monte* surface according both to our sources and estimations. We have taken into account livestock and population requirements in order to assess the required surface of shrubland in each moment by considering firewood, bedding and pasture requirements. These data allow to contrast surface declarations in our sources and to establish a more accurate picture of the agroecosystem.

Chart 25. Fonsagrada. *Monte* surface (ha): 1752, 1852, 1887

	1752	1852	1887
Undeclared surface	35,921	5,644	285
Declared *monte* surface	1,914	15,360	*10,222
Total *monte* surface	41,554	38,300	33,194
Required *monte* surface	9,168	4,138	2,847
Cropland surface	2,105	5,359	10,465

Sources: *Respuestas Generales*, Ensenada's Cadastre, 1752, http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0; *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively, and agricultural stastics from 1887, APHL, Facenda, C14491.

*Estimated according to the increase in cropland in 1887 when compared with 1852 and its declared *monte* surface.

"Undeclared surface" has been estimated by deducting total declared surface in the sources (7,929.38 ha in 1752, 38,205.99 ha in 1852, and 43,565.38 ha in 1887) from the current municipal surface of Fonsagrada (43,850 ha), as previous researchers have done in other case studies (Villares, 1982). In 1887, however, undeclared surface is much higher but we have also considered our estimated *monte* surface as declared. *Estivadas* have been included in declared surface too, both their yearly cropped surface, and its corresponding fallow extension, which has been obtained by multiplying yearly cropped surface by the corresponding number of years in which the soil is left fallow. This would indicate a maximum in surface requirements for *estivada*, although actual surface must have been more reduced. Declared surface was shorter than indicated here because of the fact that we include fallow surface requirements as well, which have been calculated according to declared data. On the other hand, in 1752 other surfaces were declared too: 105 ha of oakwoods and 86 ha of urban areas and other useless surfaces such as paths or river streams, which we have also accounted for in 1852 and 1887 as declared surface.

"Declared *monte* surface" collects data as recorded in original sources, with the corresponding conversions into the metric system when needed. In the available documents from the 1880s *monte* surface is not declared, but annually cultivated *estivada* is. Thus we have estimated *monte* surface for 1887 on the assumption that the increase in cropland surface when compared with 1852 had been done over *monte* surface[118]. If we used the datum of declared

[118] 15,360-(1,194-910)-(4,318-1,068)-(897-24)-(608-213)-(3,379-3,041)= 10,222 ha

monte surface of 1852 also in 1887, total surface would surpass the current area of the municipality of Fonsagrada, which is unfeasible. Besides, this is coherent with the process of intensification and extensification of both cropland and *estivadas*.

"Total *monte* surface" has been estimated according to total current surface by deducting all declared surface which is not *monte*. This is an approximation to the maximum possible in *monte* surface and we have not used it in any of our biophysical estimations since a considerable part of this surface is unavailable due to steepness, rocks, rivers, etc. Fallow *estivada* surface has been accounted for as *monte* as well, since that is its actual use while not cultivated.

"Required *monte* surface" has been estimated according to biophysical criteria by taking into account firewood, pasture, and stable bedding needs of population and livestock numbers in every moment. In the case of firewood we assume that the minimum average consumption was of 2 kg/cap/day, according to Infante-Amate et al. (2014). In these estimates, firewood availability from woodland and chestnut groves has been taken into account too. *Estivada's* surface has not been included here because of its different treatment in nutrient balances. Although they took place on this type of surface, the management was completely different in the year in which the land was cultivated. Therefore, *estivadas'* surface did not obey to such strict biophysical requirements and were done whenever peasants deemed it necessary in terms of shrub regeneration or food supply. This issue will be dealt with in the following section.

Finally, "cropland surface" refers to the rest of managed land: vegetable gardens, the non-irrigated cereal rotation, meadows, vineyard, chestnut groves, and yearly cropped *estivada*, all of them as declared in our sources. This refers to the concept of Used Agricultural Area[119] as defined by Soto (2006) or López Iglesias (1995). Cropland, total *monte* surface, and data for urban surface and oakwoods as declared in 1752 represent the total of the municipality in all three moments.

Our data show that the main concealment of *monte* surface in our sources occurs in Ensenada's Cadastre, in 1752, when only 1,914 ha are declared. However, this is the moment in our study when it is needed the most (9,168 ha) and is actually more abundant (41,554 ha) since cropland and *estivadas* do not cover as much territory as they would a century later. Cattle has not yet been stabled and survives mostly on these areas, thus being pasture one of the main extractions on this surface within the context of a very extensive form of farming. Bedding is not required in such big amounts as later would be, but firewood is also an important extraction.

[119] *Superficie Agraria Útil* (SAU).

The *cartilla* from 1852 declares a much bigger *monte* surface: 15,360 ha, approximately half of its total surface, although only about 4,168 ha were required. Statistical reports from 1887 do not even account for *monte* surface at all, which could be an evidence of its more reduced role within the agroecosystem before the increasing presence of meadows. We have estimated this datum in two different ways. Firstly, according to our *cartilla* from 1852 and to the land use statistics from 1887 by connecting this datum with an increase in *estivada* and cropland surface as explained before. This would result in a total of 10,222 ha of *monte*. This does not mean that all of them were appropriated, since livestock bedding, pasture and firewood requirements were satisfied with only about 2,847 ha at the time, out of the near 33,193 ha of *monte*. Besides, a statistic document from 1876[120] accounts for a total of 8,666 ha of *monte*, which is quite coherent with our first estimated datum and with the trend towards the reduction of *monte* appropriation. Even when the document refers to the whole Judicial District, the list of parishes includes only those that belonged to the municipality. Currently, four of those parishes are part of the neighbor municipality of Negueira (Barcela, Ernes, Negueira, and Ouviaño). In the absence of more detailed sources, we assume that all the documents from the 19th century refer to this parish composition, which is the same as indicated in Madoz's dictionary for Fonsagrada's municipality (1846-1850, vol. VIII: 126).

Therefore, our estimates on *monte* requirements according to the requirements of pasture, livestock bedding, and firewood validate our sources in terms of surface distribution in 1852 and 1887, since required surfaces are lower than declared ones. The case of Ensenada's Cadastre is different, since this type of surface suffered a higher degree of fraud, as explained in the corresponding section. The main extraction on *monte* surface all through the period would be in the form of pasture, and its reduction is only evident at the end of the period, when meadow surface increases the most and relieves *monte* from this task of supplying animal foodstuff.

On the other hand, our data on required surface is an estimation which serves as an element of source contrast and to analyze shrubland appropriation but it does not correspond with actual surface, which was obviously much bigger. This also means that the limits to the intensification process were not exclusively dependent on the amount of shrubland surface available, which was more than enough in all three moments of our study. The quality of *monte,* distance, transport conditions and labor are obviously limiting factors when it comes its appropriation and nutrient mobilization.

Limits to intensification in cropland are mainly related with the fact that the role of *monte* within the system changes after the moment livestock is held in stables. And this fact determines that nutrients start to be mobilized in a different way. As we will see, livestock stabling supresses an important part of direct fertilization through fresh excreta on pastureland, both on *monte* and meadows. In the case of Fonsagrada, the appropriation of

[120] *"Estadística agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491.

monte surface to sustain livestock is reduced towards the end of the period in relation with this change in livestock management and its reduction. It could be argued that such abandonment of *monte* uses might have been related with soil exhaustion, as evidenced by the decrease in the productivity of *estivadas* and the results of nutrient balances, which show net losses of potassium in *monte*. But, on the other hand, cropland productivity is more or less sustained all through the period, which indicates that the provision or fertilizer from *monte* and meadows was quite satisfactory. On the other hand, if we consider appropriation under *estivadas*, it is true that *monte* surface would have had to be much bigger in order to allow for a longer fallow period that ensured total nutrient replenishment. We think that nutrient imbalances in meadows are also related with the fact that they expanded over *monte* surface, which ended up in a historical accumulation of nutrient depletion, first as *monte* with very intensive *estivadas*, and then as meadows which were not fertilized and did not receive enough animal excreta either. Agricultural intensification was only possible by expanding the agricultural frontier over *monte* surface. Thus nutrient stocks were mobilized from *monte* surfaces that had not been intensively cultivated so far, and increasingly also from meadows too. There was a problem of nutrient scarcity related with the expansion of cropland over its sustainable limits and the increasing demand of fertilizer, which drained nutrients mainly from meadows, but also from *monte* through *estivadas*. This practice of shifting agriculture was intensified as a result of the decreasing scarce food availability in relative terms, as we will see. As a result of this overall expansion of cultivated surface, the previous land equilibrium was altered and more land would be required in order to sustain cropland fertility without generating nutrient imbalances in more extensive surfaces such as meadows and *monte*. This is the origin of the metabolic rift between society and nature, and eventually refers to land scarcity in order to replenish soil fertility in a sustainable way.

The issue of nutrient transfers from uncultivated areas to cropland arises interest in other researchers, both in Galicia and in other territories, since it is basic in order to understand territorial balances and how intensification affected them. Thus it is useful to estimate *monte* requirements in order to sustain productivity in cropland area and to assess the impact of intensification on soil fertility as well as the limits of the whole process in terms of land use distribution. With different approaches, previous research has also tackled this issue. Bouhier concluded that an average of 1 to 2 ha of *monte* would be needed for every cropped hectare in Galicia. For the "Galicia of *agras*", where Fonsagrada belongs, requirements of *monte* are lower than along the more intensive agriculture areas of the south-eastern coast. Thus between 33-50% of the territory could be dedicated to permanent cropping (Bouhier, 2001). At the beginning of the 20th century, statistics show that *monte* occupied the 70% of the agrarian surface in Galicia, being cropland the remaining 30% (Fernández Prieto and Balboa, 2000). In the Basque Country, Olarieta mentions that 5 ha of bracken, gorse and other shrubs are required for bedding in an average household. The author points out at soil exhaustion in forest and shrubland areas in the region as a consequence of the intensification process that accompanied the introduction of maize, which had also been preceeded by extensification (Olarieta, forthcoming).

In the following chart, we present our own data for the case of Fonsagrada regarding *monte* requirements in relation with cropland fertility. As explained before, appropriated *monte* surface has been estimated according to livestock and population requirements in terms of bedding, pasture, and firewood. Cropland surface in this case refers only to fertilized rotations: vegetable gardens and the biannual non-irrigated rotation, which is composed of rye-fallow in 1752, and rye-potatoes-turnips in 1852 and 1887.

Chart 26. Fonsagrada. Changes in the requirements of *monte* surface (ha)

	1752	1852	1887
Fertilized cropland surface	1,637	3,143	3,449
Appropriated *monte* surface	9,168	4,138	2,847
Monte / Cropland	5.6	1.32	0.83

Source: *Respuestas Generales*, Ensenada's Cadastre, 1752, http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0; *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively, and agricultural stastics from 1887, APHL, Facenda, C14491.

These data show that the appropriation of *monte* resources varied all through the study period. Such changes are related to adaptations in the management of soil fertility and livestock according to the requirements of agricultural intensification. At the beginning of the period, *monte* occupied about the 95% of the agrarian surface. In 1852, this percentage had decreased to the 87.5% and by 1887 it reached the 75.8%. On the contrary, cropland percentage within the total agrarian surface increased from the 4.81% to the 12.24% in the first century, and to the 23.9% in 1887. The remaining percentages refers to woodland and urban surface in all three moments. This clearly indicates that cropland expanded its frontier over *monte* areas, as it had been demostrated generally for Galicia (Bouhier, 2001; Soto, 2006).

In 1752, *monte* surface was mainly used as pastureland, but firewood consumption was also responsible for high surface requirements in the rest of the period. In this initial moment, nutrients flew from *monte* to cropland through farmyard manure in an important proportion, but nutrients relied also considerably on fallow for their replenishment. Nitrogen was replenished in a 50% by fallow and in a 30% by manure, with a deficit of the 20%. In the case of phosphorus, replenisment takes place at a 100%, with a 32% coming from fallow and a 68% from manure. Potassium was replenished up to a 47% by fallow, whereas natural reposition during fallow replenished the 30%. There was aproximately a 23% of this nutrient which remained unreplenished.

In 1852, fallow is not mentioned in our sources any longer, and *monte* is still under an extensive management although tightly connected with agricultural intensification since it supplies considerable amounts of bedding material and pasture but livestock is now mostly kept in stables and does not graze directly on *monte*. Therefore shrub is collected for them as both foodstuff and bedding in order to optimize manure production in the stables. The *Avance* *de la ganadería* for the year 1891 mentions that livestock in the province of Lugo is stabled but also goes out for grazing according to the season, except for goats and sheep which are not kept in stables at any time (Ministerio de Agricultura, 1892, vol. II: 23). However, in order to obtain a maximum threshold in manure availability we have assumed that cattle remained in the stables all through the year, which has also been stated by historiography for the general territory of Galicia (Fernández Prieto and Balboa, 2000). Fallow has been now completely suppressed and, therefore, manure requirements are much higher than in 1752, which makes sense with this strategy of permanent stabling. Therefore manure is now the main fertilizer, and *monte* supplies are also complemented with foodstuff from meadows thus freeing part of *monte* required surface. In 1887, meadows acquire bigger protagonism as foodstuff providers for livestock, thus reducing extractions of pasture in *monte,* which explains why surface requirements have decreased. Fertility management is switching towards an increasing dependence on meadows, which are not fertilized, thus resulting in considerable negative balances in nitrogen and potassium in this type of surface, as we will see. The following chart compares the proportion between meadow and *monte* on one side, and fertilized cropland surface on the other.

Chart 27. Fonsagrada. Distribution of nutrient-supplying areas and fertilized cropland surface (ha/ha) in 1752, 1852, and 1887

	1752	**1852**	**1887**
Meadow ha/cropland ha	0.15	0.34	1.25
Monte ha/cropland ha	5.60	1.32	0.83
Meadow and *monte* ha/cropland ha	5.75	1.66	2.08

Source: *Respuestas Generales*, Ensenada's Cadastre, 1752, http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0; *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively, and agricultural stastics from 1887, APHL, Facenda, C14491.

Definitely, the role of *monte* as described in 1752 was incompatible with the process of agricultural intensification and paralel livestock stabling that we see almost completed about a century later. This was related with an increasing demographic pressure over the territory.

The role of *monte* as nutrient provider for cropland in the form of pasture decreases towards the end of the 19th century. Its main role as nutrient provider in 1752 was not so protagonic either, since fallow was also an important practice in the management of soil fertility. As the 19th century draws on, meadows take over as nutrient providers for cropland in the form of foodstuff for livestock, which is combined with *monte* resources for fertilizing purposes. However, this is not enough as to keep up with a satisfactory management of soil fertility since nutrient imbalances start to appear in the agroecosystem. Initially, there are 5.75 ha of nutrient-providing surfaces for every fertilized cropland hectare. A century later, this proportion has decreased to 1.66 ha, only to be slightly improved at the end of the period to 2.08 ha.

Eventually, nutrient imbalances arise in both meadows and *monte* since the first are not fertilized and animals are withdrawn from *monte* areas, where at the same time *estivadas* are taking place with a higher frequency and over bigger and bigger areas. Livestock stabling, on the other hand, allowed for this *estivada* intensification by freeing *monte* surface from pasture. This issue will be analyzed in detail in the following section.

In the absence of energy balances, we hypothesize that further intensification and appropriation of *monte* was not possible due to the lack of labor force but also because of the physical limits of the territory (steepness, poor stoney soils, etc.) and scarce land availability after a process of cropland extensification. Migration served as a valve to relieve demographic pressure over the territory but, at the same time, deprived agricultural tasks of labor force. The creation and maintainance of meadows was less exigent in terms of labor than practices associated with *monte* management. This explains the reduction of appropriated *monte* surface as well as the expansion of meadows, which increase between 1852 and 1887 even when definite migration had just started and population clearly started to decrease. Until the 1840s population had grown steadily, and *monte* appropriation could have been higher during this first part of the 19th century. We do not have any data for this period but we assume that the use of *estivadas* in order to improve food availability must have also triggered this general switch from *monte* to meadow as main nutrient provider for cropland.

Intensification of e*stivadas*

Estivada consisted in a form of shifting agriculture that took place on *monte* surface. It had a long fallow that was aimed at allowing the soil to recover after the harvest. This could last between thirty to fifty years in 1752, according to soil quality; and about twenty years in the second half of the 19th century. However, according to Saavedra, these numbers set a maximum threshold, and land could have been broken with a shorter or longer periodicity (Saavedra, 1979).

Estivadas had different phases. In a first step, shrub was cut and land was broken. Then shrub and clods were piled and burned. After that, ashes were scattered, which allowed for some nutrients to be replenished and pH to be slightly corrected. This basification is essential for the availability of some nutrients such as nitrogen, prhosphorus, potassium, sulfates, calcium, and magnesium. In a next phase, land was laboured and prepared for cultivation with the first rains of the fall. At best, two crops were possible (Bouhier, 2001; Balboa, 1990). However, in Fonsagrada most *estivadas* were done for only one harvest. Only a case of two harvests in *estivada* was described in 1752, which consisted of rye in the first year and oats in the second. The total cultivated surface under this form of rotation reached 5.9 ha annually in 1752, whereas 94.8 ha were dedicated to rye in an annual crop, and 0.7 ha to wheat. In the rest of the period, *estivadas* are declared as being only composed of a single harvest of rye.

Illustration 6. Burning clods and shrub in an *estivada*

Source: Bouhier, 2001, vol. II: 837. Unknown year, ca. 1960/70s.

According to García Fernández, *estivadas* were already consolidated in the 18th century as a result of the increasing demographic pressure over the territory and the need of extra crops (García Fernández, 1975). However, this author misses the main point why *estivadas* were done. Bouhier described *estivadas* as a way of regenerating shrub growth, namely gorse, because of its relevant functions within the agrarian system (Bouhier, 2001). According to Sineiro's research, this explanation actually makes sense in agronomic terms since gorse grows better after fire conditions (Sineiro, 1978). This means that, generally, agricultural intensification is accompanied by a paralel *monte* intensification as well, which was usually identified with the disappearance of *estivadas* in favor of more intensive gorse extractions. Gorse seeds would be sold and even selected for their improvement, and the shrub would be intensely cultivated. The span of time between cuts of gorse was more strictly observed in privatized surfaces, which also explains why they were more productive. Bouhier described the general disappearance of *estivadas* in Galicia usually during the 18th-19th centuries as a consequence of more intensive uses over *monte* which favored gorse production. Pérez García described this process for the south-eastern coast of Galicia and Balboa also confirmed these main conclusions (Bouhier, 2001; Balboa, 1990; Pérez García, 2000). However, in the case of Fonsagrada, there is a paralel process of intensification of *estivadas* as well which had not been described so far.

There must have been a very good reason to incorporate *estivadas* as a normal practice since they required a lot of labor. If most *estivadas* in Fonsagrada were done only for one harvest, we think that the extra crop was either not worth due to diminishing yields in the second year or, mainly, because the actual aim of this practice was not to obtain an extra crop but actually to regenerate shrub production. In Fonsagrada, according to the legal regime of *montes de varas,* every co-owner had the right to collect gorse from their particular plot or to enclose a specific portion of surface for *estivada*, which remained common again for pasture after the harvest (Bouhier, 2001).

According to Bouhier, *estivadas* were intensified if required but always attending to the soil quality in order not to deplete its fertility. This author emphasizes the empirical knowledge of peasants in their management of land, thus affirming that gorse production was not to be affected. Besides, Bouhier has contradicted technical opinions regarding the destructive and backward character of *estivadas*. They were never done on steep slopes, thus reducing erosion to the average of cropland areas, and fire had a positive impact on soils by reducing acidity and favouring mineralization. Besides, their main goal was to regenerate the growth of plants such as gorse and brooms, which are leguminous plants that increase nitrogen availability in the soil. By favouring the presence of young plants, symbiotic fixation rates were also higher than with older plants (Bouhier, 1984 and 2001). However, its role as extra food supplier should not be despised. Our data show that *estivada* provided with essential calories in the most critic moments of the 19th century.

Chart 28. Fonsagrada. The contribution of *estivadas* to food availability (kcal/cap/day) in 1752, 1852, and 1887

	1752	1852	1887
Total food availability	2,518.8	1,998.6	2,078.7
Supply of *estivadas*	78.6	278.1	377

Source: *Respuestas Generales*, Ensenada's Cadastre, 1752, http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0; *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively, and agricultural stastics from 1887, APHL, Facenda, C14491.

If we deducted the supply of cereal from *estivada* in our estimations on human diets, the nutritional state of population in both 1852 and 1887 would deteriorate considerably. According to Cussó's estimates on minimun nutritional requirements of Spanish population in 1860, an average diet should sypply with at least 2,270 kcal/cap/day (Cussó, 2005). In Fonsagrada, food availability without the contribution of *estivadas* in 1852 and 1887 would be of 1,720.5 and 1,701.7 kcal/cap/day instead of 1,998.6 and 2,078.7 kcal/cap/day, respectively. Therefore, *estivadas* contributed with about 250 to almost 400 kcal/cap/day in the average diet of the inhabitants of Fonsagrada in the second half of the 19th century, with a slight improvement towards 1880s which is related with a further expansion of cropland surface. The intensification of *estivadas* must have been driven by food scarcity, whereas it also resulted in soil depletion and decreasing land productivity in *monte*, as we will see.

On the other hand, the role of *estivadas* as food supplier in 1752 was irrelevant, since *estivada* contributed only with 78.6 kcal/cap/day in a moment when the rest of surfaces provided 2,440.2 kcal/cap/day, which was more than enough according to Cussó's estimates. In the section dedicated to food availability we will explain these issues with further detail. So far we just wanted to show that the role of *estivadas* changed through time in direct relation with the intensification process and its exhaustion. Thus, in 1752, when *estivada* mainly served to regenerate shrub production, *monte* was mostly used as the support of an extensive livestock head. Cereal was cropped because labor had to be done either way in order to restore pasture but it only contributed a 3.12% of the food availability for human consumption. The harvest was clearly not the target of *estivada*. Later on, this regeneration task was also required as *monte* supplied more livestock bedding than before, although these extractions were not higher than those of pasture, which means that *estivadas* were needed for both purposes, both shrub regeneration and the extra crop, which represented the 13.91% of food availability in 1852 and the 18.14% in 1887. This demanded a lot of labor and land too but probaly not as much as the process of manure production and further expanding and intensifying cropland, which required an increase in livestock head, daily gorse cuts, frequent renewals of stable bedding, and manure distribution on cropland. The intensification of *estivadas* can be interpretated as a result of reaching the physical limits of cropland appropriation after an intense process of demographic growth. Therefore, the main target of *estivadas* during, at least, the second half of the 19th century, is to provide cereal crops.

In the following graph, we collect *estivada* surface and its frequency in order to illustrate the process of both extensification and intensification through the study period. "Total *estivada* surface" is an estimation obtained by multiplying to annually cropped surface as declared in the sources by the corresponding years of fallow. It sets a maximum threshold in terms of land appropriation but it does not mean that all surface was actually used as *estivada* surface. Again, we need to remember that this fallow surface is appropriated as *monte* once shrub has grown again, thus providing pasture, livestock bedding and firewood.

Chart 29. Fonsagrada. *Estivadas*: yearly cropped surface (ha) and fallow duration (years) in 1752, 1852, 1887

	1752	1852	1887
	3 rotations	**Rye**	**Rye**
Annually cropped surface	101	910	1,194
Fallow surface	3,719	17,296	22,687
Total *estivada* surface	3,821	18,206	23,881
Fallow duration	**30-50**	**20**	**20**

Source: *Respuestas Generales*, Ensenada's Cadastre, 1752, http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0; *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively, and agricultural stastics from 1887, APHL, Facenda, C14491.

As mentioned before, in 1752 there are three different *estivada* rotations: rye (3,681.18 ha total), wheat (21.71 ha total), and rye and oats (118 ha total). The latter is the only one with two harvests in the first two years after breaking the land and burning the vegetation. The rest of them include only one harvest in the first year and are left fallow for the rest of the rotation, just as in 1852 and 1887. The main difference as we move forward in the study period is the increase in the frequency of *estivadas*, which is reduced to an average of twenty years and does no longer adapt to quality soils according to the sources. This does not mean that fallow was strictly observed and it must have actually been reduced in case of food scarcity (Bouhier, 2001; Balboa, 1990).

The following chart collects the limits of cultivated surface under *estivada* in order to ensure total nutrient replenishment with the specified fallow periods and compares such thresholds with actual cultivated surface. Data have been obtained with the average years required in every moment in order for each nutrient to be completely replenished, which varies from about five years for nitrogen, between eleven to sixteen for phosphorus, and between forty-seven to fifty for potassium. These rates of recovery have been estimated according to the results of nutrient balances and soil requirements.

Chart 30. Fonsagrada. Surface limits for sustainability in *estivadas* in 1752, 1852, and 1887 (ha)

	Sustainability limit in yearly cropped *estivada* surface			Actual surface
	N	**P**	**K**	
1752	725	296	**76**	101
1852	3,457	1,411	**361**	910
1876	4,534	1,851	**474**	1,194
	Total required surface for nutrient replenishment			**Actual surface**
	N	**P**	**K**	
1752	534	1,308	**5,111**	3,821
1852	4,794	11,743	**45,880**	18,206
1876	6,289	15,403	**60,181**	23,881

Source: *Respuestas Generales*, Ensenada's Cadastre, 1752, http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0; *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively, and agricultural stastics from 1887, APHL, Facenda, C14491.

The chart shows that the most balanced moment in terms of *monte* appropriation with *estivadas* is 1752, although problems with potassium are already present. The gap between required surface for nutrient replenishment after and *estivada* and actual appropriated surface increases as we move forward in the study period. Nitrogen and phosphorus are within sustainable limits all through the period, but imbalances in potassium could have also led to problems with other nutrients, especially phosphorus, which is generally scarce in *monte* surfaces nowadays (Gil Sotres and Díaz-Fierros, 1979). The following chart collects average productivity in *estivadas* all through the period.

Chart 31. Fonsagrada. Average yields and land productivity in *estivada* rotations: 1752, 1852, 1887 (dry matter)

Rye *estivada* rotation		**1752**	**1852**	**1887**
Rye grain (kg/ha)		785	612	601
By-products (kg/ha)		2,079	1,621	1,591
ED (t/year)		271.57	2,032	2,618
ED (t/ha)		**2.86**	**2.23**	**2.19**
Wheat *estivada* rotation		**1752**	**1852**	**1887**
Wheat grain (kg/ha)		1,121	-	-
By-products (kg/ha)		3,142	-	-
ED (t/year)		2.98	-	-
ED (t/ha)		**4.26**	-	-
Rye/oats *estivada* rotation		**1752**	**1852**	**1887**
Year 1	Rye grain (kg/ha)	836	-	-
	By-products (kg/ha)	2,214	-	-
Year 2	Oats grain (kg/ha)	302	-	-
	By-products (kg/ha)	731	-	-
ED (t/year)		12	-	-
ED (t/ha)		**2**	-	-

Source: *Respuestas Generales*, Ensenada's Cadastre, 1752, http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0; *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively, and agricultural stastics from 1887, APHL, Facenda, C14491.

In these estimates, by-products include straw, husk, and stubble. The average productivity of all different *estivada* rotations in 1752 is 2.91 t/ha. The decreasing trend in productivity can be appreciated by comparing only the rye rotation, which goes from 2.86 t/ha in 1752, to 2.23 and 2.19 t/ha in 1852 and 1887, respectively. This shows that the intensification of *estivadas* with a reduction in the number of years left fallow and an increase in cultivated surface ends up in a nutrient mining process which can no longer sustain the yields of 1752. The similar magnitude in the last two values confirms a decreasing trend towards stagnation. However, the same yields of 1852 have been applied to 1887 and variations in productivity occur mainly due to a different land use distribution. The decrease between 1752 and 1852 is the most significative at this respect, especially considering that wheat and rye/oats *estivadas* are not mentioned in the sources of the 19th century, and had remarkably high yields. The fact that *estivadas* expand over soils of lower quality towards the end of the period is also a sign of land scarcity for cultivation and results in diminishing yields.

Definitely, as pressure over *monte* pasture decreases along the 19th century with livestock stabling and the expansion of meadows, there is a wider margin for extensification and intensification in *estivadas*, which increase their frequency to every twenty years by 1850.

These *monte* crops are especially necessary towards the middle of the century regarding the increase in population numbers and a relative scarcity of food. However, as a result of this increasing pressure over *monte* surface, nutrient imbalances worsen through the period with a paralel decrease in land productivity. The results of nutrient balances confirm such trend too, as we will see in the corresponding section. Therefore, it is clear that land availability has been overtaken by the requirements of soil fertility, and there are not enough resources to restore nutrients to the soil in a sustainable way. The expansion of cropland and more intensive rotations regarding an increasing demographic pressure are in the origin of this metabolic rift. Besides, the reorientation in livestock management in order to produce manure in stables results in soil depletion in meadows and *monte* pasture areas, where nutrients are being extracted but not replenished any more due to the relocation of animals in stables. These imbalances could be lower had we accounted for more time of free-ranging on pasture, but this would not increase total nutrient availability and imbalances would still be present in the agroecosystem, perhaps in cropland too due to a lower manure availability.

Similar conclusions regarding this metabolic rift can be found in other European case studies such as Austria (Gingrich et al., 2015) or the Mediterranean Spain (González de Molina et al., 2012; Galán et al., 2012; Infante-Amate, 2014), which generally confirm the connection between increasing demographic pressure and more intensive land uses as described by Boserup (1967).

6.3.4. Livestock in Fonsagrada: from free-range animals to stabled cattle in less than a century

Livestock fulfils a number of functions that imply the whole scope of the agroecosystem, thus integrating its different elements and allowing matter and energy to flow within its boundaries. Domestic animals help complete the cycle of nutrients by means of their excreta, optimize agrarian production by consuming certain by-products, serve as a transport means, labor force, and allow peasants to dispose of cash when sold at the market (Martínez López, 2000; Saavedra, 1979).

However, livestock is an inefficient converter in terms of energy since its returns are lower than the required investment in terms of food and labor to raise the animals. In fact, the limit of the livestock head is determined by its competition with human food, but its services are essential within an agroecosystem, especially regarding manure production and specific agricultural tasks (Cussó et al., 2006; González de Molina and Toledo, 2011 and 2014). Therefore, such specialization represents a very costly option within an agroecosystem, especially when –as in our case– it means switching from a very extensive form of animal husbandry into a more intensive one which includes keeping animals in stables and the creation of meadows as well as cultivating specific crops for cattle such as turnips. This strategy is very exigent in human labor, but also in terms of land requirements. The following chart collects livestock requirements in terms of biomass extraction through the study period in percentages of total biomass extraction.

Chart 32. Fonsagrada. Required biomass extractions to sustain livestock (%)

	1752	1852	1887
From total biomass extraction	88	63	61
From cropland extractions*	67	63	61

Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; INEbase population censuses from 1857 and 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartillas* from 1852 and 1886, Fonsagrada, APHL, Facenda, C14491 and C14992, respectively; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491.
* This includes all cropland rotations (vegetable gardens, cereal rotation, meadows, vineyard, *soutos*, and *estivadas*).

In 1752, the 88% of the total biomass extractions are required to satisfy livestock needs, which include both foodstuff requirements and bedding for the stables. If *monte* extractions are excluded, then biomass requirements to sustain livestock represent the 67% of cropland extractions. In the following moments, both percentages are reduced and their proportion within total biomass extractions and the extractions exclusively from cropland are the same in both moments: 63% in 1852, and 61% in 1887. This is related with a bigger cropland surface through the period and a more reduced livestock head, except for 1887 when cattle increases again. A more intensive management of livestock reduced pressure over *monte* resources due to the introduction of fodder crops and a bigger meadow surface. Therefore livestock maintained its relative weight in the consumption of cropland extractions, although its percentage decreases progressively regarding the expansion of cropland all through the study period.

However, these high agroecosystemic requirements to sustain livestock are balanced with essential contributions in the form of manure and labor which, in turn, allowed for more intensive cropping. Livestock intensification led to stall feeding since stabling was aimed at obtaining more manure. Therefore, gorse and bedding materials had to be collected on a daily basis in order to be added to the stable when required, but also as foodstuff. Gorse could be cut all through the year, and especially in spring and summer. This operation, along with transport and manure production and application in the fields were estimated to occupy up to a 19% of the total time required by agricultural tasks (Bouhier, 2001). Besides, producing animal foodstuff competed with food production for population in terms of land, which makes it a costly option as well in terms of territory (Fernández Prieto and Balboa, 2000).

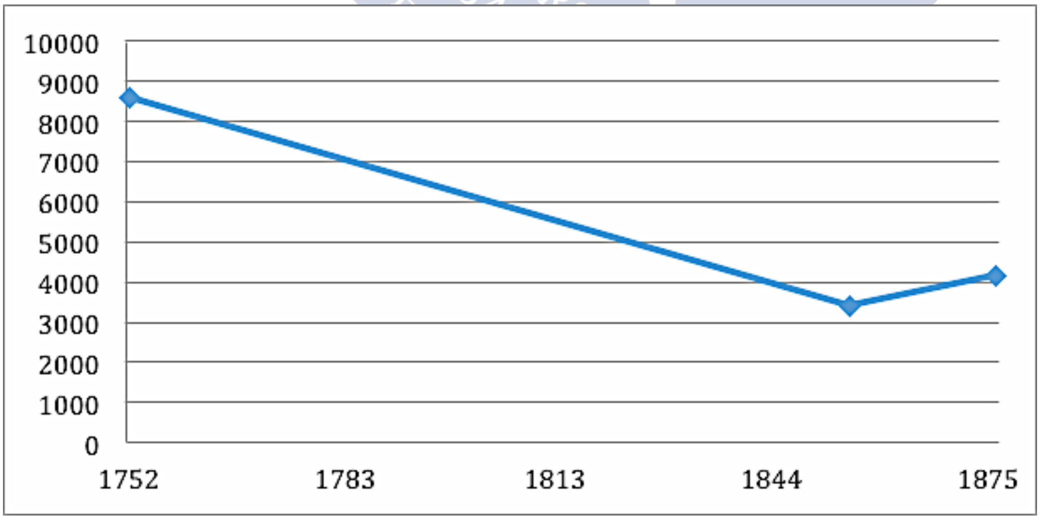
Changes in livestock head

The evolution of livestock numbers at local scale is quite uncertain due to the lack of sources and their reliability concerns, as it happens in the general of the Galician and Spanish territories that have been cadastred in the same periods (GEHR, 1991). However, in the absence of better information we have used what is available without further correction since it is not possible to know the exact percentage of concealed livestock, especially in Ensenada's Cadastre. This option offers the most conservative results, which is also convenient, and our method allows to assess its degree of internal coherence.

For the year 1752, the publication *Censo ganadero de la Corona de Castilla, año de 1752* (INE, 1996) offers all livestock data available in Ensenada's Cadastre for the whole Crown of Castile. We collected the data of all the parishes that belonged to Fonsagrada at the time. For 1852 and 1887 we have used data from two documents: a livestock *cartilla* from 1855 and agricultural statistics from 1876, respectively[121]. The document from 1876 refers to the Partido Judicial of Fonsagrada but actually only lists the parishes that compose the municipality at the time according to Madoz (1846-1850, vol. VIII: 126).

Livestock census data were converted into live weight by using converters from *Estudio de la ganadería en España,* referred to the year 1917 (Ministerio de Fomento, 1918), and then total weight was transformed into Livestock Units of 500 kg each (LU-500 kg)[122]. These data are represented in the following graph, thus allowing to see the changes in livestock numbers.

Graph 12. Fonsagrada (municipality). Changes in livestock head: 1752, 1855, and 1876 (LU-500 kg)



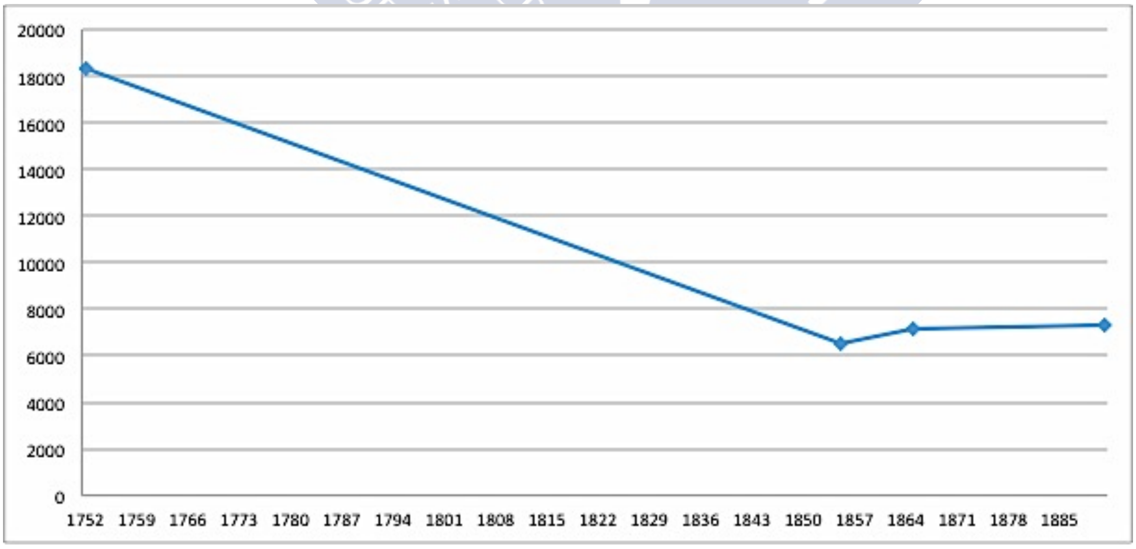
Source: *Censo ganadero de la Corona de Castilla* (INE, 1996), livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

[121] *Cartilla de ganado*, Fonsagrada, 1855, AHPL, Facenda, C14205; *Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada*, 1876, AHPL, Facenda, C14491.

[122] For more detail on estimations, see Appendix 1.

We do not have any intermediate information for the period between 1752 and 1855, although Saavedra affirms that the preference towards bovine livestock in the region can be tracked at least since 1760s, when the author documented an increasing litigation related to water supply, which is linked to the expansion of meadows (López Fernández et al., 1987).
The impact of the agrarian crisis of 1852 might have resulted in a decrease of livestock head (Rodríguez Galdo and Dopico, 1981), although not at the scale that the previous graph indicates: bovine head decreases from 5,584 LU-500 kg in 1752 to 1,953 a century later. This cannot have happened as a result of an agrarian crisis but as the result of a change in its management, that is keeping cattle in stables in order to produce manure near cropland areas. And the evolution is similar at the scale of the Judicial District (*Partido Judicial*) of Fonsagrada, which includes three more municipalities: Baleira, Meira and Navia de Suarna. For this comparison we have used other livestock censuses: *Censo de la ganadería de España* from 1865 (JGE, 1868), and *La ganadería en España* from 1891 (Ministerio de Agricultura, 1892). Data for the rest of period for these other three municipalities have also been extracted from the *Censo ganadero de la Corona de Castilla* for the year 1752 (INE, 1996), and from the corresponding livestock *cartillas* from 1855. This is relevant because data from the censuses of 1865 and 1891 had been strongly critized by the GEHR (1991) due to their under-estimated numbers, especially in the case of 1865. Our procedure validates both sources in relative terms and refutes their under-estimation in the case of Fonsagrada and Ribadavia. Besides, in the case of Fonsagrada, these sources also validate the trend indicated with the local *cartillas* and statistical documents we have used.

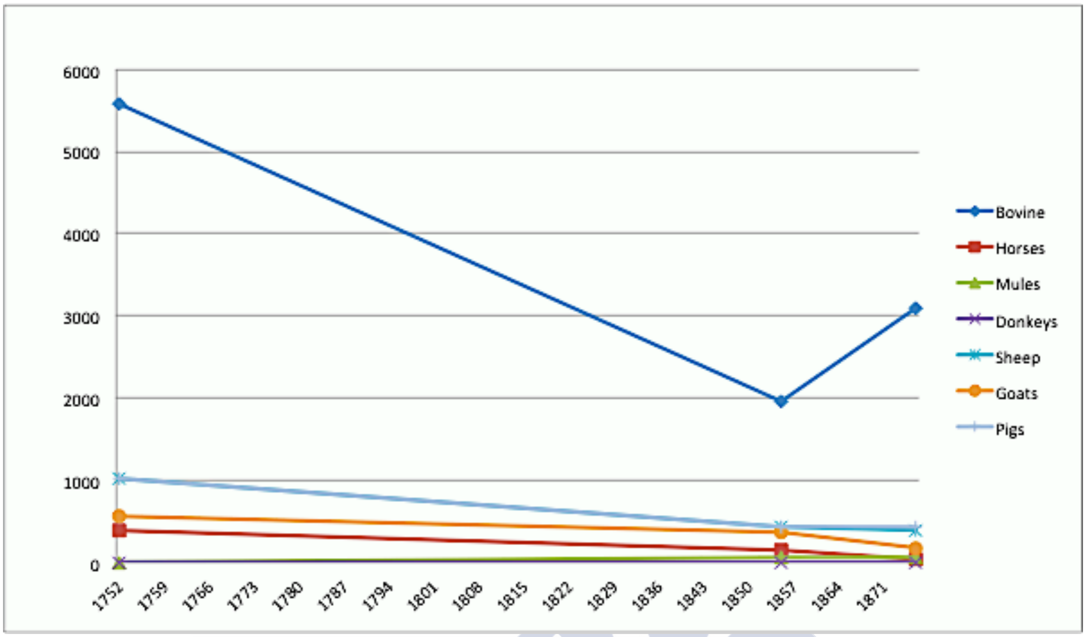
Graph 13. Fonsagrada (Judicial District). Changes in livestock head: 1752, 1855, 1865, and 1891 (LU-500 kg)



Source: *Censo ganadero de la Corona de Castilla* (INE, 1996), livestock *cartillas* from Baleira, Fonsagrada and Meira, 1855, AHPL, Facenda, C14205; livestock *cartilla* from Navia de Suarna, 1855, AHPL, Facenda, C14206; *Censo de la ganadería de España* from 1865 (JGE, 1868); *La ganadería en España* from 1891 (Ministerio de Agricultura, 1892); *Estudio de la ganadería en España* from 1917 (Ministerio de Fomento, 1918).

In the following graph and chart, which collect the same data, livestock changes in the municipality of Fonsagrada are disaggregated by animal type.

Graph 14. Fonsagrada (municipality). Changes in livestock head: 1752, 1855, and 1876 (LU-500 kg)



Source: *Censo ganadero de la Corona de Castilla* (INE, 1996), livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

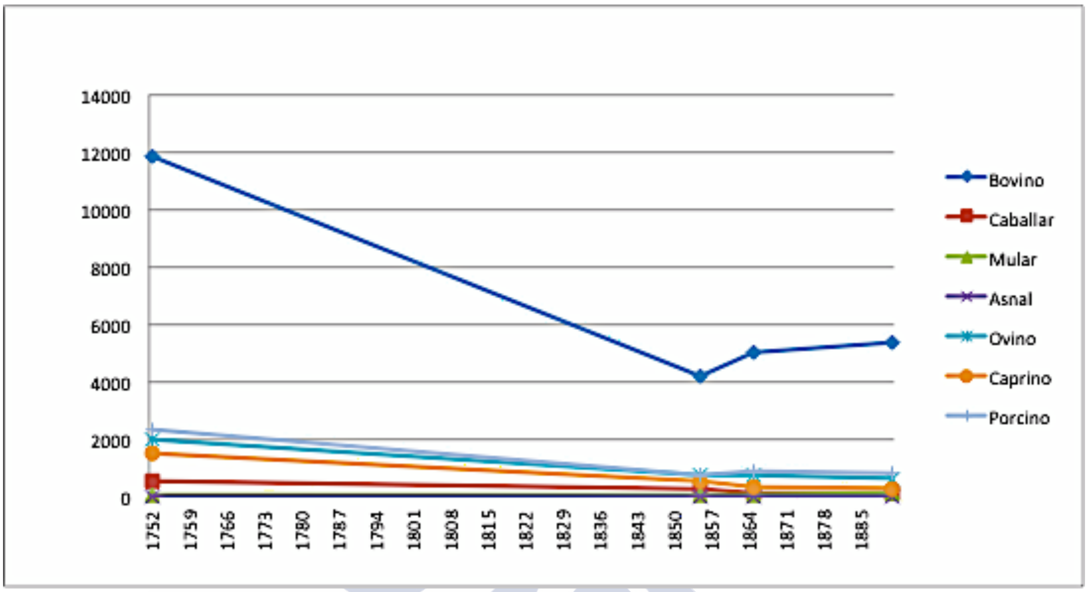
Chart 33. Fonsagrada (municipality). Livestock composition and density (LU-500 kg): 1752, 1855, and 1876

	1752	**1855**	**1876**
Bovine	5,584.80	1,953.60	3,093.60
Horses	397.20	142.20	31.20
Mules	1.80	67.20	51.60
Donkeys	0	0	4.20
Sheep	1,028.15	438.00	390.55
Goats	562.86	366.54	177.30
Pigs	1,017.48	438.24	423.48
Total	8,592.29	3,405.78	4,171.93
Livestock Density (LU/km^2)	**19.59**	**7.77**	**9.51**

Source: *Censo ganadero de la Corona de Castilla* (INE, 1996), livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Livestock density diminishes drastically between 1750s and 1850s, which is the key moment of intensification, when the whole system introduces adaptative changes in rotations, cultivated surface, and livestock management. The increase of livestock head in 1876 is related with the further advance in the intensive management of livestock in order to produce more manure, and is accompanied by an important increase in meadow surface. And, again, there is a paralel evolution at the scale of Judicial District.

Graph 15. Fonsagrada (Judicial District). Changes in livestock head: 1752, 1855, 1865, 1891 (LU-500 kg)



Source: *Censo ganadero de la Corona de Castilla* (INE, 1996), livestock *cartillas* from Baleira, Fonsagrada and Meira, 1855: AHPL, Facenda, C14205; livestock *cartilla* from Navia de Suarna, 1855: AHPL, Facenda, C14206; *Censo de la ganadería de España* from 1865 (JGE, 1868); *La ganadería en España* from 1891 (Ministerio de Agricultura, 1892); *Estudio de la ganadería en España* from 1917 (Ministerio de Fomento, 1918).

All these data indicate an important change in livestock management between 1752-1852. Unfortunately, there is no intermediate information apart from the census of 1787, which is not reliable according to Saavedra because of a very abrupt decrease in livestock head when compared with data from 1752. The author also verifies the recovery of bovine cattle regarding an increase of meadow surface towards the end of the 19th century, and hypothesizes the previous reduction of livestock in relation with the extensification that occurred before the introduction of potatoes (Saavedra, 1979).

The abundant livestock of 1752, namely bovine and porcine, could have not been kept in stables since it would have been physically impossible: houses in the villages would have been outnumbered by animals. Therefore, in order to do so, livestock head had to be reduced. This must have been a progressive process, but it implied that most livestock stopped being on *monte,* where animals grazed and lived, and started to be held in the ground floor of peasant houses. The chronology of the process is yet uncertain, but it occurred after 1760s and it was completed by 1850s[123]. The process must have started with the introduction of potatoes, which has been dated in the decade of 1780s (Saavedra, 1979).

[123] This matches what Grigg described for livestock stabling in Great Britain, where *"stall feeding [...] developed in the later eighteenth century but reached its apogee in the 1850s and 1860s"*. The first industrial

According to Saavedra, in the 18th century, the growth rates of these free-range animals were very slow and their slaughter would occur later than when stabled and fed with turnips, potatoes and fodder. The labor force of bovines must have also been weaker. Accordingly, meadows were scarce and livestock was not so intensely used for labor (Saavedra, 1979). Such animals could have not performed the agricultural intensification on the fields. They had to be better fed and looked after, especially regarding labor animals but also pregnant cows since calves were aimed for the market. These new requirements, added to an increasing manure need, are in the origin of keeping livestock in stables.

The protagonism of bovines is directly related with their multifunctional role within the agroecosystem: cows provided milk, meat, labor, and calves for the market. However, as it has been concluded before, this specialization was not market-driven and did not imply structural changes within the agroecosystem, apart from a considerable increase in meadow and fodder surface in the corresponding regions, such as the province of Lugo (Martínez López, 2000). Bovines were not oriented to either labor, milk or meat production, but supplied all of them at the same time, as it was common in organic metabolisms (Krausmann, 2004). Livestock specialization did not alter the productive and economic structure in significant terms but it was enough as to provide considerable monetary resources to certain peasant strata, who would eventually use them in order to get a ticket to America, which provided more monetary remittances, or to redeem *foro* contracts and gain access to land. After the end the 19th century, with the crisis of bovine exports to England, cattle would continue to be sold in Castile and other regions in the Peninsula (Villares, 1982; Carmona, 2000; Martínez López, 2000). Thus the foundation of a future economic specialization had been set down in the 19th century, along with major transformations of the agroecosystem in terms of intensification, and all of it in a context of a mixed farming agriculture which took the most out of the organic metabolism.

Manure availability

It has been hypothesized that manure scarcity limited agrarian intensification in Galicia along the 19th century, mainly regarding the difficulties of increasing livestock head and keeping the

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fertilizers (superphosphates) and *guano* from Peru and later on from Chile started to be incorporated to the soil after 1840s, although farmyard manure was the main source of nutrients in British farming between 1830-1930 (Grigg, 1989: 71-72). Products like guano or industrial fertilizers were not available in Fonsagrada nor generally in Galicia until about a century later. British imports of nutrients were part of its ecological imperialism practices, which were shaped according to a soil shortage in Europe. In fact, Cushman has linked industrialization processes with guano and similar fertilizing substances that were imported to the European metropolis, thus favouring the ecological conditions of an input-intensive agriculture and the related growth of population and industrial economies in the 19th century. The nutrient bottleneck was overcome by importing nutrients (soil) from the colonies in the Pacific World (Crosby, 1988; Cushman, 2013). This is another story, but to some extent it helps explain the different rythms of industrialization in Europe.

balance between cropland, livestock and *monte* in a situation in which gorse started to be cultivated in *monte* areas in order to obtain more prime matter for manure production (Soto, 2006; Fernández Prieto and Soto, 2010). This was mostly what happened along the Atlantic coast, in the most intensive agricultures (García Fernández, 1975; Bouhier, 2001; Balboa, 1990; Pérez García, 2000). In this section, our aim is to quantify manure availability and requirements in Fonsagrada.

Previous estimates used to be based on historical sources and observations of technicians in the early 20th century. For instance, Gallástegui concluded that about 16 tons of manure per hectare were needed every year in cereal cropland with an intensive cultivation. With potatoes, these requirements doubled (Gallástegui, 1958: 25). Later on, Bouhier estimated that at least 8 t/ha/year of fresh gorse were needed per cultivated hectare every year. This amount could easily duplicate in poor quality soils. Besides, these requirements increased continually through the 19th century along with agrarian intensification (Bouhier, 2001), which makes it still more difficult to determine accurate amounts withouth a biophysical approach. If a cart of gorse makes 1.5 carts of manure (Gil Sotres and Díaz-Fierros, 1979), Bouhier's gorse requirements would result in about 12 t/ha of manure. But such estimates are general averages and do not consider the requirements of specific crop rotations, which varied enourmously not only according to the crops but also to the different soils and climatic conditions.

In our case study, we have estimated fertilization requirements according to crop rotations and biomass extractions as described in the previous sections and including all kinds of by-products. Manure requirements refer to the minimun amount of fertilizer that would be necessary in order to completely replenish each of the nutrients analyzed in each fertilized rotation. We have also considered the main soil type, steepness and clima. Manure availability has been calculated according to livestock numbers as declared in the above-mentioned sources. Specific converters for the corresponding amounts of excreta of different animals and nutrient content of manure are from ASAE (2003), and bedding amounts from Soroa (1953) but also assessed with diverse data on local production[124].

According to our sources, only vegetable gardens and the non-irrigated rotation were fertilized. Therefore, we have not included other rotations even when they showed nutrient imbalances because manure was not applied to them. And, at this respect, sources seem reliable due to the fact that manure declarations compute as an expense, which is deducted from total income in order to estimate the final tax burden. In case of fraud, manure would be over-declared but never on the contrary. In fact, this seems to be the case in the *cartilla* from Castroverde of the year 1888[125], which we have used as contrast, and consigns much higher amounts of manure doses than our results. For instance, manure application reaches 18.31 t/ha in vegetable gardens, 18.31 t/ha as well in annual maize/potatoes, 19.15 t/ha in an annual

[124] See Appendix 1 for more detail.
[125] AHPL, Facenda, C14459.

turnip/linen rotation, and 15.94 t/ha in a biannual rye rotation with fallow. This last datum seems very exaggerated when compared with doses in the rest of annual rotations with up to two crops, and especially if we take into account that fallow could replenish most main nutrients in this type of rotation[126]. The *cartilla* from Cebreiro[127] from the same year consigns much lower values, which are disaggregated according to soil quality: about 6, 5 and 4 t/ha in vegetable gardens, annual rye and biannual rye with fallow. Such data seem less accurate than those of Castroverde but both have served as extreme values and orientated our manure distribution. On the other hand, even when meadows were frequently fertilized in Galicia, this was not the case in Fonsagrada, or not yet at least, and both *cartillas* from Castroverde and Cebreiro confirm such pattern.

Available manure has been distributed between vegetable gardens and the non-irrigated cereal rotation according to the best possible equilibrium for the different nutrients in both rotations. In the case of vegetable gardens, we have distributed as much manure as required by the most limiting nutrient, which was phosphorus, because this rotation used to receive abundant manure due to its intensive cropping but reduced surface. The *cartilla* of Castroverde confirms a higher manure dose in the case of vegetable gardens as well. Data are collected in in the following chart.

Chart 34. Fonsagrada. Manure requirements in fertilized surfaces in 1752, 1852, and 1887 (t/ha, fresh matter)

		1752	1852	1887
Vegetable gardens	N requirements	4	1.3	1.3
	P requirements	13	14.8	14.2
	K requirements	-2.94	-3.89	-3.75
	Availability	**13.0**	**14.8**	**14.2**
	Deficit	**0**	**0**	**0**
Cereal rotation	N requirements	2.39	6.42	6.59
	P requirements	1.33	2.34	2.21
	K requirements	2.39	6.87	6.96
	Availability	**1.34**	**4.26**	**4.80**
	Deficit	**1.05**	**2.61**	**2.16**

Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996), *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

[126] In the case of Fonsagrada in 1752, fallow in this same rotation replenished up to the 50% of nitrogen, the 32% of phosphorus, and the 47% of potassium.
[127] AHPL, Facenda, C14459.

Estimated availability refers to manure in stables, excluding animal excreta on pastureland. Availability in 1852 and 1876 has been estimated assuming that all bovine livestock is permanently held in the stable in order to optimize manure production. Intensive stabling has been described by previous literature (Fernández Prieto and Balboa, 2000). This seems too extreme for the case of Fonsagrada, but it is a conservative assumption in order to obtain the maximum manure and the most balanced nutrients possible. This would be the ideal situation for cropland in terms of nutrient availability.

Nitrogen must have never been a problem in vegetable gardens in Fonsagrada, but manure was not enough as to replenish this nutrient in the cereal rotation already in 1752. This deficit increases significantly in 1852, when it is more than twice that of 1752, but is reduced by 1887 in about half a ton per hectare with regard to the deficit of 1852. This means that peasant knowledge conducted further adaptations in the management of livestock and land uses in order to increase manure production and availability. This is the result of a bigger livestock head, which is at the same time connected with more meadow and generally more cropland surface.

Phosphorus is the most limiting nutrient in vegetable gardens, but there must have been enough manure as to keep its soil balanced during the whole study period. In the case of the non-irrigated rotation, this nutrient is also balanced. However, problems might have arisen with potassium, which is scarce already at the beginning of the period and, especially, towards the middle of the 19th century. However, potassium was not a problem at all in vegetable gardens since potential replenishment overtakes the requirements. Since vegetable garden is very reduced in comparison with cereal cropland, a transfer of manure from the first to the latter would not solve its deficits. Therefore, we assumed that the agronomic logic would aim to guarantee a complete replenishment of nutrients in vegetable gardens instead of showing imbalances in both vegetable and cereal rotations.

Regarding changes in management, it is interesting to consider total manure availability, which goes from 2,333 t/year in 1752, to 14,465 in 1855, and 17,193 in 1887. This is equivalent to an average manure availability of 1.4 t/ha, 4.6 t/ha, and 5 t/ha considering both fertilized rotations, with disregard of their particular requirements. The generally low availability for 1752 is explained by the fact that soil fertility relied not only in manure for nutrient replenishment but also on fallow. Nitrogen in the cereal rotation was replenished up to a 50.3% by fallow, manure supplied a 30.2% of the requirements, and there was a deficit of 19.5%. At the time, potassium was the most limiting nutrient in this rotation with the following replenishment supplies: manure provided the 29.6%, fallow replenished the 47.4%, and there was still a 23% of deficit. In the case of phosphorus, manure provided most of it, with up to a 68%, and fallow replenished the remaining 32%. This means that the management of soil fertility relied considerably on fallow for nutrient replenishment. These data are similar to those presented by Krausmann for Austrian pre-industrial agriculture (Krausmann, 2004).

Fonsagrada experiences a process of agricultural intensification and extensification accompanied with changes in livestock management as well. At some point between the middle of the 18th century and a century later, livestock gets stabled in villages and better looked after, which explains why there is more manure availability even though the number of animals decreases all through the period. This is the key fact that sustains more intensive rotations and a bigger cropland surface in Fonsagrada between 1752 and the late 19th century. Besides, livestock head would still increase between 1852 and 1887, thus improving manure availability and generally nutrient balances as well. Peasants must have certainly observed the decline and stagnation in land productivity shown in our data, which triggered further adaptations in agricultural management in order to supply cropland with more nutrients. This was, however, not completely successful and unsustainability problems started to be evident in the region. Extensification also resulted in a process of diminishing returns as the agricultural frontier expanded over less appropriate soils.

Manure availability had been quantified before in Galician historiography but mainly in carts per domestic unit, as recorded in historical documents. Its accountability in absolute terms is difficult with such sources but post-mortem inventories show that manure was more abundant in those areas where agriculture was more intensive, namely along coastal regions. According to Sobrado (2004), manure availability increased in a 15% in Cantabric Galicia during the 18th century when compared with the previous one, which occurs despite the reduction of livestock head. This is certainly connected with a more intensive management of animals too.

Our data regarding manure availability seem to confirm Sobrado's description, and indicate a much higher increase in manure availability during the 19th century. According to our data, manure availability in Fonsagrada increases up to 620% in 1852 when compared with 1752. From 1852, availability increases about 119% in 1876. In total, there is about seven times more manure availability in 1876 than in 1752. These data refer to an inland and mountaniuos region, where manure availability must have been a lot lower than in coastal areas as pointed out by Sobrado, which allows to think that the manure increase must have been a lot higher in the more intensive cultivated regions of Galicia. Besides, Sobrado is only accounting for declared manure in post-mortem inventories, whereas our estimations are based on livestock availability and take into account animal diets and their excreta, which allows for more accuracy.

However, this increase seems to have been insufficient according to our data for Fonsagrada. There were previous announcements of such a hypothesis, which was formulated generally for the whole territory of Galicia. For instance, Sobrado cites a report by Antonio de Salgado from the 19th century where it is said that the balance between cropland and *monte* should be restored in inland Lugo since cropping had expanded over inappropriate surfaces and manure availability could not meet soil requirements, particularly in *cortiñas* (cited in Sobrado, 2004: 63-64). Therefore, gorse is more and more frequently cultivated in *monte* areas, thus becoming its seeds a common market product towards the end of the 19th century (García

Fernández, 1975; Bouhier, 2001). Both García Fernández and Sobrado conclude that manure was more and more insufficient as the 19th century moved on, thus generating a proper context for the introduction of inorganic fertilizers. This must have been especially so for a great part of the Galician territory, especially along the Atlantic coast. The case of Fonsagrada proves that there was still margin to increase manure availability in the second half of the 19th century within an organic metabolism thus reducing manure deficits and improving nutrient balances in 1887 when compared with 1852. However, this was not enough as to achieve a sustainable management since such pattern was draining nutrients from meadows and other surfaces. Not all agroecosystems developed under the same conditions within the territory of Galicia, and most regions along the Atlantic coast, and even inner municipalities like Ribadavia, had much higher population densities than Fonsagrada and lower land availability which must have reduced such margins considerably. In the case of Fonsagrada, as in the whole of the territory, migration played an essential role, and it is no coincidence that it occurs more intensely during the second half of the 19th century, when seasonal migration switches mostly to definitive. Migration in Fonsagrada is the result of this adaptation in agricultural management, and allows both to achieve a higher food availability per capita and a relative decrease of the pressure over the territory towards 1887.

Eventually, we would like to consider those surfaces which were not fertilized but had nutrient deficits as well according to the results of nutrient balances. Our purpose is to measure the total amount of manure that would be needed in order to sustain balanced nutrient levels in the whole agroecosystem. In the following chart we have included manure requirements for all rotations once the available manure had been distributed to fertilized crops. *Estivadas* have been excluded because of their particular rotation system within *monte* surface but deficits in fertilized crops have been included as well. We have disaggregated the values of all three analyzed nutrients in t/ha of fresh matter, and then summed up the most limiting nutrient of each rotation in order to obtain a total maximum required per year. Each chart includes total manure availability to set a reference, but let us remind that these requirements are estimated after the available manure has been spread out on the fields. Therefore, the sum of both available and total required manure sets the sustainable amount of manure required. We intend to stress out that having a completely balanced agroecosystem in terms of these three nutrients is more than impossible in this case study. In 1752, nutrient requirements after fertilization are more than twice the availability of manure. Thus actual manure availability should increase 3.37 times in order to achieve a satisfactory level of nutrient replenishment. A century later, total requirements are about twice the availability. This relative improvement is a complementary consequence of the increase in manure availability, which results in more balanced nutrient levels in cropland but is also related with the process of nutrient mining in *monte,* meadows, and generally all types of woodland. Therefore, in 1887 the gap widened again to 3.19 times the availability. That is to say that a total of about 7,870 t; 29,518 t and 54,995 t of manure would be required in 1752, 1852, and 1887, respectively, in order to sustain a balanced soil fertility. Actual availability reached 2,332 t; 14,465 t and 17,193 t, respectively.

Chart 35. Fonsagrada. Required manure for total replenishment of nutrients in 1752 (tons, fresh matter)

	N	P	K
Vegetable gardens	0	0	0
Irrigated meadows	1,359	0	1,465
Non-irrigated rotation	679	0	1,442
Non-irrigated meadows	895	353	0
Vineyard	0	0	0
Chestnut groves	832	458	0
Oakwoods	904	253	0
Total	**4,669**	**1,065**	**2,907**
Maximum required after fertilization		**5,538**	
Manure availability		**2,332**	
Total requirements		**7,870**	

Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996).

If we do not consider chestnut groves nor woodland in 1752, since they would never be fertilized and were also not directly involved in cropland fertilization, total maximum required would be of 3,801 tons of manure, with disaggregated values of 2,933 t for nitrogen, 353 t for phosphorus, and 2,907 t for potassium.

Chart 36. Fonsagrada. Required manure for total replenishment of nutrients in 1852 (tons, fresh matter)

	N	P	K
Vegetable gardens	0	0	0
Irrigated meadows	3,905	0	4,060
Non-irrigated rotation	1,389	0	4,534
Non-irrigated meadows	4,100	2,512	0
Vineyard	0	0	0
Chestnut groves	1,522	1,495	0
Oakwoods	837	367	0
Total	11,753	4,374	8,594
Maximum required after fertilization		**15,053**	
Manure availability		**14,465**	
Total requirements		**29,518**	

Source: *cartilla* from 1852, Fonsagrada, APHL, Facenda, C14491; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205.

Without chestnut groves and oakwoods, the total maximum required decreases to 12,694 t, and total nitrogen, phosphorus and potassium requirements to 9,394 t; 2,512 t and 8,594 t, respectively. This means that total manure requirements would be more or less twice the availability. The following graph shows how the increase in manure availability between

1852 and 1887 is not able to fill the gap because it is sustained by draining nutrient stocks in *monte* and meadows. Besides, in this period, there is a further process of cropland extensification which increases manure demands.

Chart 37. Fonsagrada. Required manure for total replenishment of nutrients in 1887 (tons, fresh matter)

	N	P	K
Vegetable gardens	0	0	0
Irrigated meadows	6,986	0	6,021
Non-irrigated rotation	1,202	0	4,269
Non-irrigated meadows	22,025	9,506	0
Vineyard	0	0	0
Chestnut groves	3,685	2,230	0
Oakwoods	837	267	0
Total	34,736	12,002	10,290
Maximum required after fertilization		**37,802**	
Manure availability		**17,193**	
Total requirements		**54,995**	

Source: *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491.

Without chestnut groves and oakwoods, total maximun is of 33,280 t. Disaggregated values for nitrogen, phosphorus, and potassium are, respectively: 30,213 t; 9,506 t and 10,290 t.

In 1887, total manure requirements before fertilization achieve almost 55,000 tons. Out of these, only about 17,193 are available. Thus 37,802 more tons would be necessary to close the nutrien gap. This, so far, is impossible with the existing resources within the agroecosystem. The intensification and extensification of cropland is in the origin of this metabolic rift.

Definitely, adaptations in livestock management between 1752 and 1852 served to keep up with the increasing needs of fertilizers triggered by a process of agricultural extensification and intensification. As shown in the previous charts, meadows were the most costly option within this process and its complementary livestock specialization. In 1852 the situation could have led to a more or less balanced situation regarding manure availability and requirements, but further expansion of cropland until, at least, the decade of 1880, along with a previous process of nutrient mining in surfaces such as meadows and *monte* constrained the margin of improvement. This combined process of extensification and intensification was performed on the basis of a constant nutrient transfer from more extensive land uses to the more intensive ones, thus depleting the soils of the first in the benefit of the latter. Such expansion of the agricultural frontier over *monte* areas depleted its nutrient stocks, thus originating a metabolic rift. On the other hand, this expansion of cropland took place over less appropriate areas for cultivation, which also contributed to a decreasing productivity.

Changes in manure management

In the previous section we detailed changes in livestock management that determined an increase in meadow surface and a progressive complementation in cropland fertilization with nutrients from both *monte* and meadow surfaces. At the beginning of the study period, livestock in Fonsagrada spent most of the time on *monte,* thus their excreta was directly returned where they extracted nutrients from. Meadows also received part of this excreta but we also considered such surfaces as food reservoirs for the winter in the form of hay, thus reducing the time in which cattle grazed on it. Considering the nutrient replenishment rates of fallow in cropland, only a small fraction of these animals must have been kept in stables in order to obtain manure for cropland, mostly for vegetable gardens. As cropland expands and rotations become more complex, we assume that livestock gets stabled in the villages in order to accumulate nutrients near cropland and have the manure ready to spread at the very moment of sowing. This is an assumption that has not been confirmed in our sources and we are aware that livestock must have spent more time on meadows and *monte* pasture than we have accounted for. We have already explained that this is a conscious decission and it is aimed at obtaining a potential maximun of manure availability in order to determine the best possible situation regarding nutrient balances.

We are also aware that yields are underestimated in fiscal sources, therefore our results offer the best possible scenario regarding soil fertility in all three moments of our study. With higher yields and a more extensive livestock management, nutrients would certainly show more imbalances in cropland because our decission affects mostly the distribution of nutrients but not its total availability in a considerable magnitude. If animals were allocated more time on meadows or *monte* pasture, soil nutrients in these surfaces would be more balanced due to the contribution of animal excreta but cropland would show a more defficient replenishment of its fertility due to a lower manure availability. On the other hand, human excreta was conveniently added to livestock manure, especially considering that animals used to be kept in the ground floor of the houses, right below the human living area. We have not accounted for human excreta in this research, although it should be summed up in the future. This issue would require further research, and there is a useful example on how to approach the topic in Galán, 2015.

All in all, there is an environmental cost to stabling livestock which is related with the management of meadows as nutrient providers. These surfaces are not fertilized during the period we are considering, and do not receive enough animal excreta since livestock remains in the stable most of the time in order to accumulate manure, thus nutrients are no longer replenished to the soils where they are being extracted from. In 1752, when *monte* was under a more extensive management, replenishment occurred naturally on the spot. When *monte* stops receiving animal excreta and *estivadas* become a more intensive practice, nutrient imbalances appear in the soil, as we will show in the following sections. In the case of meadows, this is still worse because of their more exigent management: meadow production is higher than shrub in *monte* and extractions are certainly more intensive. However, livestock spent more time on both *monte* and meadows between the spring and early winter at this moment than later in the study period, as permanent stabling consolidated. We have assumed that, in 1752, animals spent most of the time on *monte*. After 1852, we have assumed that permanent stabling had become a common practice, especially for bovines. In fact, they must have grazed on meadows as well according to *La ganadería en España* (Ministerio de Agricultura, 1892, vol. II: 23), which informs on the mixed system of stabling and grazing in the province of Lugo for all types of livestock except for sheep and goats. Unfortunately, this issue cannot be properly quantified and, in the absence of better data we have assumed that bovines were kept in the stables through most of the year. The following chart collects our distribution of animal excreta in percentages.

Chart 38. Fonsagrada. Allocation of animal excreta (%)

	1752	1852	1887
Stable	5.2	92.3	74.9
Monte	94.1	0	0
Irrigated-meadow	0.3	2.5	3.9
Non-irrigated meadow	0.4	5.1	21.1
Oakwoods	0	0.1	0.1

Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); *cartilla,* Fonsagrada, 1852, APHL, Facenda, C14491; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *cartilla* of Fonsagrada, 1886, APHL, Facenda, C14992; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491.

This distribution has been done according to nutrient requirements in fertilized rotations, changes in land use and in the size of livestock head. Therefore, with a bigger livestock head in 1752, animals were mostly allocated on *monte*, where they deposited most of the excreta. In 1852, with a much smaller head, we assumed that bovines spent most of the time in the stable in order to produce the necessary manure for an intensified cropping. In 1887, with an increase in the number of animals, more livestock was allocated on meadows. *Monte* pasture was also required in both moments, although primary crops and meadow surface satisfied most of their nutritional requirements, especially in 1887. We have not allocated livestock on *monte* because its percentage in animal nutrition was not relevant, even when they must have indeed spent time on this surface, espcially goats and sheep, which are usually not stabled. Our decision simplifies estimates and implies that the required complement of *monte* pasture was collected and given to both bovines and equines in the stable, which they used to eat grindered and mixed with a fraction of primary crops such as turnips, maize or potatoes (Hernández Robredo, 1936; Sineiro, 1983; Balboa, 2000).

Thus, our results show the worst possible scenario regarding nutrients in meadow surface, but also the best one for manure availability after 1850s. The actual situation was certainly different but this does not change the unsustainable pattern followed by livestock specialization in Fonsagrada since the lack of nutrients that we see in meadows according to our data would simply be relocated in cropland due to the scarcity of land to replenish soil fertility in a sustainable way. Nutrient availability was limited, and must have constrained the degree of crop extensification and intensification towards the end of the 19th century as well. The fact where we allocate such nutrients, whether in meadows by grazing during part of the year or in farmyard manure with permanent stabling, does not make a considerable difference in the amount of available nutrients, even when their efficiency in terms of nutrient replenishment is slightly higher when excreted on the spot than with the process of manure production. This has to do with losses associated with fermentation and with the fact that most of the nutrients excreted by animals are contained in urine, which is more difficult to retain when animals are stabled even if the use of absorbent bedding mitigates such losses[128]. About half of the nitrogen and potassium in manure comes from urine. However, nutrients in urine are more easily lost than those of feces due to their soluble form, which can rapidly leach or vaporize when manure is exposed to air. This explains the high deficits of both nutrients in meadows. On the other hand, even if part of the nutrients in manure is lost due to oxidation, fermentation or leaching[129], the organic matter content is hardly lost, which is an important advantage of using this type of fertilizer (Logsdon, 2010; Pfeiffer, 2004). Bad practices regarding manure management such as exposing it to air have been documented in Galicia towards the end of the 19th century (Sobrado, 2004). In our estimations, standard losses of nutrients have been taken into account.

Definitely, the switch to a more intensive management of livestock allows for more manure availability for an expanding cropland. On the other hand, it triggers a process of nutrient mining in the surfaces where they are mobilized from, especially in the case of meadows. The territorial cost of sustaining soil fertility in cropland overtakes the limit of the agroecosystem due to land scarcity for the replenishment of all nutrient extractions without depleting these stocks in other surfaces. Besides, since both nitrogen and potassium are highly imbalanced in meadows, phosphorus could have been too due to their interdependent functioning in soils, even if its levels seem to be alright in our results. This matches the pattern described by previous research on fertilization in European agricultures, where processes of nutrient depletion are evident in woodland and pastureland, which generally functioned as nutrient suppliers for cropland (Shiel, 2006b; Sattari, 2014).

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[128] According to Logsdon, rye straw is less absorbent than that of wheat or oats (Logsdon, 2010: 27), although the main bedding material is Fonsagrada was shrub (mostly gorse) from *monte* areas. Straw was either fed to the animals or applied as bedding as well. For each year, we have distributed straw according to the requirements of livestock diets.

[129] Logsdon points out that, even with a scrupulous management, between 15-30% of nutrients contained in urine and manure are lost by the moment when manure is ready to be applied to plants (Logsdon, 2010). This refers to contemporary observations. We include the datum as a reference.

6.3.5. Agricultural intensification and changes in food availability

The ultimate objective of a social metabolism is to ensure its reproduction. This necessarily implies satisfying the nutritional requirements of both society and livestock, apart from achieving a sustainable agricultural management.

Regarding the process of intensification of agriculture within an organic metabolism and, eventually, the process of change into a different sociometabolic arrangement, Schandl and Krausmann observe that human nutrition is a *"prerequisite to a successful transition"*, and

> *"food supply has to accommodate population growth because the basic metabolism of humans has to be secured. The nutritional base is a fundamental element of the socioeconomic energy system and lies at the very core of social metabolism. To allow for a transition from an agrarian mode of production, where the majority of the labor force is engaged in agriculture, to an industrial mode, this basic requirement has to be met. This entails increasing labor productivity in agriculture to free workers from the land and allow for a shift to manufacturing and industry. In the early periods of industrialization this is achieved by an optimization of the traditional agricultural production system within the general conditions of the solar-based energy regime"* (Schandl and Krausmann, 2007: 84).

We transpose to our case study the authors' question on "*how the agricultural system (...) could be rearranged to support an increasing population in the period (...) when food trade played an insignificant role and the whole nutritional requirement of the populations had to be met by domestic production*" (Schandl and Krausmann, 2007: 86). Schandl and Krausmann show that nutrional requirements in England stopped being fulfiled with domestic production after 1830, thus early orienting production towards the market. Most of imports came from the so-called "New World", but part of them were also imported from Galicia, namely bovine livestock that traveled alive by boat to England (Carmona, 2000; Martínez López, 2000). In the case of Galicia, we can find answers to this question in agrarian historiography (Bouhier, 2001; Dubert, 1996; Pérez García, 2000; Soto, 2006) and in our results. The increase in land productivity was possible with the introduction of new crops such as maize and potatoes, the supression of fallow, and a paralel intensification of animal husbandry as well, along with the subsequent rearrangement in land uses (increase in meadow surface, cropland expansion, intensification of *estivadas*). Higher manure availability is the key element that allows to understand how food needs could be met in a context of population growth. Moreover, the whole agroecosystem structure was altered in order to rearrange the nutrient cycle and support a more intensive cropping and, especially, a bigger cropland surface. As a result, a nutrient mining process was triggered in extensive rotations that provided cropland with fertilizer, which means that such pattern could not be sustained in the long term, although peasants managed to improve it towards the end of the period.

In this section, we will present some data on food availability. In our estimations, we have considered the whole biomass production of the agroecosystem and distributed it to both society and livestock. Within livestock, we have attended to the particular food requirements of each animal species and the products they could consume. By-products such as straw are mostly assigned to livestock but some of them were also used as litter for bedding.

Reconstruction of food availability for human consumption

Food availability has been estimated according to yields and surfaces as declared in our sources, and multiplying each product by the corresponding converters for nutritional and caloric content (Farran et al., 2004). Considering human consumption, there is a part of these productions that is not eaten (stems, rotten parts, peel, etc.), which we have not accounted for. This provides slightly distorted results but does not alter the magnitude of data. On the other hand, we have deducted the corresponding amount of seed that should be kept for the planting of the following year. These percentages are from Soroa, 1953. A datum on pouldry (eggs included) and hunt consumption from 1925 compiled by GEHR (1991) has been added to our estimates. Meat and milk productions have been estimated according to livestock numbers from our censuses and the corresponding converters used by González de Molina et al. (2014b). On the other hand, source declarations are likely to be underestimated, and there are other food resources that we have not been able to account for either, such as fishing or wild harvesting, which might as well serve of some balance for the residues that we have not deducted. Our data are a first approach to this topic and show a maximun potential in food availability. Besides, the margin of error in our estimates introduces some precautions, even when magnitudes are coherent with changes in population, cropland, livestock, and land productivity. For more detail on estimates, see Appendix 1.

According to our estimations, human nutrition in Fonsagrada between 1750s and 1890s must have been within acceptable limits only in 1752. Food availability increases in absolut terms through the eighteen hundreds but it cannot keep up with the demographic growth, thus showing a relative food scarcity in the second half of this century at least, and especially towards the middle of the century. Besides, these average values hide inequalities in the access to resources, which could easily be translated in more scarcity for part of the population whereas a minority could still have a satisfactory nutritional intake, mainly regarding meat and overall protein consumption as we move forward in the period.

Cussó calculated the average nutritional requirements of Spanish population in 2,270 kcal/cap/day for the year 1860, and 2,260 kcal/cap/day for 1900. These estimates take into account human biophysical features and energetic requirements derived from their main occupation which, in the 19th century, was mostly agriculture (Cussó, 2005). Our average data are well over this minimum requirements in 1752, when daily availability of kcal per person is about 2,500. However, most of these calories were contained in animal productions such as milk and meat, which might have been both processed and sold at local markets. In 1852 there must have been a considerable food shortage, with a lack of about 270 kcal/cap/day regarding the average of 2,270 kcal/cap/day established by Cussó. As shown in the following chart, the situation improves slightly in 1887 with an availability of 2,079 kcal/cap/day. If prolonged in time, as it seems to have happened, this situation could have resulted in malnutrition, worse quality of life, and higher mortality. In this case, migration was clearly a scape valve, since people start to flow out of the municipality especially in the second half of the 19th century.

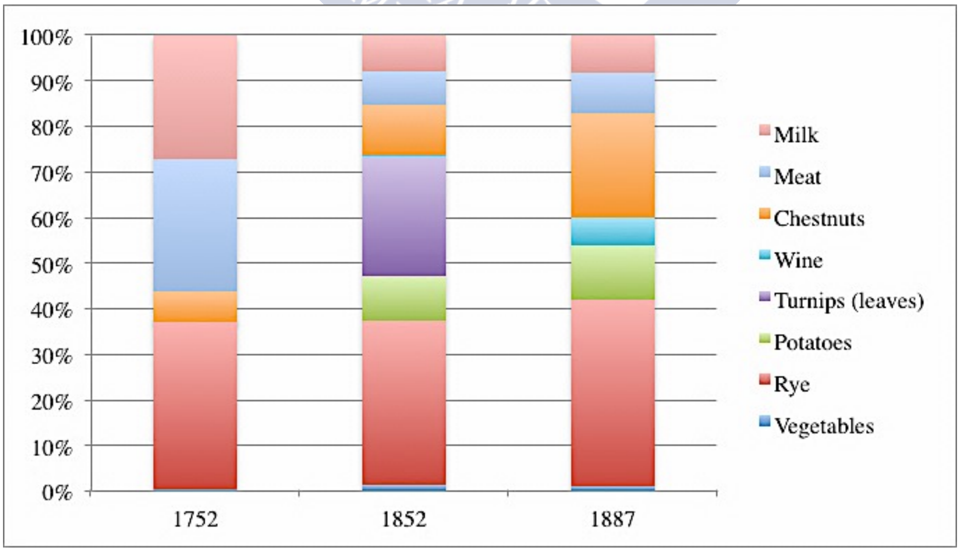
Chart 39. Fonsagrada. Human nutrition in 1752, 1852, and 1887 (kcal/cap/day)

	1752	1852	1887
Primary crops	1,099.5	1,840.6	1,720.9
Meat	735.8	146.1	181.5
Milk	683.5	161.9	176.6
Total	**2,518.8**	**1,998.6**	**2,078.7**

Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; INEbase population censuses from 1857 and 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartillas* from 1852 and 1886, Fonsagrada, APHL, Facenda, C14491 and C14992, respectively; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

In the following graph, we show all types of products that composed human diets in Fonsagrada through the study period.

Chart 40. Fonsagrada. Composition of the average human diet in 1752, 1852, and 1887 (%)



Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; INEbase population censuses from 1857 and 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartillas* from 1852 and

1886, Fonsagrada, APHL, Facenda, C14491 and C14992, respectively; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Vegetable gardens supply the 0.27% of the diet in 1752, as it corresponds to their reduced surface (13.73 ha). It increases up to a 1.22% in 1852 and then decreases again in 1887 to a 0.87%, thus matching the reduction of its surface. Rye is the main energy supply all through the period, and we see it increases every year as a result of the expansion of its surface as well. Its proportion within available food for human consumption is quite steady through the period, being around the 36 % in 1752 and 1852, and 41% at the end of the period. Chestnuts are an important part of the diet all through the period, and especially in 1887, thus going from a 6.6% of the available food in 1752, to 11% in 1852, and 22.8% at the end of the period. This is slightly contradictory with the decreasing productivity of chestnut groves, the pest outbreaks towards the end of the century and the introduction of potatoes, which might also indicate a previous underestimation of *souto* surface in the sources, especially in 1752.

It is interesting to remark how changes in the structure of the agroecosystem and in livestock management translate into a more varied but also more scarce diet in relative terms as we move into the 19th century. In 1752, meat and milk represent a maximum of the 29 and 27% of a person's daily intake, respectively. In 1852, such percentages have been reduced to 7.3 and 8.1%. In 1887, there is a relative improvement in meat and milk availability which rises both percentages to 8.7 and 8.5%. The following chart collects milk and meat availability through the period.

Chart 41. Fonsagrada. Milk and meat availability in 1752, 1852, and 1887 (fresh matter)

	1752	1852	1887
Meat (kg/cap/year)	69.35	14.6	18.25
Milk (l/cap/year)	332.15	76.65	83.95

Source: *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; INEbase population censuses from 1857 and 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491.

In 1752 daily milk availability reaches 0.9 l/cap. Of course, it was also used for making cheese, butter and other foodstuff but these transformed products have not been accounted for, nor fat availability. Besides, livestock specialization had also a market goal, especially for calves, which were sold at local markets and even exported to other regions such as Castile. This means that part of this meat must have not been available for the majority of the population of Fonsagrada. And, in 1752, livestock was mainly held on *monte* surface, which means that their yields in milk and meat must have also been lower than in the 19th century, when animals were kept in stables. Thus, even when meat availability must have been high, 69 kg/cap/year seems a lot. However, we have not been able to obtain more accurate data for this year since specific converters are not available.

Definitely, population in Fonsagrada certainly included more meat and milk in their diets in the 18th century than in the 19th, which had already been concluded by Saavedra (1979), and had also been stated for other cases in mountainious regions such as the Austrian Alps, where the caloric food intake from dairy products varied between the 38% to the 75% of the human diet, depending on the case (Krausmann, 2004; Gingrich et al., 2015). Besides, as González de Molina states regarding the Spanish aggregated data on food availability, the further back we go in time (before the 20th century), the higher meat consumption must have been, which the author also connects with a general decrease in livestock numbers along the eighteen hundreds. Average meat consumption in Spain towards the middle of this century reached the amount of 22 kg/cap/year, which is even higher than in Fonsagrada. By 1900 it had fallen down to 14 kg/cap/year, and from that moment on it would slowly increase again until 21 kg/cap/year in 1922 and 1933 (González de Molina et al., 2014b: 174-175). Besides, our data on milk and meat availability are also coherent with the pattern described by González de Molina and Guzmán (2006) for the case of Santa Fe (Granada) in the same period.

In 1852 and 1887 we see the impact of the changes in rotations along with the introduction of potatoes, which allow for more diversity in the diet as well as more food supply in absolut terms. In 1852, potatoes represent the 9.7% of the average diet, whereas in 1887 this percentage has achieved a remarkable 12%. Regarding turnips, which rotate with potatoes and rye, in 1852 we assigned the *grelos* (turnip leaves) exclusively for human consumption due to the decrease in food availability per capita, and they represent up to a 23.36% of the diet. They do not appear as a product for human consumption in 1887 due to a better situation at this respect, thus we assigned them completely to livestock although limits in this distribution were actually not so drastic. Both humans and livestock consumed both the *grelos* and the roots of this tuber all through time. We have simplified food distribution in order to more easily estimate a balance between food requirements and availability. Animals certainly consumed turnip leaves in 1852 and humans kept consuming them all through these centuries because it was (and still is) one of the main ingredients of *caldo*, a sort of soup with vegetables and, in special occasions, with meat as well, which was accompanied with rye bread (Saavedra, 1979).

The steady increase in total food availability is not only related with new and more productive crop rotations such as that of rye/potatoes/turnips, but mostly with an increase in cultivated surface. This is particularly evident in the case of chestnuts and vineyard, which acquire a bigger presence in the diet towards the end of the period: 22.78% and 6%, respectively. There might have been a considerable concealed chestnut surface in 1752 but, even in that case, the expansion of chestnuts is certainly related with the general restructuring of the agroecosystem after livestock stabling, which allowed for *monte* surface to be used for the creation of meadows, chestnut groves and even for cropland expansion, apart from the intensification of *estivadas*.

However, such improvements could not keep up with the demographic growth. Population in Fonsagrada increases all through the first part of the 19th century and reaches a turning point in this evolution towards 1860, when definite migration towards America begins. This means that food availability must have still decreased between 1852 and the end of the decade. A slight population recovery takes place after 1880, with a moderate but steady increase until the end of the 1910s, reaching at that point approximately the same inhabitant numbers as in the late 1850s.

These data allow to affirm that migration in Fonsagrada served as an escape valve to potential famine and social conflict over resources. This migration was performed over previously constructed patterns for temporary migration and domestic strategies such as calve production for the market, which allowed to finance travel expenses. For the same period, Saavedra mentions other relevant facts in the municipality at this respect such as conflicts over the commons, an increased number of people per household, higher celibacy rates, and more children of single mothers (López Fernández et al., 1987).

Migrants were mostly young men, who required more energy intake than elderly people and children. Thus their absence certainly implied a better nutritional availability for the remaining population, who also performed a further cropland expansion and intensification. Migration seems to have been a deliberate strategy to deal with scarcity problems and look for new soils to live off.

Finally, it is worth noting that our estimations are based on declared surfaces and productions. Since most of these data, as we have seen, are likely underestimated in our sources, the resulting data are also a conservative option. This means that actual food availability could have been higher, especially considering activities such as fishing and wild harvesting, which we have not accounted for. But even in this case, nutritional difficulties in the second half of the 19th century are evident, thus coinciding with the beginning of the most intense migrating process. More research should be done at this respect, considering both our data and the particularities of migration and demographic features in Fonsagrada.

Reconstruction of food availability for livestock consumption

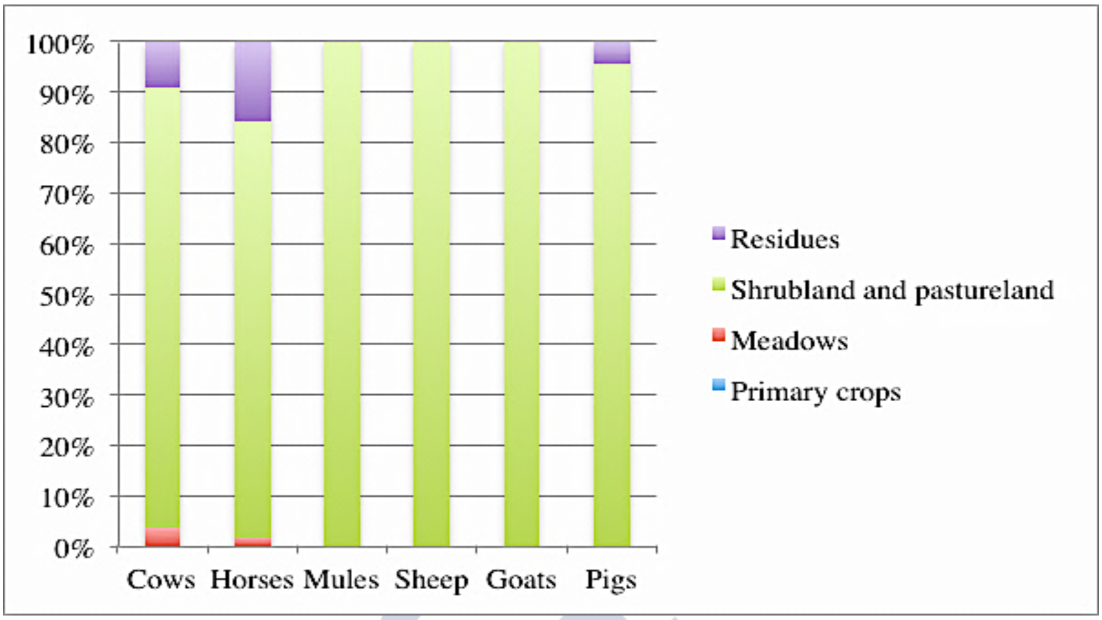
According to Bouhier (2001), *monte* is widely used for pasture until 1940-50s. Cows could obtain up to the forth or even third part of their diet from this type of surface, and some cows called "*vacas bravas*"[130] were actually all the time on *monte*. Sheep and goats spent their whole live on *monte*, where they obtained their food from. Horses' diet can be satisfied up to 3/4 or 4/5 with tender gorse, either on *monte* or in the stable. Both cows and horses were given grinded gorse in their food, and this practice was common in other regions where gorse was also an important part of the economy such as the French Brittany, Ireland and the United Kingdom (Sineiro, 1983). Thus, towards the middle of the 18th century, livestock's diet depended mostly on *monte*. Along with the intensification process and livestock stabling, animal nutrition changed too. New crops were specifically aimed at feeding them such as fodder and turnips, and were related with the stabling process since they could be kept in warehouses (*palleiras*) for the winter. This resulted in a varied diet that combined meadows, *monte*, pasture on cropland after the harvest and, especially, intercropped fodder within the main rotations (Bouhier, 2001).

For simplification purposes, we have grouped all different kinds of animal foodstuff in four main categories: primary crops (turnips, potatoes, fodder), meadows (both irrigated and non-irrigated), residues (straw, domestic and garden residues, grape pomace), and *monte* pastureland (pasture on *monte* surface, composed of gorse and several other shrubs and plants, either grazed or cut and stored for stall feeding during the winter).

As the following graphs show, available foodstuff for livestock changes through the period. In 1752, most livestock was not kept in *monte*, and most of their foodstuff was provided by this shrubland. For this year, we assigned all meadow productions for bovines and all domestic residues for swines, as well as a small fraction of primary crops. As several authors have pointed out, *monte* pastureland was of inferior quality than meadows, and cows were not as well adapted to its grazing and assimilation as other animal species such as equines, sheep or goats. However, tender gorse frequently was grinded and given to cattle, either alone or mixed up with turnips, potatoes or maize flower as these crops become more common along the 19th century (Hernández Robredo, 1936; Sineiro, 1983; Balboa, 2000).

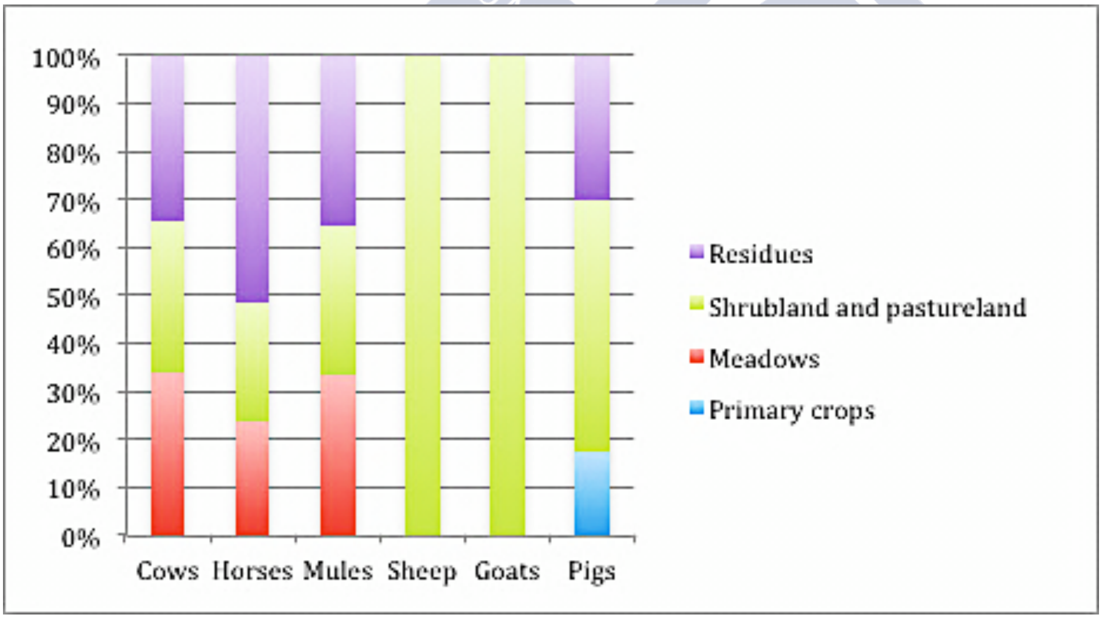
[130] "Wild cows".

Graph 16. Food availability for livestock in Fonsagrada in 1752



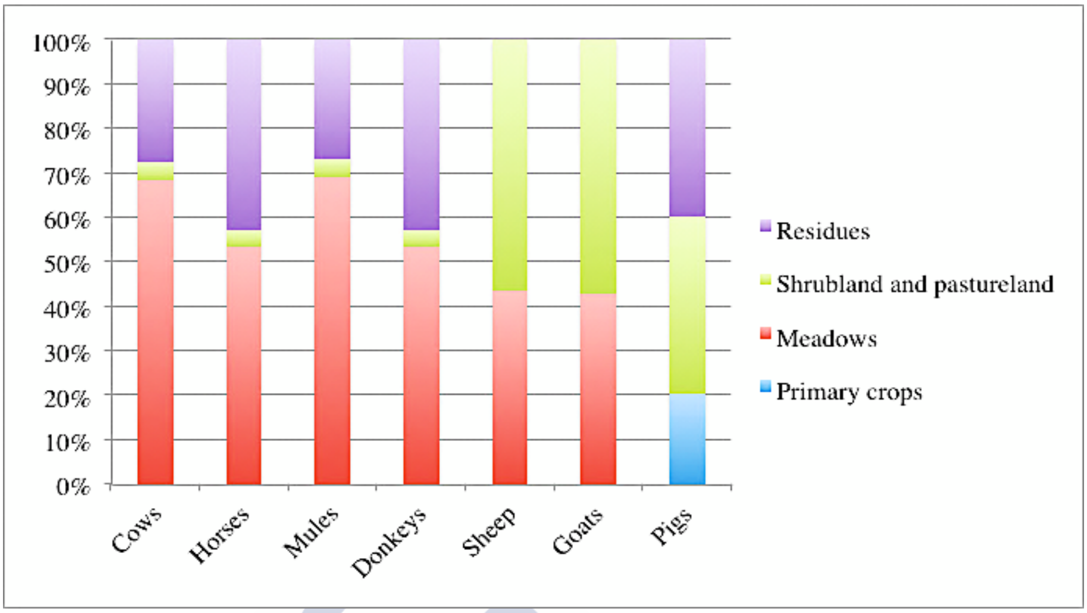
Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Graph 17. Food availability for livestock in Fonsagrada in 1852



Source: INEbase population census from 1857 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartilla* from Fonsagrada, 1852, APHL, Facenda, C14491; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Graph 18. Food availability for livestock in Fonsagrada in 1887



Source: INEbase population census from 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartilla* of Fonsagrada, 1886, APHL, Facenda, C14992; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Turnips, potatoes and fodder appear in our sources in 1850s and 1880s, when they have consolidated as an important part of livestock feeding. The increase in total agrarian production is also visible through the increase of residues in livestock diets. Both changes are related with the process of stabling, which required more foodstuff in order to feed animals during the winter and even through the whole year with permanent stabling (Fernández Prieto and Balboa, 2000).

In 1852 and 1887, we assigned most of the turnips and potatoes to pigs and meadow production to cows, either fresh on site or in the stable as hay. Cows were also fed on turnips, but we have assigned most of them to pigs in order to simplify estimates, which have been done according to metabolizable energy[131].

Data in these graphs are also coherent with an increase in pasture surface per livestock unit. In the following chart we collect meadow and *monte* pasture distribution per LU, including all types of animals.

[131] See Appendix 1 for more detail on the methodological procedure.

Chart 42. Fonsagrada. Distribution of livestock units per hectare in 1752, 1852, and 1887

	1752	**1852**	**1887**
Total LU-500 kg	8,592	3,406	4,172
LU/meadow ha	36.17	3.19	0.97
LU/appropriated *monte* ha	0.94	0.82	1.47
LU/meadow and appropriated *monte* ha	0.91	0.65	0.58
LU/total *monte* pasture ha	0.21	0.09	0.13

Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); *cartilla* from Fonsagrada, 1852, APHL, Facenda, C14491; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; *cartilla* of Fonsagrada, 1886, APHL, Facenda, C14992; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491; *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

These data allow to see how meadow availability per LU increases through the period in order to keep up with the process of livestock specialization. In 1752, there are 36 LU-500 kg per each hectare of meadow, which at the time occupy 238 ha. The expansion of meadows and the reduction of livestock head between 1752 and 1852 results in a much better distribution of this resource achieving 3.19 LU per meadow ha. In 1887, meadow availability has increased again, even with a bigger livestock head than in 1852, thus having 0.97 LU per meadow ha. Pasture appropriation in *monte* decreases as meadows expand, thus the evolution in this distribution is different, going from 0.94 LU/ha in 1752, to 0.82 in 1852, but increasing in 1887 to 1.47 LU/ha. Let us remind that this datum of appropriated *monte* surface has been estimated according to pasture, bedding and firewood requirements altogether. Taking both pasture surfaces into account, the evolution is perfectly coherent with the process of livestock intensification. In 1752, there are 0.91 LU per total pasture hectare, which decreases to 0.65 in 1852, and still to 0.58 in 1887.

Either way, as explained before, pasture surface was not a limiting factor at this respect since total *monte* surface was much bigger than the appropriated area. If we consider only the total availability of *monte,* which amounts more or less to 41,500 ha in 1752, 38,300 ha in 1852, and 33,200 ha in 1887, then pasture availability is huge at any time of the period with 0.21; 0.09 and 0.13 LU/ha, respectively. This means that the limits to its appropriation were more likely related with transport and labor costs but mostly with the intensification of *estivadas*, which triggered a process of nutrient mining in *monte,* especially of potassium.

As mentioned in the section on methodology, the biophysical approach allows to double check the reliability of our sources since it takes into account both dietary requirements and food availability according to declared livestock and agrarian productions. In general terms, there is enough food in Fonsagrada for livestock in all three years. Problems with sources at this respect appear only in 1752, when food requirements exceeded those of available foodstuff according to Ensenada's Cadastre. This food scarcity has been sorted out in our estimations by adding pasture from *monte* areas, which, as explained in the corresponding section, was the main concealed surface in this source, which only assigns 1,914 ha to *monte* in Fonsagrada. However, due to the extensive livestock management, this surface would not be enough to satisfy their nutrient requirements. Our estimations indicate that 9,168 ha were required in order to sustain livestock (including pasture and livestock bedding but also firewood requirements). At this time, *monte* surface was not a limiting factor, which occupied up to about 41,500 ha. Our data are therefore coherent with previous criticism on this source, and provide a more accurate picture of the agroecosystem in 1752.

For the rest of the years, livestock and *monte* productions match in terms of nutritional requirements. In fact, declared *monte* surface in 1852 (15,360 ha) and the estimated one for 1887 according to our sources (10,222 ha) exceed actual requirements of this resource in terms of firewood, livestock foodstuff and bedding, which are 4,138 and 2,847 ha, respectively.

Of course, there must have been a certain percentage of information concealment in the sources, but it is either irrelevant or both documents show a similar percentage of fraud, which is difficult to assess. Either way, what has more value to us is not the absolute numbers but the resulting pattern and the changes when compared with the rest of the period and with previous research. This is the most reliable guarantee of reliability for our sources and our results.

6.3.6. Nutrient Balances in Fonsagrada: agrarian management of soil fertility

In this section we will present balances at rotation scale. This will allow to assess the functioning of the agroecosystem. There is a margin of error in our results as it is logic considering the methodology, the sources and the estimations required to replace missing data and other required information. However, the magnitude of the results is coherent, both internally and when contrasted with the evolution of land productivity. In these balances, land uses are distributed in order to sustain soil fertility in cropland, which is done at the expense of other surfaces, namely *monte* and meadows.

In the case of Galicia, historiography had already assessed the role of *monte* as a nutrient reservoir for cropland (García Fernández, 1975; Bouhier, 2001; Balboa, 1990; Pérez García, 2000; Soto, 2006). Through the case study of Fonsagrada and its nutrient balances in 1752, 1852, and 1887, the essential role of this resource is less evident since its protagonism changes through time. However, the long history of nutrient extractions from this area, and increasingly from meadows as well, resulted in a process of nutrient mining and soil depletion in this type of surfaces, which relied more and more exclusively on natural processes for nutrient replenishment as we move forward in the period. Such nutrient deficits had been concluded by specialized literature in Galician soils referred to the present, which confirms the reliability of our balances. Díaz-Fierros remarked the general lack of calcium, phosphorus and potassium in cropland in the 1970s and 1980s. Even with yearly manuring practices, soils in Galicia are still poor and acidic, and show high requirements of fertilizers and acidity correctors. The author relates this fact with a very intensive cropping without fallow and the combined action of geology and climatology, which result in permanent soil washing (Díaz-Fierros, 1982).

Livestock usually returns over 3/4 of the plant nutrients ingested, although excreta does not necessarily occur where the extraction takes place. Thus animals, and particularly managed livestock, alter the fertility of soil by enriching certain areas at the expense of others. Besides, when grazing, animals prefer the mineral-rich species, which they eat more intensely. Equally, conserved forages in the form of hay, for instance, also remove bigger amounts of nutrients than just grazing. This basic land use strategy for nutrient management has been common in European agricultures since long ago, thus resulting in soil depletion of these nutrient reservoirs which provided livestock with foodstuff, namely grasslands or woodland (Shiel, 2006b; Sattari, 2014).

In our case, this is particularly evident in meadows, which are not fertilized in Fonsagrada during the study period and show a rapid depletion process. *Monte* soils keep mostly balanced due to natural reposition processes and to *estivada* practices as well, but this situation easily evolved into unsustainable with the intensification of *estivadas* which, on the other hand, was possible by the creation of meadows and the subsequent relieve in the pressure over *monte* pasture. The intensification of *estivadas* led to a remarkable imbalance in potassium in *monte* surfaces.

In Fonsagrada, woodland and *soutos* also show nutrient imbalances, which are related with extractions of chestnuts, leaves, acorns, wood and firewood, and the lack of fertilization. The use of leaves from *soutos* as bedding material for livestock is documented in our sources. Because amounts are not specified, we have assumed that only the 25% of them were removed from under the trees. At this respect, Pfeiffer points out that

> "*a complete cleaning of the fallen leaves out of the woods and forests has always proved harmful. The fertilizer that the woods themselves produce should be left to them. Leaving only the small twigs and a portion of the fallen leaves as a soil cover, however, has been found satisfactory*" (Pfeiffer, 2004: 100).

Regarding acorns, we have distributed them for pigs according to nutritional requirements, especially in 1852, when there is less food availability per capita. Finally, we have assumed that wood extraction rates are equal to production. This seems too extreme but it allows to see the worst possible scenario in the case of woodlands and, besides, we have no better data. The actual situation must have been more balanced in both woods and *soutos*, but depletion in woodland has been remarked before as a result of the way in which the nutrient cycle worked in most European agricultures (Pfeiffer, 2004; Shiel, 2006b). These imbalances occurred in the forests of Fonsagrada as well, either cultivated (*soutos*) or simply appropriated (oakwoods or other forests). None of them were fertilized with manure but inputs in the form of animal excreta when grazing have been considered.

All the above-mentioned flows of nutrients highlight the important role of livestock at integrating the different land uses within the agroecosystem, thus allowing the transfer of nutrients from *monte* and meadows into cropland. This basic strategy of nutrient trasnfer from extensive areas into cropland has been described with detail in previous research on pre-industrial agricultures, where it is also emphasized that livestock could digest biomass that humans could not, thus optimizing by-products (González de Molina and Guzmán, 2006; Cussó et al., 2006; Krausmann, 2004 and 2006; González de Molina et al., 2010; Tello et al, 2010; Olarieta et al., 2010; Galán, 2015; Infante-Amate, 2014; Gingrich et al., 2015).

In the following charts we show the nutrient balances of the main rotations in Fonsagrada. Data are disaggregated by nutrient, thus presenting their evolution in each rotation all through the period. We have excluded *monte* and *estivadas* due to their particularities and longer cycle. These rotation will be analyzed in a specific section.

Chart 43. Nitrogen balances in Fonsagrada: 1752, 1852, and 1887 (kg/ha)

	1752	1852	1887
Vegetable garden	30.4	44.2	42.4
Cereal rotation	-3.5	-6.4	-4.6
Meadows	-38.5	-30.0	-26.1
Non-irrigated meadows	-23.6	-23.5	-22.8
Vineyard	7.9	4.4	3.8
Soutos	-21.8	-25	-21.2
Woodland	-28.1	-28.1	-28.1

Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; INEbase population censuses from 1857 and 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartillas* from 1852 and 1886, Fonsagrada, APHL, Facenda, C14491 and C14992, respectively; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Nitrogen is the most conditioning nutrient when it comes to crop yields in the short term (Shiel, 2006b; García-Ruiz et al., 2012). It is one of the most abundant elements on earth but most of it is in an unreactive form which makes it unavailable for biological systems. In order for this to naturally occur in the soil, the intervention of nitrogen-fixing organisms is required. However, reactive nitrogen is so mobile that it gets easily removed by leaching, erosion, volatilization, combustion or denitrification (Cushman, 2013).

Within fertilized rotations in Fonsagrada, there is enough manure as to replenish nitrogen in vegetable gardens all through the period. This is the reason why gorse plays such an important role within the agroecosystem. Imbalances in the cereal rotation remain within acceptable levels and are within the margin of error of our estimations. In fact, nitrogen balances could not be so negative because, otherwise, land productivity would have decreased a lot more.

We can see some improvements in nitrogen levels in 1887 when compared with 1852, which are especially relevant in the case of the cereal rotation and imply that there was a conscious strategy in order to increase nutrient availability in cropland. The case of meadows indicates, however, that nutrient balances in cropland depended mostly on the over-exploitation of these other surfaces. The situation is worse in irrigated meadows due to their higher productivity, which result in higher rates of extractions and denitrification. In the case of both *soutos* and woodland, data indicate that there is a long-term process of nutrient mining although we cannot assess its magnitude due to the above-mentioned problems with the quantification of extractions. The decreasing yields of chestnut groves would confirm such trend, but we do not have reliable data at this respect in our sources. Finally, the situation in vineyard, which is also not fertilized, indicates that nutrients were being extracted over the possibilities of natural replenishment but, so far, nitrogen balances are positive all through the period.

Contrary to what we expected according to previous research on Galician soils (Gil Sotres and Díaz-Fierros, 1979), the situation of phosphorus seems to have remained more or less balanced all through the period, as shown in the following chart.

Chart 44. Phosphorus balances in Fonsagrada: 1752, 1852, and 1887 (kg/ha)

	1752	**1852**	**1887**
Vegetable garden	0	0	0
Cereal rotation	0	2.2	3.2
Meadows	0.4	1.7	2.4
Non-irrigated meadows	-1.7	-1.7	-1.6
Vineyard	1.5	0.9	0.8
Soutos	-2.2	-2.9	-2.1
Woodland	-1.5	-1.5	-1.5

Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; INEbase population censuses from 1857 and 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

"Compared with nitrogen, phosphorus makes up a tiny proportion of the world's biomass and has received almost no attention from historians, but it is no less dispensable for life" (Cushman, 2013: 10). In the form of phosphate, it is a basic element in structural tissue of plants and in bones and teeth, and is essential for energy transfer within organisms, as well as for early plant growth. Its cycling in the atmosphere is much slower than in the case of nitrogen since it begins with the erosion of rocks by the action of wind and water (Busman et al., 2002; Cushman, 2013).

Phosphorus is transferred from cropland to pasture areas through livestock feed, and exported from pastureland to cropland in the form of manure. In Eastern and Western Europe, as a result of the intensive agricultural practices of the past it has been historically common to fertilize pastureland with manure, thus recovering phosphorus and other nutrients removed with biomass production and consumption (Sattari, 2014). This was usually the case of meadows in Galicia, where they were frequently manured, but it did not seem to be that way in Fonsagrada, at least not before 1890s and according to our sources. Whereas nutrients extracted from meadows and *monte* pastureland helped sustain and intensify cropland production, the fertility of these nutrient-provider soils was progressively mined. According to Sattari, in contemporary agriculture, there is a problem of phosphorus depletion in grassland soils globally, although lessened in the case of Eastern and Western Europe regarding historical manuring practices (Sattari, 2014). Gil Sotres and Díaz-Fierros concluded the same for Galician soils, where up to a 75% of the nutrient was of organic origin through humus formation or manuring. Thus, historically manured cropland can be easily distinguished from uncultivated land for its higher phosphorus content in a form which is available for plants. However, these authors conclude that phosphorus balance in cropland after centuries of agriculture led to productivity stagnation in the second half of the 20th century due to its scarcity (Gil Sotres and Díaz-Fierros, 1979). This might be the reason why we have not seen big phosphorus imbalances in our analysis. On the other hand, negative balances in both nitrogen and potassium, mainly in meadows, could have resulted in phosphorus imbalances as well.

Besides, there is evidence that animal bones were exported from Galicia to other regions of Europe where they were used as fertilizer. It has been said that their use was not possible here due to the absence of chemical industry to provide the required acids to decompose the bones (Carmona, 1990). We do not dare to say that their complementary use was not necessary, especially considering that the initial use of phosphate fertilizers in the first third of the 20th century led to a considerable increase in land productivity (Fernández Prieto, 1992), but phosphorus replenishment with farmyard manure must have been succesful at this respect by incorporating shrub and by-products such as straw or leaves, or at least this was the case in Fonsagrada. However, we are not able to provide a more solid explanation and this issue requires further interdisciplinary research. In the following chart, we collect the results of potassium balances.

Chart 45. Potassium balances in Fonsagrada: 1752, 1852, and 1887 (kg/ha)

	1752	1852	1887
Vegetable garden	95.7	111.9	107.6
Cereal rotation	-6.3	-15.6	-13
Meadows	-35.2	-23.3	-17.8
Non-irrigated meadows	0.2	0.3	1.1
Vineyard	8.6	6.4	6.1
Chestnut trees	15.1	11.7	15.4
Woodland	12.1	12.1	12.1

Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; INEbase population censuses from 1857 and 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

High potassium availability in vegetable gardens is not an evidence of its abundance, but a reflection of the amounts contained in all the manure that we have virtually applied to this rotation. It is a maximum potential of its availability in the soil, and it would be rare to have such big amounts of this nutrient. However, its depletion is a fact in the cereal rotation and, particularly, in irrigated meadows. The impact of the historical extraction of potassium from *monte* and meadows is finally also evident in balances in cropland, especially after livestock is mostly kept in stables, which results in a less efficient recovery of potassium in manure when compared with the reposition of fresh excreta.

All in all, we need to remark that the results of these nutrient balances are reliable as indicators of a particular trend towards soil exhaustion in meadows and woodland areas, where nutrients are extracted from but not sufficiently replenished with manure supplies. This is particularly serious in meadows because of their more intensive management. Low negative values are within the margin of error of the methodology, which means that the cereal rotation could have more balanced nutrients. However, the evolution of land productivity confirms such unsustainable pattern.

In the case of vegetable gardens, manure availability was enough in all three moments as to ensure the complete replenishment of these three main nutrients. Besides, there was a conscious effort at optimizing the management of soil fertility between 1850s and 1880s, which can be observed in the general improvement of balances. However, data show that this pattern of intensification with livestock specialization was not sustainable in the long term, since nitrogen and potassium were clearly being depleted in some rotations, mostly in meadows and in the cereal rotation in the case of potassium, and in meadows and woodland (including *soutos*) in the case of nitrogen. As mentioned before, this is the result of the expansion of the agriculture frontier over *monte* surfaces. The nutrient stocks of these soils were invested in the process of both intensification and extensification, thus widening the metabolic rift. On the other hand, the combination of this unsustainable pattern and the lower suitability of such soils for agriculture is evident in both the results of nutrient balances and in the trend towards productivity stagnation. Definitely, even when there is a margin of error in these results due to the nature of the sources and the methodology of nutrient balances, it all portrays a very coherent picture of this agroecosystem and its changes through the process of intensification.

Nutrient replenishment in *monte* surface

We have separated nutrient balances in *monte* because of its specific characteristics, the long duration of the *estivadas* rotation, and the multifunctional role of this surface within the agroecosystem. Besides, the use of fire in *estivadas* is also a very distinctive trait.

The effect of fire on nutrient availability varies according to each nutrient, since their volatilization temperatures are different. All or most of the nitrogen in vegetal matter is lost to the atmosphere, but phosphorus and potassium remain in the ashes in a higher proportion, as well as calcium. Regarding nitrogen, such losses are not worrying due to the role of gorse as leguminous plant. Besides, fire increases soil pH as well as general availability of most nutrients due to the process of mineralization, particularly of phosphorus (Guitián, 1993; Shiel, 2006b; Olarieta et al., 2010; Gómez-Rey et al., 2013).

During the process of drying the vegetation at open air, which can last between several weeks and even a few months, a considerable part of nutrients is lost. After the fire, most phosphorus and potassium return to the soil and, eventually, nitrogen is naturally replenished with the regeneration of the leguminous shrubs, namely gorse species but also *Ericaceae* (Izco et al., 2006). After livestock stabling and the reduction of the time that animals spent on *monte* and meadows, the replenishment of nutrients in these soils is reduced since animal excreta does no longer take place on the spot but in stables.

Balances in *estivadas-monte* have been estimated according to the type of labor and crop and the period of fallow as indicated in the sources. During fallow, these surfaces are in fact appropriated as *monte*, which means that biomass extractions are frequent. Therefore we have accounted for the whole *monte* surface in each moment, as if *estivadas* could take place in any part of it, although we know this is not accurate because peasants picked the spot for *estivadas* very carefully in order to minimize their impact on the soil. This could have actually led to some soils being more intensely used for *estivadas* as others, but we cannot know how this actually occurred. The surface considered in each period is the sum of appropriated *monte* surface, yearly cultivated *estivada*, and its fallow requirements in terms of surface. These balances refer therefore to a rotation of 41,554 ha in 1752[132], 38,300 ha in 1852, and 33,194 ha in 1887.

The corresponding periods of fallow as indicated in the sources have been taken into account when calculating the rates of nutrient replenishment. In these balances, output values are mostly nutrient extractions and losses that take place in the year in which the land is broken and cultivated in *estivada*, and also shrub extractions during the fallow period. Inputs are due to natural processes occurred during the time that soil remais uncultivated. The final balance that we show in the following chart is the difference between inputs and outputs at the end of the fallow period.

Chart 46. Fonsagrada. Nutrient balances in *monte* in 1752, 1852, and 1887 (kg/ha)

	N	P	K
1752	57.4	1.8	27.3
1852	46.1	0.7	-7.4
1887	46.2	1.0	-22.6

Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; INEbase population censuses from 1857 and 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

The span of time required for soil restoration after an *estivada* varies according to the nutrient and the degree of intensification. It is important to note that *estivadas* take place with a higher frequency as we move forward in time. In 1752, they take place on an average of 40.1 years. First quality soils are cultivated every 30 years; second ones, every 40; and third ones, every 50, with little exceptions that remain within these values as well. In 1852 and 1887, all soil qualities are cultivated every twenty years. For nitrogen, about 5 years is enough to get fully recovered; phosphorus takes between 11 and 16 years, and potassium between 47 and 54, aproximately. This explains why potassium levels are the most affected by *estivadas* as the period of fallow is reduced and land is broken and cropped with higher frequency.

In 1752, an average of 40.1 years fallow allows for all nutrients to be fully replenished. Natural reposition in *monte* surface occurs at an average rate of 58.2 kg/ha for nitrogen, 1.9

[132] In nutrient balances there is a total surface of 41,574 ha because, as explained before, *cortiñas* were not disaggregated due to the lack of information for nutrient balances. Therefore, their corresponding surface (19 ha) was not accounted for as cropland.

kg/ha for phosphorus, and 30.9 kg/ha for potassium. In 1852 and 1887, sources[133] confirm that all types of *monte* qualities are cultivated under *estivada* every twenty years. For the estimations of total inputs and outputs in kg/ha we have taken into account annual balances of *monte* for the 19 years that land remains fallow after an *estivada*. Reposition rates decrease to 54.3 kg/ha; 1.2 kg/ha, and 27.3 kg/ha in 1852, which is related with the intensification of this rotation. Therefore, at this point, problems with potassium start to be evident. In 1887, reposition rates recover to similar values as in 1752 regarding the reduction of pressure over *monte* pasture after the stabling of livestock and the increasing protagonism of meadows as nutrient suppliers for cropland. In this moment, nitrogen and phosphorus are still getting fully replenished but net losses of potassium are more evident, thus indicating the existence of a nutrient mining process, which is directly linked with the intensification and extensification of *estivadas*. However, these reposition rates indicate that more frequent *estivadas* were not only likely considering low food availability at the moment, but also possible due to this quite satisfactory levels of nutrient replenishment, especially with nitrogen.

Besides, it is necessary to remark that positive balances in nutrients do not mean that the corresponding amount of the nutrient is available, since their accumulation rate is dependent on the other main nutrients, as we mentioned in the case of vegetable gardens as well. In this case, for instance, potassium must have conditioned nitrogen and phosphorus availability although we cannot know to what extent. On the other hand, potassium deficits are limiting in a longer term than nitrogen, which can also explain the decrease in the productivity of *estivada* between 1752 and 1852, with Domestic Extraction going from 2.91 t/ha in 1752 to 2.23 t/ha in 1852, and 2.19 t/ha in 1887 (dry matter). Productivity must have been lower in 1887 but we cannot assess this issue more accurately since yields for this year have been taken from the *cartilla* from 1852, and changes are mostly related with a different soil quality distribution.

So far, research on *monte* in Galicia had mentioned the variations on the frequency of *estivadas*, concluding that they were repeated on the same surface once the vegetation had recovered or when an extra crop was needed, thus avoiding a high impact on the soil (García Fernández, 1975; Bouhier, 2001; Balboa, 1990). However, *estivadas* and their period of recovery had never been approached from a biophysical perspective. This opens new thresholds for the interpretation of the sustainability of this practice, which definitely contributed to the depletion of soil fertility in *monte* areas in the case of Fonsagrada. On the other hand, this confirms that *estivadas* were perfectly integrated in the logic of the agrarian system, and they were not a mere complement. In fact, their contribution to food production was essential during the 19th century, especially when the expansion and the intensification of cropland was reaching its biophysical limits in terms of land and manure availability. Besides, such case of intensification in *estivadas* had not been documented before, and actually

[133] *Cartilla* of Fonsagrada from 1852 and agricultural statistics from 1887, both in AHPL, Facenda, C14491.

contradicts the general description of their disappearance along the 19th century, as observed by Bouhier (2001).

Aggregated balances at agroecosystem scale

This scale offers a different insight into the management of soil fertility. Firstly, we will present balances at agroecosystem scale, considering the surface of the whole municipality. Then, we will separate the main cropland surfaces from the areas that provided them with nutrients. Cropland includes vegetable gardens, the non-irrigated cereal rotation and vineyard, even when this last rotation was not fertilized. Areas that served more clearly as nutrient providers for cropland are meadows and *monte* and, by extension, woodland but also *soutos*, since they were not fertilized and actually provided a fraction of livestock bedding in the form of leaves, apart from chestnuts and wood, thus having a similar function to that of woodland. However, this is also not a very accurate division since an increasing part of the nutrients proceeded also from cropland itself since it also provided livestock foodstuff. The comparison is aimed at showing how costly it was to sustain soil fertility.

Chart 47. Fonsagrada. Aggregated nutrient balances in the agroecosystem in 1752, 1852, and 1887 (kg/ha)

	N	P	K
1752	54.3	1.7	25.9
1852	40.5	1.3	-13.6
1887	33.7	1.5	-37.4

Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; INEbase population censuses from 1857 and 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491.

These data show that there are no big nutrient problems at agroecosystem scale, except for potassium, with an evident mining process since, at least, 1850s, which is mostly related with the intensification of *estivadas* and a bigger and non-fertilized meadow surface, as previously concluded. The relative abundance of nitrogen is in direct relation with a vast *monte* surface where natural processes achieve high potential levels of nitrogen fixation, thus hiding imbalances of this nutrient at rotation scale. Phosphorus should be unproblematic all through the period. However, we cannot know whether these nutrients were affected by potassium scarcity. This chart is complementary to data on the agroecosystem's overall Domestic Extraction, which increases from 3.86 t/ha in 1752 to 4.41 t/ha in 1852, and decreases in 1887 to 3.94 t/ha. The increase in extractions over the first century of the study period is responsible for the negative balances in extensive rotations, especially considering the expasion of cropland. This is connected with an increasing demographic pressure in a period when population goes from 9,099 inhabitants to 17,368, but also with the stabling of livestock, which is is connected with the expansion of meadows and its more intensive management when compared with *monte* pasture. The decrease in extractions per hectare observed in the last moment is related with a lower demographic pressure, since population decreases to 16,419 inhabitants in 1887. In fact, when Domestic Extraction is presented in tons per capita, data are self-explanatory of this trend in pressure over the territory: 1.74 t/cap, 5.29 t/cap, and 5.20 t/cap, respectively. Again, the decrease in productivity of the agroecosystem and the reduction of domestic extraction per capita match the process of migration, thus giving evidence of the exhaustion of the intensification process. Data are summed up in the following chart.

Chart 48. Fonsagrada. Average Domestic Extraction in the agroecosystem in 1752, 1852, and 1887 (dry matter)

	1752	**1852**	**1887**
DE (t/ha)	3.86	4.41	3.94
DE (t/cap)	1.74	5.29	5.20

Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; INEbase population censuses from 1857 and 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491.

If, according to the above-mentioned criteria, we disaggregate these values into the categories of cropland and extensive rotations, results offer a more precise picture of the management of soil fertility within the agroecosystem due to the complementariety of these two main areas in terms of nutrient cycling. The following chart collects the aggregated balances of cropland on one side, and *monte*, meadows and woodland on the other (including both *estivadas* and *soutos*). Data are self-explanatory when both series of data are analyzed together.

Chart 49. Fonsagrada. Aggregated nutrient balances in cropland in 1752, 1852, and 1887 (kg/ha)

Cropland	**N**	**P**	**K**
1752	-1.07	0.02	-1.61
1852	-0.09	0.54	-0.12
1887	0.5	0.84	0.25
***Monte,* meadows and woodland**	**N**	**P**	**K**
1752	56.58	1.78	27.02
1852	43.64	0.69	-7.27
1887	37.35	0.73	-19.79

Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; INEbase population censuses from 1857 and 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491.

Cropland seems generally balanced all through the study period. In 1752, the more extensive management seems to have achieved a considerable equilibrium within the agroecosystem and its land uses. Values from 1852 are the result of a balanced management in cropland through time, which developed and adapted the strategy of nutrient replenishment in order to suit the increasing requirements of the process of agricultural intensification and extensification. However, such process had not yet been concluded and there woudl still be a further effort at increasing manure availability by sustaining a bigger livestock head until, at least, 1876[134]. This was accompanied with an increase in cropland and meadow surfaces and an intensification of *estivadas* in order to produce more food for an increasing population, which was now struggling with problems related with less food availability and the beginning of a complex process of migration. Thus, in 1887, results seem to have improved slightly regarding nutrient availability in cropland. However, we need to remind as well that manure availability was estimated at its potential maximum, and that the actual situation could have been less balanced.

But, definitely, nutrient levels in cropland remain more or less stable through the study period, thus indicating a proper adaptation to the requirements of new crop associations and more intensive rotations. Peasants must have been aware of such process by harvesting diminishing yields as the 19th century moved forward, thus having incentives to focus their efforts towards nutrient replenishment more clearly. This is coherent with the fact that land productivity in the main cereal rotation was stagnant through the period, going from 1.88 t/ha in 1752, to 1.80 t/ha a century later, and to 1.79 in 1887. Let us remind that most yields from

[134] Livestock numbers used in the balances of 1887 are from the statistical records from 1876 (AHPL, Facenda, C14491).

1852 have been applied to both this year and 1887, and this is also the case for cereal rotations. The fact that the increase in its surface keeps a similar proportion between soil qualities in both moments explains that land productivity is almost the same, thus the most significative comparison is between 1752 and the 19th century in general terms. Yields for vegetable gardens do not allow for the same comparison since they proceed from a neighbor municipality and are only available for 1888. On the other hand, yields in vineyard are also not useful to illustrate such trend because this rotation was not fertilized. However, there is a remarkable increase in its productivity between 1752 and 1852 which goes from 1.34 t/ha to 1.62 t/ha. Productivity remains in the same magnitude towards the end of the period because yields from 1852 have been applied to this moment too and differences are only related with a different soil quality distribution. On the other hand, data from 1752 and 1852 give evidence of a balanced management regarding soil fertility in cropland, which was only possible with a deep knowledge of the land and its requirements. Finally, the increase in vineyard surface, especially in 1887, and its positive balances all through the period mask imbalances in the cereal rotation, as shown in the disaggregated data. Besides, overall productivity in cropland reflects a slight increase through the period, going from 2.55 t/ha in 1752, to 2.57 t/ha in 1852, and 2.76 t/ha in 1887. These data include vegetable gardens, the cereal rotation, vineyard, *soutos, estivadas*, and meadows.

But this virtuous development in cropland had an important impact in other parts of the agroecosystem. The transference of nutrients from *monte* and meadows to cropland, and the intensification of *estivadas* in order to keep up food production with the increasing demographic pressure were mining potassium stocks in these surfaces. In the long-term, phosphorus would have likely followed the same trend.

By 1750s, the situation seems generally balanced since potassium stocks in the soil are usually very abundant and therefore its net losses are not limiting for agrarian production in the short term (García-Ruiz et al., 2012). We do not know if this potassium scarcity towards the end of the study period could have affected the general availability of other nutrients, but we hypothesize that agricultural practices as described for the year 1887 could have continued for some time without drastic reductions in land productivity, which was mostly affected in *estivadas*, where Domestic Extraction goes from 2.91 t/ha in 1752, to 2.23 t/ha in 1852, and 2.19 t/ha in 1887 (rye *estivada*), but also in the main cereal rotation, which decreases from 1.88 t/ha in 1752 to 1.79 t/ha at the end of the period. However, the use of the same yields data in both 1852 and 1887 introduces some precautions at this respect, since changes in land productivity between both moments are mostly related with different soil quality distributions. The decrease between 1752 and 1852 is the most significative.

On the other hand, nutrient balances indicate that biomass extractions in 1852 were not sustainable since there is an evident nutrient mining process of potassium and considerable imbalances in cropland as well, which means that land productivity was likely going to be affected at some point. Besides, considering demographic factors such as migration and the future evolution of population numbers, pressure over land would have remained within similar parameters in the following thirty years. This would certainly aggravate the imbalances of nutrients in the soil, namely of potassium, but land appropriation could have perhaps remained in the same levels for a few more years or decades. This is so far just a hypothesis.

However, unsustainability is especially evident if we present balances at aggregated cropland scale, including all surfaces that we consider cropland instead of distinguishing surfaces by their role as either nutrient provider or receiver. In this case, nutrient imbalances are more evident, as shown in the following chart. In both cases, woodland (oakwoods and *soutos*) are included in *monte* but yearly cultivated *estivada* surface is considered cropland.

Chart 50. Fonsagrada. Nutrient balances in cropland and *monte* considering *estivadas* as part of cropland: 1752, 1852, and 1887 (kg/ha)

		N	P	K
1752	Cropland	-6.07	-0.23	-4.36
	Monte	58.02	1.86	30.87
1852	Cropland	-57.23	-3.21	-250.73
	Monte	54.11	1.22	27.29
1887	Cropland	-44.93	-2.34	-167.61
	Monte	58.40	1.71	29.28

Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; INEbase population censuses from 1857 and 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491.

If the previous option was not completely coherent due to the fact that cropland surfaces such as meadow or *souto* were considered as *monte* in terms of nutrient supply, now it is also unconsistent to include *estivadas* in cropland due to their specific management. For this reason, we will present another option as well, which includes *estivada* as part of *monte* and therefore considers the resulting balance at the end of the rotation as *monte* surface. This different impact of *estivadas* depending on where we include them, can also be appreciated in the charts in the years 1852 and 1887. In 1752 the difference is almost irrelevant since *estivada* surface is much more reduced. The most accurate option would be to consider them as *monte,* where they alternate between cereal and shrub production, as collected in the following chart.

Chart 51. Fonsagrada. Nutrient balances in cropland and *monte* considering *estivadas* as part of *monte*: 1752, 1852, and 1887 (kg/ha)

		N	P	K
1752	Cropland	-5.93	-0.21	-2.40
	Monte	57.14	1.80	27.23
1852	Cropland	-7.57	0.19	-1.87
	Monte	45.91	0.74	-7.30
1887	Cropland	-12.12	-0.09	-0.29
	Monte	46	0.97	-22.51

Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; INEbase population censuses from 1857 and 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartillas* from 1852 and 1886, Fonsagrada, APHL, Facenda, C14491 and C14992, respectively; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491.

Definitely, agriculture had managed to "produce" and, up to some point in the first half of the 19th century, also sustain an increasing demographic pressure in Fonsagrada. Eventually, food availability per capita diminished between, at least, 1850s and 1880s, which is definitely connected with the expulsion of the demographic excess that could no longer be sustained with the available soil. Migration functioned as a mechanism to control pressure over land by saving soil, and the slight recovery of nutrient balances in 1887 seems to give proof of it.

Considering the wide surface of the municipality and the fact that pressure over *monte* resources had decreased through the period in relation with lower shrub requirements for livestock, one could think that there was still some margin for higher levels of nutrient mobilization from these areas into cropland. But the role of *estivadas* should also be taken into account, since their intensification was related with higher food requirements and their decreasing productivity is clearly indicating the exhaustion of soil. Besides, their intensification was not compatible with a more intensive extraction of gorse, and with such an abrupt terrain further *monte* appropriation must have been very difficult, both in terms of labor costs and due to the diminishing returns of less suitable surfaces for cultivation.

The situation in terms of food availability in 1852 also seems to be a clear symptom of exhaustion in the pattern of agricultural intensification, and is related with the subsequent migration process, even though we do not mean that there is a causal relation between food shortages and migration since this phenomenom is much more complicated. Further intensification and cropland expansion were still performed until, at least, 1887, which means that, despite migration, nutrient mobilization was not constrained in terms of labor, and that land availability had not yet been overtaken in terms of nutrient mobilization to cropland by 1850s, even when nutrient imbalances were evident in more extensive rotations such as meadows. As a result, there was an adaptation in land uses and management that allowed to sustain a bigger livestock head to produce more manure for an expanding cropland, thus increasing total food availability. Therefore, between 1850s and 1880s, migration seems to have functioned as a nutrient saving strategy. A slightly increasing population between 1880s and 1920 –in spite of the ongoing migration- could have certainly reached the limits of intensification within the organic metabolism at the light of these balances, since there was not more surface available for closing the nutrient gap within the agroecosystem boundaries. It seems clear that migration is connected with the rupture of the equilibrium between land uses that we described for the 18th century since prior population movements were only seasonal and did not imply a decrease of population nor its stagnation. After 1850, migration becomes mostly definitive (towards America), and involves more people, thus resulting in a population decrease. However, in both moments migration was an integrated element within peasant economy. This particular connection between intensification, its exhaustion, and migration remains an open question for future research, which should also incorporate the energy standpoint.

Eventually, biophysical constraints to intensification in terms of land availability would be overcome with the introduction of industrial fertilizers at the beginning of the 20th century generally in Galicia (Fernández Prieto, 1992). Research on their spread through the municipality of Fonsagrada accompanied with nutrient balances for the beginning of the 20th century are required in order to better assess whether there was a nutrient bottleneck among the driving forces into an industrial metabolism in this case study. Our data suggest so, but imbalances mostly affect potassium so far, which does not constrain productivity in the short term. In fact, the slight demographic increase between 1880s and 1920 seems to support the hypothesis of continuties in this pattern of agricultural production. It is necessary to find out whether this was related with the introduction of industrial fertilizers after 1900 or if it was still happening within an organic metabolism. Besides, we also hypothesize that the definitive and steady decline of population after the decade of 1920s in Fonsagrada could have allowed to sustain agriculture within the equilibrium of the late 19th century without such external inputs.

6.4. A biophysical approach to migration flows

The historiographical interpretation of migration in Galicia has also been mediated by the more general debate in terms of backwardness and progress that we described in the first chapter. Accordingly, there have been two main opposed readings of this phenomenon, which have eventually complemented each other. The first one, mainly sustained within Economic History, considers migration within the context of a general failure in the introduction of capitalism. Thus, migration would be the symptom of an ongoing mismatch between demographic pressure and the productive system, which is described as an underdeveloped economy with a subsistence agriculture (Rodríguez Galdo and Dopico, 1981; Carmona, 1990; Beiras, 2008). This vision is slowly being overcome by those who see migration in connection with a high agricultural productivity in the 18th and 19th centuries that allowed to sustain an increasing population density (Saavedra, 1979; Pérez García, 2000; Bouhier, 2001; Soto, 2006), and as the final trigger of important socioeconomic and political transformations in Galicia during the first third of the 20th century by means of economic remittances and the ideological influence of those who returned (Villares, 1982; Fernández Prieto, 1996; Núñez Seixas, 1998).

Our approach to migration is inspired in this last research line that explains high population densities in Galicia in relation with the productive capacity of the agrarian system. As Soto has remarked, the interpretation of migration should be reconsidered according to the increase in land productivity through the 18th and 19th centuries. Thus, migration would be the result of an efficient agriculture, which allowed to produce excedentary population (Soto, 2006). A complementary hypothesis at this respect, which has been articulated in general terms for European migrations in the 19th century, refers to the need of looking for new soils to live off. This would be the consequence of the exhaustion of soil and decreasing yields in these old agricultures after a long process of intensification, accompanied by an increasing demographic pressure (Shiel, 2006b).

From a biophysical perspective, migration functions as a mechanism to control population growth and to prevent demographic pressure from altering the balance between population and appropriated land (González de Molina, 2010a). Livi Bacci has also interpretated this phenomenon as a structural factor of society, which is in tight connection with the capabilities to change of residence. The transformations related with the Industrial Revolution and its impact in transport systems only made it possible to travel further away for societies where migrations were already common. Thus long-distance migrations in Europe during the 19th century are related with an increase in agricultural productivity, a very intense demographic growth, and a numerous labor force which was absorbed by industrialization in certain regions within an increasingly integrated world market (Livi Bacci, 2012).

Historians have also remarked the links between migration and demographic features, which are essential in order to obtain a wider understanding of such processes in the past. In the case of Galicia, relatively low mortality rates and long life expectancy resulted in quite a modern demographic system already in the seventeen hundreds (Pérez García, 1986; Eiras Roel, 1992a, 1992b and 1996; Dubert, 1996). During the second half of the 18th century, average birth rates in Galicia were between 32-34 per mil, whereas mortality remained between 30-31 per mil. In the same period, average rates were of 43 and 38 in Spain, respectively; between 30-34 and 26-27 in Norway; and between 34-38 and 28-27 in England. In Galicia and other Atlantic territories of the North of Spain such as Cantabria or the Basque Country, this demographic pattern was more similar to those of Northern European countries than to the Spanish average. Mortality crisis were also not as frequent nor catastrophic in Galicia as in the rest of inner and southeastern Iberia since the 17th century at least. Dubert relates such trait with the social conditions and the productive system, which in Galicia was based on small holdings and complex crop rotations within a mixed farming agriculture that assured two harvests a year (Dubert, 1996). Eiras Roel has remarked that this "*demographic miracle*" occurred precisely during the Ancien Regime, within a territory with a relative low availability of arable land, far away from the main commercial routes (both internal and international), with a low or nil share in colonial exploitation, and low levels of marketable rural proto-industry (Eiras Roel, 1986: 15). Between 1600 and 1800, demographic growth in the territory of Galicia is over the Spanish average, especially between 1630-1750, when Galician population increases in a 130%. This is due to the contribution of the Southern Atlantic coast, where the absence of mortality crisis altogether with the introduction of maize explains the cumulative growth of population during two hundred years and its high density already at the beginning of the seventeen hundreds. In 1860, population density in Galicia doubled the Spanish average. Thus demographic pressure found its valve out through migration. After a general period of stagnation in the second half of this century, inner regions take over in demographic growth with a succesful incorporation of potato and a marginal introduction of maize (Eiras Roel, 1986, 1992b, and 1996; Sobrado, 1996). However, this general vision should not ignore different rythms and geographical differences, and the fact that innovation and changes were also present before the 18th century. For instance, the most intense demographic growth in the eastern mountains, where Fonsagrada belongs, takes place between 1780 and 1830. Apart from potato, maize was introduced in certain valleys since 1690 and fodder crops and turnips were also important (Saavedra, 1990 and 1992b). In the case of Ribadavia, the introduction of maize is more remarkable after 1750, when it reached from the lower stretches of the Miño and Limia rivers (Bouhier, 2001), and it belongs to a different pattern within the inner territory which has its demographic specifities regarding substantial demographic growth and regulation through mortality in the Ancien Regime but also combined with migration, especially in the second half of the 19th century towards America, as explained before.

Generally, migration patterns followed these main trends of agrarian intensification and introduction of new crops, thus being more significant initially along the coast and, later on, expanding through inner regions as well. This process transferred population mainly towards America from the middle of the eighteen hundreds and up to a century later, especially between 1880-1930. Compared with the rest of the Iberian Peninsula, and despite the difficulties of getting precise numbers of the people who left Galicia, migration in this territory is a paradigmatic case in quantitative terms. According to Eiras Roel, about 4.6 million Spaniards migrated to America in the period 1836-1936, out of whom 1.7 million were Galicians. Considering only the period 1836-1900, out of the 5.7 million people who left Spain between 1836-1900, about 2 million left from Galicia, which at the moment had only about a 10% of the Spanish population. Thus, in relative terms, Galician migration was four times the Spanish one (Eiras Roel, 1992b). According to Beiras and López (1999), Galicia lost more than 300.000 inhabitants in the three first decades of the 20th century. Until the

1950s, the natural movement of population would allow to keep up with the population loss to migration. However, this would dramatically change in the second half of the century, when the territory of Galicia lost more than half a million inhabitants. As a result, demography evolved towards an ageing and stagnated population.

In conclusion, the general population growth in the territory of Galicia during the seventeen and eighteen hundreds is related with a continued decrease in mortality rates, especially in the first half of the 19th century, thus slowing down in the second one due to the action of two regulatory mechanisms: the restriction of marriage and migration (Hernández Borge, 1986; Eiras Roel, 1996). This noteworthy demographic growth was sustained by the agrarian practices of the first wave of the Socio-Ecological Transition, namely by the introduction of new crops such as maize and potato and the supression of fallow. It has been hypothesized that, as a result, the territory got over-populated since a massive migrating process would soon start afterwards, which led to demographic stagnation towards the second half of the 19th century (Eiras Roel, 1986 and 1996; Precedo Ledo, 1998).

Let us now relate this general picture with our case studies, which more or less fit in the two main trends described. In the first place, Ribadavia shows a more similar pattern in agrarian changes and population fluctuations to the coastal regions than to the inner provinces where it geographically belongs. Therefore, a remarkable population growth takes place in the central years of the 18th century. Wine specialization plays a role in this evolution, thus breaking the isolation that is more characteristic of inner regions within Galicia. Wine exports provided with cash to import soil, that is to say food and fertilizers that could not be produced within the boundaries of Ribadavia due to the priorization of vines, but it also made the population very dependent on the fluctuations of wine production and prices. We have not developed nutrient balances for this case study but data allow to hypothesize that agricultural intensification and vineyard monoculture resulted in a nutrient mining process towards the end of the 19th century, which could be related with the later expulsion of population due to soil scarcity.

In the case of Fonsagrada there is an important demographic growth in the first half of the 19th century which is accompanied by introduction of potato, the expansion of cropland and the intensification of rotations. Then, towards the middle of the century, a tight balance between demographic pressure and land use distribution results in a decreasing availability of foodstuff per capita and triggers a constant migration flow out of the municipality, which continued during the first third of the 20th century. Fonsagrada is a good example of the general inner pattern since population growth follows the introduction of potato after 1790, more than two hundred years later than in the south-west regions where maize had been introduced already at the beginning of the 17th century, around 1610 (Saavedra, 1992b).

These agricultural regions, with their corresponding demographic patterns, which are different in family structure and inheritance mechanisms, had their corresponding migrating patterns.

Galician migrants within the Iberian Peninsula can be tracked in sources, at least, since the 17th century, although with regional differences in destination, duration, and occupation. The region of Burón, which comprises both Fonsagrada and the neighbor municipality of Negueira de Muñiz nowadays, mainly took part in temporary migration to Castile at least during the 17-19th centuries, either seasonal to the wheat harvest or multiannual towards Madrid and other villages. The region of the Avia valley, and especially Ribadavia and the surrounding mountainious region of Melón, registered both seasonal and multiannual migrants towards Castile at least since the second half of the 17th century and during the following one. Afterwards, and at least since 1715, both regions of Melón and Ribadavia also sent workers to Portugal. Thus, as the century moved on, the neighbor country would slowly replace the previous destination of Castile, especially during the 19th century. Within the Avia valley, inner migration towards other Galician provinces was also common, mainly towards Vigo and its surroundings, but also towards other municipalities within the Ribeiro. After 1870, and especially 1890, both regions of Fonsagrada and Avia (including both the valley of Ribadavia and the mountains of Melón) started to take part in direct migration to America[135], especially Ribadavia, thus progressively abandoning previous and closer destinations. The province of Ourense had been the least affected by migration during the whole period of our study. However, and in the same way as the province of Lugo, this would change towards the last third of 19th century, when both engaged in transoceanic migrations (Eiras Roel, 1992a).

The purpose of the biophysical approach is to assess migration by checking whether biomass production matches the nutritional requirements of the population, which we have developed for the case of Fonsagrada. An energy approach would be more useful by assessing productive capacity in terms of labor force as well but we have not applied this method so far. The basis for our estimates is a minimum consumption of 2,270 kcal/capon/day, as proposed by Cussó for 1860 (2005). Our data are a conservative approximation since declarations in our sources are slightly biased and we have not accounted for fishing or wild harvesting. The results are aproximative and certainly hide inaccuracies and, mainly, inequalities in the access to resources, as we already explained. However, data are reliable as indicators of a general trend and give evidence of a decrease in relative food availability in Fonsagrada towards the middle of the 19th century, and a slight recovery towards 1887. The following charts collect disaggregated data of available foodstuff and biophysical indicators related with food production such as cropland and livestock distribution per capita.

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135 Among the Ribadavians, Argentina, Cuba and Brasil, in this order, were the most frequent destinations, but some of them also migrated to Puerto Rico, Chile, USA or Uruguay. Most migrants from the coast of Lugo used to go to Cuba, those from inner regions went mainly to Argentina, and secondly to Puerto Rico and Mexico (Eiras Roel, 1992b).

Chart 52. Fonsagrada. Disaggregated food availability in 1752, 1852, and 1887 (kcal/cap/day)

	1752	1852	1887
Cropland	1,099.5	1,690.6	1,720.6
Meat	735.8	146.1	181.5
Milk	683.5	161.9	176.6
Total	**2,518.8**	**1,998.6**	**2,078.7**

Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; INEbase population censuses from 1857 and 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Chart 53. Fonsagrada. Biophysical indicators related with food production in 1752, 1852, and 1887

	1752	1852	1887
Population	9,099	17,368	16,419
Cropland productivity (t/ha, dry matter)	2.55	2.57	2.76
DE (t/cap/year, dry matter)	0.58	0.79	1.76
Cropland ha/cap	0.23	0.31	0.64
LU-500 kg/cap	0.94	0.20	0.25

Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; INEbase population censuses from 1857 and 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartillas* of Fonsagrada, 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Cropland surface in this chart includes vegetable gardens, the cereal rotation, *soutos,* meadows, vineyard and yearly cropped *estivada* surface. The efforts to increase cultivated surface between 1752 and 1852 resulted in a 0.08 ha more of cropland per person but with 0.74 less livestock units per capita. This means that the availability of meat and milk decreased from a total of 1,419.3 kcal/cap/day in 1752 to 308 kcal/cap/day in 1852. In 1887, this datum is slightly higher, reaching the 358.1 kcal/cap/day. The percentage of such products represented the 56% of total kilocalories available for human consumption per person and day in 1752. In 1852, this datum had decreased to the 15.4%, and in 1887 it reached the 17.2%[136]. Thus, food availability from cropland reached 1,099.5 kcal/cap/day in

[136] As specified before, we have not accounted for meat nor milk processed products, which were the most common form of consumption of both protein sources: cheese, butter, cured and smoked meat or other type of preserves with salt, herbs, etc.

1752; 1,690.6 in 1852, and 1,720.6 in 1887. In order to balance food availability with less livestock head, the inhabitants of Fonsagrada increased cultivated surface per person from 0.23 ha in 1752, to 0.31 in 1852, and to 0.64 ha/cap in 1887. But the improvements in food availability in 1887 when compared with 1852 are not only related with this increase in cropland but also with a slight improvement in average cropland productivity, which increased through the whole period from 2.55 t/ha to 2.76 t/ha (dry matter).

This clearly indicates that the reduction of livestock head between 1752 and 1852 had an important impact on the nutritional state of population in Fonsagrada. Moreover, the recovery in 1887 is related with the expulsion of population during this second half of the century, which decreases from 17,368 to 16,419 inhabitants, and allows for an increase in livestock head and in cropland surface per capita. Thus migration functions as a regulatory mechanism to control demographic pressure over the territory and prevents from further imbalances in land use distribution and food availability. Since nutrient balances show a certain recovery between 1852 and 1887, this is also indicating that migration had a positive impact on soil fertility. Therefore, migration in Fonsagrada functions as a nutrient (soil) saving strategy.

On the other hand, previous demographic growth, especially in the first third of the 19th century, is related with the increase in land productivity and the expansion of cropland, even when livestock productions were more and more scarce. This clearly evidences that animal husbandry competes with biomass production for human consumption, which means that the limits to the size of livestock head are conditioned by the size of human population, and viceversa. Fonsagrada reaches its limits of demographic pressure during the first half of the 19th century, and definitive migration towards America provides an escape valve to a decreasing food availability. These changes are summed up with data related to Domestic Extraction of biomass per capita, which increases steadily all through the period, thus going from 0.58 t/cap in 1752, to 0.79 t/cap in 1852, and to 1.76 t/cap in 1887. At the beginning of the period, primary crops are complemented with livestock productions in order to satisfy the main nutritional requirements of the population. In 1852, food scarcity seems evident after the reduction of animal contribution to human diets. By 1887, a more or less balanced situation is achieved in terms of food availability, which is mostly satisfied with cropland surface. If we include *monte* and oakwoods productions as well, then Domestic Extraction in the whole agroecosystem reaches the following amounts: 1.74 t/cap in 1752; 5.29 t/cap in 1852, and 5.20 t/cap in 1887. If we consider the cereal rotation exclusively, which was the one of the most basic staple crops for human consumption all through the period, these values remain more or less stable: 0.33 t/cap; 0.32 t/cap, and 0.37 t/cap, respectively.

In the case of Ribadavia, land productivity was much higher than in Fonsagrada from the very beginning of the period we are considering. This could have compensated for more scarce cropland and livestock units per person. Besides, the function of vineyard as a cash crop allowed for food importation in order to outweigh lower food availability. On the other hand, the exhaustion of the intensification pattern is also evident towards the end of the period with a slightly decreasing or stagnant productivity. But this can be partially explained by our incomplete data, as referred in the corresponding section. The following chart collects the main biophysical indicators of land productivity and food availability in this agroecosystem.

Chart 54. Ribadavia. Biophysical indicators of food availability in 1764, 1860, and 1888

	1764	**1860**	**1888**
Population	1,066	3,568	4,830
Land productivity (t/ha, dry matter)	2.23	3.74	3.54
DE (t/cap, dry matter)	0.63	0.94	0.63
Cropland ha/cap	0.28	0.25	0.18
LU 500 kg/cap	0.03	0.04	0.03

Source: Ensenada's Cadastre, *Comprobaciones*, AGS, DGR, 1RE, 1129_01; *Censo ganadero de la Corona de Castilla, año de 1752* (INE, 1996); *cartillas* from Ribadavia, 1860 and 1888: AHPOu, Facenda, C459/03 and C459/06, respectively; *Producción agrícola, con aplicación a las subsistencias y a la industria,* 1857, AHPOu, Facenda, C459/04; *Interrogatorio para reunir datos para redactar una memoria sobre el estado de la agricultura en la provincia*, 1876, AHPOu, Facenda, C459/04, INEbase censuses from 1857 and 1887, http://www.ine.es/inebaseweb/71807.do?language=0.

Let us remind that data for 1888 have been estimated with the same surface distribution as in 1860, and that data for 1764 include only the two parishes of Francelos and Ribadavia. Data for 1860 refer to the whole municipality and therefore are more representative and, compared with those of 1888, also more accurate. Cropland in this case includes vegetable gardens, cereal rotations, vineyard and chestnut groves. Productivity in cropland is generally higher than in Fonsagrada and reaches 2.23 t/ha in 1764; 3.74 t/ha in 1860, and 3.54 t/ha in 1888, whereas in Fonsagrada it reached 2.55 t/ha in 1752; 2.57 t/ha in 1852, and 2.76 t/ha in 1887.

However, data are generally lower in terms of cultivated hectare and LU-500 kg per capita. In Ribadavia, there are 0.28 cropland ha/cap in 1764; 0.25 in 1860, and 0.18 in 1888. In Fonsagrada, these values reach 0.23 cropland ha/cap in 1752; 0.31 in 1852, and 0.64 in 1887. The availability of LU-500 kg per person is very reduced in Ribadavia: 0.03 in 1764; 0.04 in 1860, and 0.03 in 1888. In Fonsagrada, such values are: 0.94 in 1752; 0.2 in 1852, and 0.25 in 1887.

Domestic Extraction in tons per person and year (dry matter) offers also dissimilar values: 0.58 t/cap in 1752 in Fonsagrada and 0.63 in Ribadavia towards the middle of the 18th century, and 0.79 t/cap in 1852 in Fonsagrada and 0.94 in Ribadavia in 1860. Values are much separated in 1880s, when Fonsagrada keeps increasing biomass extraction until 1.76 tons per person and year, and Ribadavia, where cropland could not keep expanding to match population growth, remains in 0.63 tons of Domestic Extraction per person. This comparison must be read with caution, since data for Ribadavia in 1764 refer to only two parishes, and data for 1880s do not include wheat production and we have not assigned the corresponding surface to any other crop.

However, all these data clearly indicate that food availability in Ribadavia could have not met the nutritional requirements of its population with the existing productions within the boundaries of the agroecosystem due to a reduced livestock head and low levels of Domestic Extraction per capita. Besides, if we consider only production for inner consumption by excluding vineyard rotation from these estimates, results are still more evident regarding the lack of self-sufficiency within this agroecosystem. Cropland ha per capita would descend to 0.07 in 1764 and 1860; and 0.05 in 1887. Equally, Domestic Extraction per capita without vineyard productions would decrease to 0.25; 0.51, and 0.31 t/cap, respectively.

On the other hand, higher productivity functioned as a compensatory mechanism for this lower land availability. Migration had the same function here as in Fonsagrada but could have been lessened by the fact that cash availability allowed for food importation in a market integrated economy. Further research is required at this respect in order to assess food availability more accurately, especially in the case of Ribadavia, where we have not deducted seed expenses from harvest and actual availability must have been even lower.

All in all, the biophysical perspective allows to shed more light on why and when migrations occurred by considering material conditions and resource availability. This is particularly clear in the case of Fonsagrada, where we have accounted for food availability and connected its decrease with migration in chronological terms. However, this should not be read as a causal relation. From this perspective, we can determine whether the material conditions were appropriate for living or not, but we cannot assess why people decided to migrate. This is coherent with what Thompson wrote about food riots in England during the 18^{th} century. This form of protest had its own logic and functionning but its rationality within a moral economy has been systematically misunderstood by the general economic theory. We do not know yet why in certain cases people starved to death, like in 19^{th} century Ireland or India, instead of rioting, like in England (Thompson, 1995a and 1995b) or in Montefrío, in the province of Granada (Villa, 2017). But the biophysical approach can provide new arguments for a better understanding of the past, and we know that migration in Fonsagrada, and likely in Ribadavia and generally in Galicia, was related with a decrease in food availability and the exhaustion of the intensification pattern that had allowed, precisely, to increase population densities all through the territory in the previous centuries. Definite migration to America was developed on the previous experience of seasonal population movements that were an inherent part of the socioeconomic structure. The inhabitants of Fonsagrada must have been very aware of the limitations of their agricultural practices and the imbalance in the land use distribution that resulted from the intensification and extensification of the cultivated surface through the 18^{th} and 19^{th} centuries.

In the future, energy balances should also be incorporated in the analysis of migration in order to account for labor availability and requirements. This will offer a more accurate approach on this relevant topic within Galicia's history, and will also allow to connect migration, productive capacity and mechanization, and to see whether the incorporation of new technologies after the late 19th century and, especially, in the beginning of the 20th, is behind a more dramatic expulsion of population or not.

6.5. Two intensification patterns within a wider context

The optimization pattern within an organic metabolism in terms of agricultural intensification as described here in both cases of Ribadavia and Fonsagrada was very common accross European agricultures in the 19th century (Schandl and Krausmann, 2007). In this section, we will compare our results with those of previous studies of the SFS project on the same topic that have used similar methods. Since most data in Austrian cases within the SFS project have used different units and parameters, and usually put the emphasis on the energy analysis, we will mainly refer to two other within Mediterranean Spain: Montefrío (Granada) in the years 1752, 1852, and 1897, and Sentmenat (Barcelona) in the year 1861. This comparison allows to further explain the general differences between Mediterranean and Atlantic agroecosystems. The authors have applied the methodology of nutrient balances and the theoretical approach of Social Metabolism, even when certain criteria might have been adapted to the specific characteristics of the agroecosystems or particular methodological decisions might have been different.

Data are collected in the following charts. Cropland in Ribadavia and Fonsagrada includes vegetable gardens, cereal rotations, vineyard, *soutos,* yearly cropped *estivada* and meadows. All these rotations are included in our estimates regarding cropland productivity in t/ha, cultivated hectare per capita, DE/cap, and LU per cropland hectare. In Montefrío and Sentmenat, *estivadas* and *soutos* do not exist but pasture surfaces, vineyard and olive groves have been included in total cropland surface as well as in these previous indicated data. However, in the aggregated balances for cropland in Fonsagrada, we have included only fertilized rotations because *soutos*, *estivada* and meadows were not fertilized and functioned in fact as nutrient reservoirs for cropland. Besides, management was particularly different in the case of *estivadas* due to their high impact on soils in the short term but their benefit in nutrient replenishment in the long run. However, to facilitate comparability, we will also introduce aggregated balances for the whole cropland surface in the text because balances in Sentmenat include forage surface, as well as vineyard and olive and fruit groves, and those of Montefrío exclude pasture but include olive groves and vineyard. Pasture in Mediterranean cases would have the same role of nutrient provider as *monte* in our case studies. Thus we believe that data in the chart offer the most similar indicators for comparability, since they have been determined according to the specific land management of each case study. For this reason, our data regarding manure availability in tons per cropland hectare has been established according only to fertilized rotations whereas these other cases estimate manure availability by considering the whole cropland surface. In this case, we have adapted our own data to this criterium in the comparative chart, thus manure per cropland hectare accounts also for vineyard, meadows, *soutos,* and yearly cropped *estivada* surface, even when these rotations were not fertilized. However, we will also refer to manure availability per fertilized hectare in the text for more accuracy.

On the other hand, cropland and pasture percentages refer to the total of agrarian surface, and include all *monte* surface in our cases, and all pasture surfaces in the rest of the cases. Therefore, pastureland designates all types of grasslands, either managed or not. We are aware of the difficulties of assimilating such different rotations but this is necessary for comparability reason. In the case of Fonsagrada, pastureland includes both irrigated and non-irrigated meadows, but also appropriated *monte* surface according to the requirements of both society and livestock. However, as we have already explained, *monte* pasture availability was much higher than this all through the period.

Chart 55. Ribadavia, Fonsagrada, and Montefrío towards the middled of the 18th century: main biophysical indicators

	Ribadavia (1764)	Fonsagrada (1752)	Montefrío (1752)
Population density (cap/km^2)	-	20.8	23.0
Total agrarian surface (ha)	403	43,763	24,476
Total cropland (ha)	301	2,105	7,681
Cropland (%)	75	4.18	31.38
Cropland ha/cap	0.28	0.23	1.49
Pastureland (ha)	0	9,406	16,795
Pastureland (%)	0	21.49	68.62
LU-500 kg	32.79	8,592	5,147
LU-500 kg/km^2	-	19.59	21.03
LU-500 kg/cropland ha	0.10	4.08	*0.67
LU-500 kg/pasture ha	-	0.91	*0.3
Cropland productivity (t dry matter/ha)	2.23	2.55	1.02
Cropland DE (t dry matter/cap)	0.63	0.58	1.51
Manure (t fresh matter/cropland ha)	-	1.11	2.7
N balance in cropland (kg/ha)	-	-1.07	1.22
P balance in cropland (kg/ha)	-	0.02	2.20
K balance in cropland (kg/ha)	-	-1.62	-19.49

Sources: own elaboration with data for Ribadavia and Fonsagrada from previous charts, and González de Molina, 2010a, and González de Molina et al., 2014a, for Montefrío.
*Estimated according to total cropland surface and total LU as collected in this chart, with data from González de Molina et al., 2014a. In González de Molina, 2010a, LU/cropland ha is 0.24 and LU/pasture ha is 0.20. Variations in data occur when different publications on Montefrío are considered. This obeys to the application of different criteria, therefore we have unified data related to this case study and our own data in terms of comparability by using data for Montefrío mostly from González de Molina et al., 2014a, but also from González de Molina et al., 2010a, when required.

One of the main differences between our Atlantic cases and the Mediterranean ones is that cropland requirements per capita in Montefrío (in all three moments) and Sentmenat (1860s) are much higher than in our cases. In 1752, there are 1.49 cropland ha/cap in Montefrío, whereas in Ribadavia and Fonsagrada cropland requirements per capita are more reduced: 0.28 and 0.23 ha/cap, respectively. This is related with lower levels of productivity in the Mediterranean region, which results in a higher land cost of production and soil fertility replenishment. Montefrío would be more similar to Fonsagrada in terms of low market integration and a higher degree of self-sufficiency. It is not surprising that it has the largest cropland surface of all three cases: 7,618 ha before 300 ha in Ribadavia and 2,105 in Fonsagrada in 1750s, even when population density is in a similar magnitude as Fonsagrada: 23 inhabitants per square kilometer in the former and 20.8 in the latter. Therefore, the percentage of cropland over the total of agrarian surface is higher in Montefrío than in Fonsagrada, with 31% before the 4% of the latter. Ribadavia would have a 77% of cropland, but this is mostly related with its vineyard monoculture and it is a biased datum since it includes only a small fraction of the territory, which is precisely the most urban and with a more reduced *monte* percentage. Besides, its population density is the highest of all three cases in the rest of the period, and probably at this moment too although this datum is not available. In Montefrío, average land productivity reaches 1.02 t/ha in 1752, whereas Fonsagrada and Ribadavia achieve higher levels: 2.55 t/ha and 2.23 t/ha, respectively.

If we attend to the distribution of Domestic Extracion per capita in cropland, Ribadavia produces 0.63 t/cap of biomass, whereas in Fonsagrada there are 0.58 t/cap. At this respect, Montefrío extracts up to 1.51 t/cap, which refers to the whole cropland surface, excluding forest resources. For Ribadavia and Fonsagrada we have accounted for all primary crops and their corresponding by-products in total cropland area, of which *monte* resources are also excluded. However, in the case of Fonsagrada biomass production has been technically assessed by Roc Padró and data include by-products such as cereal husk and stubble which are not included in Ribadavia, where we only accounted for the main by-products such as cereal straw or vineyard shoots.

Let us remind that livestock productions also achieved an important percentage of food availability for human consumption in Fonsagrada at this moment. In fact, there are 0.94 LU/cap whereas in Ribadavia this datum is only of 0.11 LU/cap. In Montefrío, there is 1 LU/cap[137], and both population and livestock densities are very similar to those of Fonsagrada. However, if we attend to livestock distribution per cropland hectare, density is much higher in Fonsagrada, with 4.08 LU/ha before 0.67 in Montefrío. This is not only related with land availability but also with a higher land cost of sustaining livestock in Montefrío than in Fonsagrada, which is due to their different levels of productivity. Ribadavia still has lower values of livestock density, reaching only 0.10 LU per cropland hectare, but this is mostly a consequence of the vineyard specialization and its excluing land uses regarding animal husbandry.

[137] Population in Montefrío in 1752 reaches 5,108 inhabitants (González de Molina et al., 2014).

Considering all these facts, the differences in manure availability are evident. It is higher in Montefrío, with 2.7 t/cropland ha before 1.11 in Fonsagrada but, as González de Molina indicates (2010a), not all of it was used at this moment since requirements were lower than availability. Besides, methodological decisions explain this huge disparity between Montefrío and Fonsagrada despite a bigger livestock head and more reduced cropland surface in the latter. We have assumed that most of animals in Fonsagrada spent their whole life on *monte* at this point, and therefore manure production was lower than in Montefrío: 2,333 total tons before 20,440. It is a moment of manure abundance in both cases. In Fonsagrada, nutrient requirements at this initial moment are fulfiled with both manure and fallow practices, which are also frequent in Montefrío. In fact, both fertility managements seem to achieve quite balanced soils, except for a clear potassium mining in Montefrío already at this point. Nutrient imbalances also start to be evident in Fonsagrada if we consider all the cropland surface and not only the fertilized rotations. In such case, nutrient balances remain as follows: -6.07 kg/ha of nitrogen, -0.23 kg/ha of phosphorus, and -2.40 kg/ha of potassium. These values are not terribly imbalanced and could still be within the margin of error of our estimates. If we do not account for *estivada* because of its very particular management, results remain more or less the same: -5.93 kg/ha of nitrogen, -0.21 kg/ha of phosphorus, and -2.40 kg/ha of potassium.

All these data show that the agroecosystems have a remarkable extensive component in both cases of Fonsagrada and Montefrío, especially in the 18th century, and also explains a wide pasture surface, which occupies the 68.62% of the total agrarian surface in Montefrío and the 21.49 % in the case of Fonsagrada –or actually 94.95% if we consider all *monte* surface, which was potentially pasture. Rotations include fallow in both cases and rely on a wide surface for nutrient replenishment, which allows to sustain a big livestock head in a moment of low population densities. Ribadavia's agriculture is under a very intensive management and due to its market integrated production relies mostly on a cash crop in order to obtain external inputs to close its nutrient gap. This is constant all through the period.

The following chart collects the main biophysical indicators of this three agroecosystems and the Catalonian one of Sentmenat during the decades of 1850 and 1860.

Chart 56. Ribadavia, Fonsagrada, Montefrío, and Sentmenat in 1850/1860s: main biophysical indicators

	Ribadavia (1860)	Fonsagrada (1852)	Montefrío (1852)	Sentmenat (1861/65)
Population density (cap/km^2)	158.6	39.6	38.0	59.0
Total agrarian surface (ha)	2,044	43,763	24,476	2,750
Total cropland (ha)	896	5,359	13,748	1,618
Cropland (%)	43.83	12.24	56.16	58.83
Cropland ha/cap	0.25	0.31	1.7	1.4
Pastureland (ha)	0	5,206	10,728	341.4
Pastureland (%)	0	11.89	43.83	12.41
LU-500 kg	145	3,406	1,892	199
LU-500 kg/km^2	6.43	7.77	7.73	7.25
LU-500 kg/cropland ha	0.16	0.64	0.07	0.12
LU-500 kg/pasture ha	-	0.65	0.08	0.46
Cropland productivity (t dry matter/ha)	3.74	2.57	1.09	*
Cropland DE (t dry matter/cap)	0.94	0.79	1.88	*
Manure (t fresh matter/cropland ha)	3.76	2.70	0.8	1.5
N balance in cropland (kg/ha)	-	-0.09	0.26	-1.1
P balance in cropland (kg/ha)	-	0.54	-1.18	0.9
K balance in cropland (kg/ha)	-	-0.12	-19.93	-0.7

Sources: own elaboration with data for Ribadavia and Fonsagrada from previous charts; González de Molina, 2010a, and González de Molina et al., 2014a, for Montefrío, and Galán, 2014 and 2017, for Sentmenat.
*These data are only available in fresh matter.

In Sentmenat, productivity is only estimated in fresh matter. Total production in cropland reaches 6,325 tons in 1861 (Galán, 2015), which divided by 1,618 ha results in 3.9 t/ha of fresh matter (by-products included). Our equivalent data in fresh matter for Fonsagrada in 1852 are 47,431 tons and 8.85 t/ha. The proportionality between these data and those in dry matter between Fonsagrada and Montefrío is similar. Productivity per land unit is more than twice in the Atlantic case when compared with the Andalusian one: 2.57 t/ha before 1.09 t/ha. This proportionality remains similar all through the remaining period, with cropland productivity between 1.02 and 1.13 t/ha in Montefrío, and between 2.55 and 2.76 t/ha in Fonsagrada. Because of the extensive character of agriculture in Fonsagrada, this productivity gap increases if compared with Ribadavia, where average cropland productivity reaches 3.74 t/ha (dry matter) in 1860. These values correspond to different population densities, which are similar in Montefrío and Fonsagrada (38 and 39.6 cap/km^2, respectively), slightly higher in Sentmenat (59 cap/km^2), and very high in Ribadavia (158.6 cap/km^2). Higher land productivity sustains a higher population density, although in the case of Ribadavia the market-oriented specialization should also be considered since it allowed to import the fertilizer and foodstuff that could not be produced within the boundaries of the agroecosystem. Besides, these data are also proportional with cultivated surface per capita: 0.25 ha/cap in Ribadavia; 0.31 ha/cap in Fonsagrada, and 1.7 and 1.4 in Montefrío and Sentmenat, respectively. In 1880s, 0.64 ha are cultivated for every individual in Fonsagrada whereas Montefrío needs 1.6 ha/cap. Ribadavia is the most extreme case with 0.17 ha/cap. The evolution in Fonsagrada is conditioned by a bigger livestock head with a more intensive management, as well as a more reduced contribution of animal productions to human nutrition which had to be replaced by increasing amounts of biomass extraction.

These differences between Atlantic and Mediterranean agroecosystems have been explained before regarding environmental conditions and a lower nutrient availability in the Mediterranean regions, which is also related with a more reduced water availability and the subsequent difficulties to introduce the mixed farming techniques that we have described for Fonsagrada and Ribadavia (González de Molina, 2010a; Fernández Prieto and Soto, 2010). In this moment, there is higher livestock availability per cropland hectare in Fonsagrada, with 0.64 LU-500 kg/cropland ha, than in Ribadavia, Montefrío and Sentmenat, with 0.16; 0.07 and 0.12 respectively. This translates into a better manure availability and is also connected with different productivity levels, which allow to sustain a bigger livestock head with a lower territorial cost, even if densities at municipal scale are similar in all four cases (between 6.43 and 7.77 LU-500 kg/km^2). Ribadavia would have no significative pasture surface according to our sources but, in the case of Fonsagrada, one hectare of pasture (meadows and *monte* appropriated surface) sustains up to 0.65 LU in 1852, whereas in Montefrío there are only 0.08 LU per pasture hectare in the same decade, and Sentmenat has 0.46 in 1861. This is coherent with a process of cropland expansion in Montefrío and vineyard specialization in Sentmenat and the subsequent reduction of pasture and forest surface and, therefore, livestock head. As the authors have explained, this meant a lower manure availability and triggered a nutrient mining process that exceeded the optimization threshold within an organic metabolism, thus resulting in a nutrient bottleneck and the stagnation of land productivity (González de Molina, 2010a; Galán, 2015).

Nutrient scarcity is a fact in Mediterranean agroecosystems, and has implications regarding soil fertility and land productivity since it is certainly constraining the intensification of rotations in terms of a mixed farming system. However, at this point, nutrient balances indicate that land management is generally sustainable, except for potassium in Montefrío. Let us remind that data for Fonsagrada include exclusively fertilized rotations. However, if we consider the whole cropland surface with *estivadas* as well, balances are much more negative: -57.23 kg/ha of nitrogen, -3.21 kg/ha of phosphorus, and -250.73 of potassium. Excluding *estivadas,* values are less imbalanced: -7.57 kg/ha of nitrogen, 0.19 kg/ha of phosphorus, and -1.87 kg/ha of potassium.

This corresponds to different levels of manure availability, which in Fonsagrada could reach an average of 2.7 tons per total cropland hectare, whereas this availability in Montefrío is only of 0.8 tons, and almost twice this value in Sentmenat with 1.5 t/cropland ha. If we only consider fertilized rotations, manure availability in Fonsagrada was actually of 4.6 t/ha. Of course, we need to remember that this is a potential threshold that has been estimated according to a permanent stabling of livestock, which was unlikely in Fonsagrada. The following chart collects all these parameters in the last decade of our study period.

Chart 57. Ribadavia, Fonsagrada, and Montefrío in 1880/1890s: main biophysical indicators

	Ribadavia (1888)	Fonsagrada (1887)	Montefrío (1897/1901)
Population density (cap/km^2)	214.67	37.44	37.08
Total agrarian surface (ha)	2,044	43,763	24,476
Total cropland (ha)	863	10,465	16,306
Cropland (%)	42.22	23.91	66.62
Cropland ha/cap	0.17	0.64	1.6
Pastureland (ha)	0	7,164	8,170
Pastureland (%)	0	16.37	33.38
LU-500 kg	157	4,172	1,587
LU-500 kg/km^2	6.98	9.51	6.48
LU-500 kg/cropland ha	0.18	0.39	0.07
LU-500 kg/pasture ha	-	0.58	0.05
Cropland productivity (t dry matter/ha)	3.54	2.76	1.13
Cropland DE (t dry matter/cap)	0.63	1.76	1.77
Manure (t fresh matter/cropland ha)	-	1.64	0.60
N balance in cropland (kg/ha)	-	0.50	-0.82
P balance in cropland (kg/ha)	-	0.84	-1.38
K balance in cropland (kg/ha)	-	0.25	-20.37

Sources: own elaboration with data for Ribadavia and Fonsagrada from previous charts, and González de Molina, 2010a, and González de Molina et al., 2014a, for Montefrío.

Population densities have decreased in both Fonsagrada and Montefrío, which now reach almost the same value, about 37 cap/km^2. Ribadavia has increased its population considerably, with about 214 cap/km^2. The percentage of cropland has increased in both Fonsagrada and Montefrío: from 12.24% to 23.91% in the first, and from 56.16% to 66.62% in the latter. The bigger increase in Fonsagrada is related with meadow expansion, which now sustains a livestock head 2.6 times bigger than Montefrío, which is also proportional to manure availability in these cases. Data for Ribadavia at this respect are not completely reliable because wheat surface of 1852 has been removed from land distribution in 1887. However, the percentage of cropland must have been similar in both moments, about the 43% of the territory, considering that some parishes could have up to a 77% of cropland such as Ribadavia and Francelos in 1752.

These percentages also match data related with cultivated surface per capita, which reaches higher values again in Montefrío, going from 1.7 to 1.6 ha/cap between 1850s and 1880s, whereas these values go from 0.31 to 0.64 ha/cap in Fonsagrada. In the case of Ribadavia, this cropland distribution per capita is highly reduced due to an important demographic increase and a low land availability, thus going from 0.25 cultivated hectares per capita to 0.17 ha/cap.

However, apart from the demographic increase, wheat surface has been removed from agrarian surface in our analysis of 1887, which also determines a reduction in this datum.

Biomass production per capita in cropland reaches now very similar values in Fonsagrada and Montefrío (1.76 and 1.77 t/cap, respectively), but remains considerably reduced in Ribadavia (0.63 t/cap) as it corresponds to its vineyard economy. Cropland productivity shows slight increases in Fonsagrada and Montefrío all through the period, especially in Fonsagrada. Data for Ribadavia are less reliable for the 18th century but indicate a slight decrease from 3.74 t/ha in 1860 to 3.54 t/ha in 1888.

In all cases there is an increasing pressure over the territory all through the period which results in nutrient mining processses at least in Fonsagrada and Montefrío, and very likely in Ribadavia as well. This translates in more negative balances in cropland in Montefrío. Fonsagrada, as we already explained, improves its nutrient balances slightly in cropland at the end of the period. But generally, intensification is performed at the expense of soil depletion in other surfaces such as meadows, woodland, and *monte*, which in fact indicates the existence of a mining process and a metabolic rift wihin the agroecosystem. The overall stagnation of land productivity in this case is also indicative of such process, which occurs in a similar chronology as in Montefrío.

If we consider total cropland surface in Fonsagrada, nutrient balances would have improved when compared with 1852, but would still be highly negative: -44.93 kg/ha of nitrogen, -2.34 kg/ha of phosphorus, and -167.61 kg/ha of potassium. Without *estivada* rotation, these values would be of -12.12 kg/ha of nitrogen, -0.09 kg/ha of phosphorus, and -0.29 of potassium. The case of Ribadavia requires further research at this respect, but our hypothesis is that its higher degree of intensification and vineyard specialization along with lower land availability per capita would have resulted in highly negative balances if it were not for nutrient imports from surrounding agroecosystems.

Definitely, agriculture and the process of intensification through the 19th century differ in Galicia from most of the Peninsula because of the Atlantic influence in bioclimatic terms (Soto, 2006; Fernández Prieto and Soto, 2010). Mediterranean cases have been studied under a biophysical perspective in Catalonia and Andalucia, where rotations are not as intensive as the ones described here, and water and nutrients are very important limiting factors (González de Molina, 2010a).

Nutrient balances show similar trends in other Andalusian studies by González de Molina et al. (2015) such as Baena or Castilleja de la Cuesta, where fertilized rotations show generally positive balances, whereas unfertilized ones tend to be more imbalanced, although lessened in the case of nitrogen by the cultivation of legumes. In fact, rotations with legumes and/or fallow displayed positive balances for nitrogen. The authors relate phosphorus and potassium deficits with manure shortages, which affected arable land. The particular path to the so-called "agricultural revolution" in southern Spain consisted in the supression of fallow in certain rotations and a paralel application of manure along with the introduction of legumes in association with cereal. This rotation expanded enourmously and, as a result, production increased generally accross Andalucia in the 19th century. The specialization on woody crops, namely olive trees in these case studies, was unsustainable in the long-term, mostly regarding net losses of both phosphorus and potassium, but also imbalances in nitrogen with the intensification of the 19th century, which consisted mostly in increasing tree density. All these Andalusian territories reached their limit in intensification with available resources within their agroecosystems towards the end of the 19th century. The authors detect a clear process of potassium mining, as in Fonsagrada, but also with net losses of phosphorus. This was mainly due to a decrease in the fertilization capacity. In 1752 there was more manure than required, but its availability progressively diminished with the expansion of cropland at the expense of pastureland and, therefore, resulted in a decrease of livestock head and manure when this fertilizer was most needed. Cereal intensification and olive specialization are in the origin of this unsustainable pattern since nutrients were mined from the soil due to the lack of fertilizer. The authors conclude that soil fertility was the key factor for the sustainability of agrarian metabolisms based on solar energy. Therefore, nutrient mining processes related to intensification were in the origin of the transition towards an industrial metabolism in agriculture. Industrial fertilizers allowed for intensification to continue in the region by compensating for the general decline in manure availability per cultivated hectare through the 19th century (González et al., 2015).

We conclude similarly in the case of Fonsagrada, where intensification led to soil depletion in specific areas of the agroecosystem that functioned as nutrient reservoirs to sustain land productivity in cropland. Stagnation and soil exhaustion seem evident towards 1880s, and were already evident towards 1850 when the land equilibrium that we described for the 18th century had been altered by an increasing demographic pressure. Nutrient scarcity was not as constraining as in Montefrío and other Mediterranean cases, which on top of this had also water limitations, but it determined the exhaustion of the intensification pattern that had allowed to feed an increasing population during the first half of the 19th century by eliminating fallow practices and introducing potatoes and turnips. Livestock intensification played an important role in the production of manure, and agricultural management allowed even for an improvement in balances towards the end of the 19th century by increasing manure availability constantly through the study period. However, the process of nutrient mining in meadows and *monte* is evident. Food availability seems to have been scarce towards the middle of the 19th century, and determined a further expansion of cropland and the increase of livestock head between 1850s and 1880s. The situation was relatively more balanced at the end of the period, after the beginning of a process of definitive migration, but nutrient mining was irreversible and cumulative. The stagnation of land productivity towards 1880s confirms such fact. In the case of Ribadavia, the expansion of vineyard and very intensive agricultural practices with a scarce land availability are likely responsible for a similar process of nutrient mining. We cannot know whether the imports of fertilizer and foodstuff were enough as to close the nutrient cycle, but certainly the use of a cash crop relieved this pressure over the territory by exporting the land cost of sustaining soil fertility to neighbor areas, which mitigated the unsustainability of land management in Ribadavia.

Similar research on different Austrian cases towards 1830s undertaken at the Institute of Social Ecology of Vienna concludes that the general agricultural pattern was also mostly unsustainable since manorial states reduced the capacity of small peasant economies to succesfully restore soil fertility because of the surplus extraction, which resulted in a lower share of livestock and other land resources in a context where the agricultural frontier could only be expanded by transfering nitrogen from extensively managed land into cropland. Thus sustainability problems arouse as a result of an unequal access to natural resources, which led peasants to use their resources more intensely than their landlords, even when agricultural intensification was so far rather exceptional. This has been demonstrated with nutrient balances, which show negative values for nitrogen in peasant economies and positive ones in manors. For this reason, peasant economies had lower yields and relatively more scarce food availability and, as a consequence, livestock density was kept low too. On the contrary, landlords created margins for intensification within sustainable thresholds, which were based on the surpluses generated by the small peasant economies. When the introduction of such practices was possible, the pattern was similar as in Fonsagrada: fallow fields were planted with potatoes and turnips during the first half of the 19th century, as well as other tubers and fodder. This ensured abundant livestock feedstuff, and animals provided with meat, milk, wool and manure in considerable amounts. Besides, in areas where pastureland was abundant, agricultural management has also proved generally unsustainable since this surface showed negative nitrogen balances as a result of the nutrient transfer to cropland. Eventually, another strategy to deal with the sustainability costs of inequality and to allow for more intensive management focused on the replacement of diverse cropping for a cash crop specialization, which could be compared to Ribadavia and to the Catalonian case of Sentmenat (Neundlinger and Güldner, 2017). The inequality approach is also a pending issue in the case of Fonsagrada, where Ensenada's Cadastre and a land assessment of the late 19th century allow for a similar approach, at least in some parishes.

When comparing the general structure of valley and mountain economies of our case studies, it is surprising how similar patterns are also found in pre-industrial agriculture in Austria, where mixed farming was also wide-spread. The prealpine Enns valley achieved higher productivity levels with a more intensive agricultural management than the Möll alpine valley but its local production could not sustain total population due to the abundance of non-agricultural workers in the mining and metal industries. Population density reached 36 inhabitants per square kilometer in 1830. On the contrary, in the alpine region of Möll, population density was lower at the moment, with only 19 cap/km^2, and was in fact sustained with local production but at the expense of soil nitrogen depletion due to an intensive land-use system already by 1830. Just as it occurred in Fonsagrada, total pastureland surface was wide and occupied an important part of the agrarian surface, up to its 38% in 1830 if both meadows and alpine pastures are considered. Besides, more extensive practices were common on the high alpine case study, where cropland alternated with grassland for hay production in six to twelve years cycles. Fallow periods were also longer and one of the villages even developed a type of slash-and-burn agriculture which was cropped for hay every twenty years. Due to altitude and climate, potatoes and turnips were also important but only in the Enns valley. In both cases, cereal grain yields about 800 kg/ha. In Fonsagrada, rye grain in yields an average of 973 kg/ha in a biannual rotation with fallow[138] in 1752, and 673 kg/ha in a biannual rotation with potatoes and turnips in 1852. In Ribadavia, cereal yields about 1,200 kg/ha in 1860 but in an annual rye rotation[139]. Food imports were necessary in the Enns valley, but food production exceeded local demand in the Möll alpine economy by a 4%. These subsidies from mountain economies to the lower valley and its specialized economy were also frequent in the region of Ribadavia. Biomass extraction reached 2.26 t/ha in the prealpine Enns valley and 1.14 t/ha in Möll (fresh matter). In Ribadavia, average land productivity reached 3.74 t/ha[140] (dry matter) in 1860. In Fonsagrada, average domestic extraction of biomass, with all by-products and *monte* productions included, reached about 8.9 t/ha (fresh matter) in 1852. In both Austrian cases, livestock density was similar: 10.76 LU-500 kg/km^2 in Enns and 8.38 LU-500 kg/km^2 in Möll in 1830, which was higher than the 7.77 LU-500 kg/km^2 in Fonsagrada in 1852 (municipal scale). However, the authors point at a likely nitrogen depletion process in the Möll region in the long-term with negative balances of up to -6 kg/ha in cropland and an average of -1.3 kg/ha in the agroecosystem, whereas Enns valley managed to achieve quite balanced nitrogen levels both at regional and cropland scale. However, grasslands did show negative balances in Enns but positive in Möll, which is connected with different grazing management since livestock was mostly kept in stables in Enns and accumulated manure during the night, whereas in the alpine region of Möll animals spent even months on pastureland. Forest balances were positive in both regions. The wide surface of more extensively used areas in these cases, which had positive balances, result in overall positive balances (Gingrich et al., 2015). The case of Fonsagrada shows a very similar functionning at this respect, since nutrient imbalances are only detected at rotation scale, whereas average balances at agroecosystem scale are always positive for nitrogen, although increasingly negative for potassium. Besides, as in the case of Enns, manure availability ensured quite balanced nutrient levels in cropland, especially in fertilized rotations, but at the expense of nutrient stocks in other more extensive surfaces, namely meadows. This has been concluded before for Catalonian and Andalusian case studies as well (Galán et al., 2012; González de Molina et al., 2012).

Moreover, this metabolic rift, which is a disequilibrium in land uses and results in a process of nutrient mining, has been connected with the agrarian crisis that generally affected Europe towards the end of the 19th century, thus being one of the main driving forces of the

[138] Only first quality soils were cultivated annually without fallow.
[139] All yields data in fresh matter.
[140] *Monte* productions excluded, as well as most by-products (only straw is included in cereal crops).

socioecological transition. The biophysical approach contributes to the explanation of the agrarian crisis by putting the focus on fertility management. At this moment, two different fertility systems came into contact, thus revealing the gap in their land costs. European agricultures, with a much longer history of cultivation over the same soils, had developed management practices for nutrient replenishment which were not required at this point in American or Australian soils due to their unspoiled nutrient stocks. Thus the land cost of fertility in Europe was much higher than in these other territories, which took advantage of these nutrient reservoirs to produce cheaper cereal whereas European agricultures were starting to show soil exhaustion problems and productivity stagnation after a process of agricultural intensification during the 18th and 19th centuries.

The introduction of industrial fertilizers would ease the land cost of fertility in European agricultures and allow for further intensification and productivity increases after the beginning of the 20th century (Garrabou and González de Molina, 2010; González de Molina et al., 2012; Cunfer and Krausmann, 2009). This seems to have been the case in Fonsagrada as well. Soil fertility was based on a high territorial cost and, once the equilibriums of the 18th century were broken, the agroecosystem underwent several changes and adaptations in order to sustain an increasing demographic pressure. Livestock management was also intensified in order to optimize manure production, meadow surface increased, *estivadas* were also intensified and overall cropland surface expanded over *monte* areas, thus depleting its nutrient stocks. Balances were more or less sustained in cropland, and even improved towards the end of the study period, but this was done at the expense of less intensely used soils. While the agricultural frontier could expand over *monte,* productivity coud be sustained in cropland. More nutrient balances are required in order to determine whether this agroecosystem functionning was completely exhausted or not towards the end of the 19th century. So far, our data indicate that exhaustion was irretrievable within this land use distribution considering the diminishing returns of *estivadas* through the period and the overall stagnation in cropland productivity towards the end of the 19th century.

Conclusions

In this research we have used the theoretical framework of social metabolism, which addresses the interaction between social and natural systems by analyzing the processes that occur within the different sociometabolic arrangements. Despite being a thorough and powerful proposal to understand the coevolution of societies along with nature, we have found it difficult to translate this theory into applied research because methods have not been specifically designed, as previous authors have also acknowledged (González de Molina and Toledo, 2011).

However, Agroecology provides some useful methods to measure material flows such as energy, water or nutrients which can be adapted to historical research. The methodology of nutrient balances developed by García-Ruiz et al. (2012) is useful in order to assess both the functioning and sustainability of agroecosystems in the past, especially when approaching the management of soil fertility. However, its application implies many difficulties which can only be overcome with a multidisciplinary approach, which allows to interpretate agrarian changes in a sustainability key. The margin of error inherent to the method does not distort the reliability of the results, which show coherent magnitudes. In fact, the method itself leads to self-correction and helps to further criticize historical sources. In our case, preliminary results of nutrient balances presented inconsistencies and contradictions that allowed to detect errors and problems with calculations and estimates. Besides, the biophysical reconstruction required by the methodology also allows to assess whether sources are reliable or not. In the Spanish case, research had questioned the general reliability of livestock data in *cartillas* and in the censuses from 1865 and 1891 (GEHR, 1991; Pro, 1992). We are aware that such documents have general reliability concerns but their validity as information source should be tested locally. For instance, livestock data in the above mentioned censuses are coherent with biomass production in the case of Fonsagrada according to our sources, which means that the described pattern in livestock decrease in the 19th century is coherent even when both biomass production and livestock numbers must have been globally higher. A bigger livestock head could have not been sustained with biomass productions as declared in the *cartillas*. This is also an evidence of the competition between humans and livestock for biomass production and how this fact conditioned the different land use arrangements through the study period.

On the other hand, the methodology of nutrient balances allows to reach where conventional historical research cannot. In our case, we have been able to reconstruct the functionning of the agroecosystem of Fonsagrada in terms of its nutrient cycle, thus assessing the sustainability of the management of soil fertility and its connection with the intensification process. We have also evaluated changes in food availability by estimating the nutritional requirements of population and livestock in every year of the study, which evidenced the link between material conditions and migration in the case of Fonsagrada. Besides, we have constructed biophysical indicators that allow to compare our case study with similar research.

Our results show that peasants had a deep and precise knowledge of the resources they depended on. In 1750s, right before the development of a more intensive agriculture, our estimations on manure availability and requirements for Fonsagrada show that doses applied to crops were enough as to keep soil fertility in a sustainable balance. Nutrient losses are within acceptable limits in cropland and they could actually be due to the margin of error of our methodology. Besides, nutrient balances in more extensive land surfaces such as *monte* and meadows are positive at an aggregated scale, which means that this situation was not likely to lead to a metabolic rift. In the year 1852, nutrient requirements increased regarding more complex and intensive rotations as well as a wider cropland surface. The amount of total manure increased accordingly due to an adaptation in livestock management, but nutrient defficiencies widened since requirements overtook nutrient availability. As a result, management was still modified in order to increase livestock head and to obtain more manure which, by 1887, results in less imbalanced nutrient levels in both cropland and extensively used surfaces. At this point, migration should also be considered as a soil saving strategy which allowed to relieve pressure over the land during the second half of the 19th century. More cattle was raised and a more appropriate nutritional situation was achieved in terms of average calories per capita. Peasants also managed to increase cropland surface, thus improving food availability both in relative and absolut terms. Nutrient balances in 1887, even when relatively improved regarding the situation of 1852, are still considerably negative, especially in extensive rotations such as meadows, which is a clear sympton of the exhaustion of the intensification and extensification practices developed through the 18th and 19th centuries and a consequence of the metabolic rift between land uses and soil requirements. In fact, overall land productivity increases slightly in the agroecosystem through the study period, but decreases in the main cereal rotation and also in *estivadas,* which are managed in an increasingly unsustainable way in order to secure foodstuff provision.

This matches previous research in Mediterranean Spanish regions, where nutrient bottlenecks were among the main triggers for the socioecological transition by exhausting the possibilities of intensification, which created a proper context for the introduction of industrial fertilizers (González de Molina et al., 2010 and 2015; Galán, 2015). This situation shares common traits with other European agricultures regarding the development of a complex management of soil fertility which eventually, after a long process of agricultural intensification and increasing demographic pressure, resulted in the depletion of more extensive land uses in the benefit of cropland (Shiel 2006a and 2006b; González de Molina et al., 2010; Olarieta et al., 2010; Garrabou et al., 2010; Sattari, 2014). Besides, in the case of Fonsagrada, this situation was aggravated by the intensification of *estivadas* on *monte* surface. A reduced frequency and a higher surface of yearly cropped *estivada* through the 19th century resulted in a clear mining of potassium stocks. On the other hand, such a trend had not been documented before in Galician historiography, where *estivadas* were said to progressively withdraw through the eighteen hundreds. Our results demonstrate that their functionality changed through the study period as well. In 1752, this practice was mostly aimed at regenerating pasture in *monte* areas, whereas a century later its contribution to peasants' diet was essential but their role as shrub regenerating practice was not so much required since livestock nutritional requirements could be easily assured with cropland productions.

At the same time, there is a change in food availability for human consumption, which goes from plenty of animal protein-based foodstuff to more and more varied vegetables, thus reducing also the dependence on the one main cereal crop. Rye keeps its protagonism all through the period but potatoes and turnips also become an important component in the diet, without dismissing chestnuts. However, the agricultural changes that initially allowed to sustain an increasing population resulted in the rupture of the previous land equilibrium. Thus food availability becomes more scarce in relative terms due to the demographic growth even when total amounts of biomass production increase all through the period. Apart from the nutrient mining process which results from more intensive agricultural practices, this rupture is also evident in the migration pattern. The metabolic rift is strongly connected with the switch from seasonal to definitive migration, which allowed to save soil and achieve a better balance both in food and manure availability by the end of 1880s by increasing livestock numbers.

In the case of Ribadavia we cannot be so conclusive since nutrient balances have not been developed but our data on land uses and productivity as well as preliminary estimates on manure availability and soil requirements allow to affirm that vineyard specialization resulted in an unsustainable management that required the early importation of nutrients from nearby agroecosystems in the form of both fertilizers and foodstuff. The nutrient cycle could not be closed with local resources and the metabolic rift must have appeared a lot sooner than in the case of Fonsagrada. The intensification pattern, combined with a wide vineyard surface which was abundantly manured, exported this unsustainability to the mountainious areas of the Ribeiro, where vineyard was not a common crop and land uses must have been more integrated although also dependent on the regional wine economy. Nutrient and energy balances would allow more precision in this analysis, especially considering that people also migrated from the mountains to the valley in peak season of vineyard labor, but population movements were also frequent in Ribadavia, especially after the wine crisis.

Besides, our results allow to extrapolate some basic conclusions to the rest of the Atlantic territory in the North-West of the Iberian Peninsula. If the intensification pattern consisting in the supression of fallow and in the incorporation of new crops into more complex rotations resulted in the depletion of soil fertility and originated a metabolic rift in Fonsagrada, where high land availability allowed to cope with the land cost of fertility more easily, it is very plausible that this was also the case in the more intensive agroecosystems of the Atlantic coast, where this exhaustion must have ocurred sooner due to their earlier intensification and higher population densities. However, the availability of other marine resources which were used as fertilizers must also be taken into account in coastal areas. Future research needs to address this issue.

Eventually, this kind of applied research aims at understanding the present situation of socioecological crisis by digging into its historical roots. One of the targets is to describe land management practices that could be adapted to agriculture in the present in order to improve its degree of sustainability, which seems quite feasible in Galicia due to the functionality of small scale agriculture (Carreira and Carral, 2014). However, we are skeptical about the concept "sustainability" as it has been formulated after the 1970s according to Meadows and Brundtland reports. As other authors have pointed out, this is a problematic term due to the fact that it combines both the interests of those who defend economic growth and capital accumulation with those of ecologism (Valero and Naredo, 1999). Thus it is common to speak about "sustainable development", an oxymoron (Haberl et al., 2016) which, according to Picado, also lacks temporal perspective both regarding the past and the future. When it comes to the past, it ignores economic cycles and the fact that environmental problems have been accumulating over time. When it comes to the future, it does not establish a concrete connection between the future generations it addresses and the way in which the current resource-consumption patterns should be arranged. That is to say, there are no proposals nor indicators as how to address resource distribution in an inter-generation prospect (Picado, 2016). The concept is ambiguous enough as to please political and economic powers which do not aim at subverting the current world order. Despite this conceptual inconsistency and its political weakness as a transformation tool, we acknowledge it is a necessary concept in order to address and analyze the current situation of socio-ecological crisis. In fact, our aim is to contribute to this debate at local scale by providing knowledge on how agricultural practices from the past could help develop a more sustainable land management today. This is critical from the point of view of soil fertility. With the widespread of industrial fertilizers after the Second World War, nutrient availability for crops has been sorted out but at the expense of creating other problems in soil management such as erosion, decreasing content in organic matter, increased drainage, a depleted soil structure, drought, and leaching of nitrates into water supplies. Previous research has connected these issues with the supression of crop rotations and the disuse of livestock manure (Pfeiffer, 2004; Shiel, 2006a and 2006b), and has contributed to outline the importance of reusing and recycling materials in varied forms of litter, compost and manure, so that nutrients can be recovered from the agrifood system, especially in the case of limited resources such as phosphate stocks (Smil, 2000; Sattari, 2014; Cordell et al., 2009). We have presented basic practices of fertility management which were widely spread within the agrarian system in the territory of Galicia, and we have also assessed their long-term sustainability. Even though intensive mixed-farming agriculture resulted in a process of nutrient mining in connection with an increasing demographic pressure, we are aware of the importance of further agronomic research on these practices and resources such as gorse (and by extension *monte*), which should definitely be reincorporated into current agricultural practices accompanied with modern labor saving technologies.

What is next?

All through the text we have evidenced issues that research needs to address in the future in order to complete our results and to advance in the environmental understanding of the coevolution of nature and society in the Atlantic territory of Galicia. We will briefly summarize them in the following paragraphs.

In the first place, the chronological frame should be expanded in the case of Fonsagrada, especially to the beginning of the 20th century, so as to assess whether the nutrient bottleneck conditioned the industrialization of agriculture or not. Unfortunately, we have so far not located enough sources for this purpose.

Besides, energy balances are also necessary in order to properly assess migration and agricultural practices in terms of labor availability. This methodology will allow to approach the energetic functioning and the efficiency of the agroecosystem through time. Labor information in our sources is satisfactory for such purpose, at least in 1752, 1850s, and 1880s. Both methodologies, nutrient and energy balances should be applied to the case of Ribadavia, at least for the year 1860, which is so far the most complete year regarding source availability.

Another relevant topic that we should consider is inequality in the access to resources and its environmental consequences. Neundlinger (2017) and Villa (2017) have approached this issue in their PhD dissertations according to the theoretical proposal of social metabolism by González de Molina and Toledo (2011 and 2014), which connects inequality with unsustainability. Saavedra concludes that inequality among peasants was lower in the territory of Galicia and nearby regions than in Castile or other European regions. However, in relative terms, inequalities were also remarkable among peasants regarding access to land. For instance, the author mentions the case of the south of the province of Lugo, where the 10% of peasants had access to about 15 ha of land whereas the rest cultivated only an average of 1.5 ha. Allodial possession was not unfrequent among peasants, but it used to correspond to marginal poor quality land. Even if this form of property could reach up to 30% or 40% of cultivated land in certain regions, it was more than rare for a peasant not to pay rents. Therefore, the highest inequalities were between those who paid the rents and those who received them. In the case of Fonsagrada, those who did not pay rents were a clear minority, only a 6.6% of peasants out of the 463 neighbors of the seven parishes studied by Saavedra within Fonsagrada in 1752, which represented a 6.2% of the cadastred land in those parishes. However, this was not a synonym for economic wellbeing for this minority since most of them had very little land and/or livestock, or not land at all, or livestock under an *aparcería* contracts. The relevant datum is that 93.8% of land that was subject to the payment of rents. Direct property and useful domain rarely happened to meet on the same person. Since rents were proportional to labor required, it would be essential to estimate the labor cost of peasants to produce their own subsistence level and the rent value (Saavedra, 1979 and 1992a). This could be feasable not only with previous research by Saavedra for the year 1752 with the *Real* *de Legos* of Ensenada's Cadastre, which lists neighbors and properties along with rents, but also with data from the *amillaramiento* of several parishes of Fonsagrada from 1880s[141], which lists individuals and their properties with surface and crop data, although not their corresponding rents. This individual analysis could also contribute to clarify whether collective tenure was related with the capacity of fertilization.

With all these results, it would be possible to approach the nutritional transition with FAO's methodological proposal of food balances, as other authors have already done (González de Molina et al., 2014b). This method consists on estimating foodstuff availability by subtracting exports, seeds, and non-edible residues, and adding imports. However, sources with quantitative data on imports and exports are scarce, especially in the 18th and 19th centuries. On the other hand, the cases of vineyard monoculture like Ribadavia are easier to assess at this respect, at least for wine production.

Finally, it is also pertinent to apply this kind of biophysical research to other case studies within Galicia, especially along the Atlantic coast. This will improve our knowledge on the territorial patterns of intensification and their outcomes in terms of sustainability, both in nutrient and energy terms, and the connection with the socioecological transition. Besides, in the long term, local research should also be complemented with the regional approach in order to assess the integration of different scales.

[141] We have not used this document in our research, since we have only approached the aggregated municipal scale. The source is located at the municipal arquive in Fonsagrada: AMF, *Facenda, Amillaramentos*, C543 and C544.

APPENDIXES

Appendix 1. Methodological report on material flows in Fonsagrada

This report collects methodological decisions, and sources and references regarding data used in the elaboration of nutrient balances and material flows within the agroecosystem of Fonsagrada for the years 1752, 1852, and 1887. Our first task was to accomplish the balance for one year, 1752, which would serve as a template for the other two moments. However, we will also comment on the differences between them.

Our main sources for surface distribution, rotations and yields are Ensenada's Cadastre for 1752, and land registries or tax assessments and other statistical and/or fiscal documents for the 19th century, mainly *cartillas*. For 1852 a *cartilla* with surface distribution and yields was available but the corresponding of 1886 is mostly a copy of this previous one. Therefore we have used a surface summary from agrarian statistical documents from 1887 and most yields from 1852. Specific yields for the decade of 1880's were also taken from *cartillas* from neighbor municipialities such as Cebreiro and Castroverde.

Missing data were obtained either from other sources or specialized literature of the studied period or from bibliography and current references. Our main guideline when replacing missing data is chronology and source reliability. Traditional livestock breeds and plant varieties had different yields as a result of different uses that were prioritized by peasants (Guzmán et al., 2010; Soto et al., 2016b). Therefore original data from sources or specialized literature from the study period are preferred to current bibliographical references that usually study modern breeds and varieties. Our sources offer sometimes contradictory or missleading information. In such cases, current data have been used. For all cases, unless otherwise specificied, dry matter content and by-products data are from Guzmán et al. (2014).

We have used the Spanish map of agrologic classes[142] in order to assess different aspects of the nutrient balances and to complete data related to erosion. This map classifies land according to its agrarian potential, which is useful for a better understanding of land uses in Fonsagrada. However, the map is not finished and almost 15,000 ha from the municipality are missing. We have used data from adjacent municipalities which were also part of Fonsagrada at some point along the 18th and 19th centuries: Navia de Suarna and Negueira de Muñiz.

Surface and yields

Most data regarding yields and surface distribution in Fonsagrada have been extracted from fiscal sources from the municipality and distributed in spreadsheets according to rotation in

[142] Ministerio de Agricultura, 1978, "Mapa de clases agrológicas: Fonsagrada (Lugo)", Servicio de Publicaciones Agrarias, Madrid.

order to proceed to their analysis. Some yields are generally missing in the sources since they refer to products that, despite their huge value in the agrarian system are not especified as they are either by-products, residues, or shrubs, or simply difficult to account for. These missing data such as pasture extraction, turnip yields[143], straw, hay or shrub, or even manure doses and wood production have been collected from statistical sources of the late 19th or early 20th centuries, mainly elaborated by the *Junta Consultiva Agronómica* (JCA), institution that depended from the Ministry of Agriculture. We have also used bibliography produced by engineers such as Soroa (1953) or Cascón (1918), and residues have been calculated with data from Guzmán et al. (2014). For shrubland surface, which is poorly accounted for in the sources, we estimated its totality by using the total current surface of the municipality. Urban surface is not consigned in the sources of the 19th century thus we assume it is the same as detailed in Ensenada's Cadastre in 1752, although it must have increased after the population increase of the first half of the 19th century (Saavedra, 1992b).

Another type of inaccurate data in our sources is seeding expenses. For crops such as barley, maize, millet, linen, and fodder, data are from Soroa (1953: 273, 320).

Irrigated cropland

According to the above mentioned sources, there are only two irrigated rotations in Fonsagrada in 1752, 1852 and 1887: vegetable gardens and pastureland.

Vegetable garden

Since productions in this rotation are the most difficult to evaluate due to a continued cultivation, related data in sources are less accurate than usual. The documents that we consulted for the study of Fonsagrada only assign monetary value to these crops but never estimate production in kg/ha. Fortunately, the *cartilla* of the neighbor municipality of Castroverde from 1888 does account for vegetable yields in kg/ha for five crops: collards, lettuce, cabbage, onions, and green beens. Given the lack of better data, these same yields have been applied to all three moments of the study, 1750s, 1850s and 1880s. Therefore, the difference between these years will only be in the surface, which has been detailed in the sources.

[143] Turnip and green beans do not appear in our sources in 1752 but they do in sources from the late 18th century such as the "Frutos Civiles" of 1788 (Saavedra, 1979). Yields for turnip fodder, which can reach up to 9,000 kg/ha, have been obtained from Ministerio de Agricultura, 1905. *La ganadería en España* (Ministerio de Agricultura, 1892) provided root yields, which can range between 40,000 and 60,000 kg/ha. Sources express such yields in carts, for which we have estimated a converter that is coherent with data in these references. We also estimated yields according to soil quality by taking into account the proportion between the yields expressed in carts in our sources.

The surface of vegetable gardens in balances has been distributed according to season, which means that all crops listed in the sources have been asigned all the surface at one time because they are all cultivated in different times of the year. It is still a conservative approach since there must have been other crops as well which, however, are not listed. And the same applies to manure, which is barely mentioned but mostly in carts or monetary value as well. Data at this respect have been estimated according to livestock and soil requirements, and assessed with data from the *cartillas* of Cebreiro and Castroverde (1888).

Green beans, which appear in the above mentioned *cartilla* of Castroverde and are mentioned in sources for Fonsagrada in 1852 and 1887, have not been included in 1752 since its cultivation is not documented in the area until 1780s (Saavedra, 1979). Yields from Castroverde, as registered in the *cartilla*, are detailed the following chart.

Chart 58. Castroverde. Yields in vegetable garden (kg/ha, fresh matter) in 1888

	Soil 1	Soil 2	Soil 3
Collards (*berzas*)	5,924	4,443	3,413
Lettuce	780	613	425
Cabbage	690	575	411
Onions	650	530	475
Green beans	375	315	239

Source: *cartilla* from Castroverde, 1888, AHPL, Facenda, C14459.

Irrigated pastureland

According to sources, grass is harvested for hay three times a year in first quality soils and twice a year in second and third. Grass yields are from *Prados y pastos* (Ministerio de Agricultura, 1905), which estimates hay production in 9,000 kg/ha. Following the proportion of production given in carts in our sources, we estimated production in second and third quality soils to be of 6,750 and 4,500, respectively. In order to obtain fresh matter weight we have multiplied these productions by 5 as stated in Soroa (1953). This factor of conversion is validated by data in Guzmán et al. (2014), where grass is assigned with a 0.2 % of dry matter.

Non-irrigated cropland

Apart from shrubland, woodland, pastureland, vineyard, *soutos,* and *estivadas,* there are four non-irrigated cereal rotations in 1752: rye, wheat, and wheat-barley. The wheat-barley rotation will not be taken into account for the balances due to its reduced surface in 1752 (only 0.14 ha in the parish of San Juan de Seoane) and to the fact that it is no longer mentioned in the 19th century. Wheat is assigned with 0.66 ha in 1752, it is still present in the *cartilla* from 1852 but without surface. Thus it will also be excluded from nutrient balances. For the same reason, in 1852 oats and maize rotations cannot be included in nutrient balances either.

By 1852 rotations have changed. New crops from America have been introduced in the agroecosystem: potatoes, corn and beens. Potatoes, turnip and rye are associated in a two year rotation. In 1887 rotations remain the same as in 1852. In 1752, in the case of two-year rotations which include fallow we have divided surface by two in order to estimate yearly productions and average land productivity. This is the case of the rye rotation in soils of second and third quality, as well as rye and rye-oats *estivadas*.

Ratios to calculate straw yields in all these rotations have been obtained by using yields for both straw and grain from Ministerio de Fomento, 1915. Husk and stubble productions are from Kernan et al., 1984.

Non-irrigated pastureland

In this case, yields have also been obtained from Ministerio de Agricultura, 1905, which specifies 3500 kg/ha of hay. For their proportionality in all quality soils (assuming these are the yields for first quality), we have applied the same relation as established in our sources with yields in carts. In order to obtain fresh matter yields we have applied the same criteria as in irrigated pastureland.

The difference in use between irrigated and non-irrigated pastures is that the first ones were meant both for pasture and harvesting whereas non-irrigated ones were only used for grazing.

Estivada

The main *estivada* rotation produces rye in the year in which land is broken and then rests for a certain number of years which varies along the study period and according to soil quality. There is a second type of *estivada* which is not very extended and produces two cereal crops, rye in the first one and oats in the second, but this is only mentioned in 1752.
In 1752, first quality soils rest an average of 29 years; second quality, 39; and third quality, 49. In 1852 and 1887 all three qualities rest for a period of twenty years[144]. During these years, several uses converge on this surface: pasture for livestock, extraction of firewood and *esquilmo*.

[144] Averages in 1752 have been calculated with the years that soils are left fallow in every parish as stated in Ensenada's Cadastre. For 1852 the datum is from the *cartilla,* and for the last year if proceeds from the surface report of 1887.

Vineyard

Grape production in kg/ha has been calculated according to data from Ministerio de Fomento (1915), where it is stated that 100 kg of grape result in 62.34 litres of juice. Litres are converted into kg/ha of wine by multiplying by 1.054 (FAO, 2012). We have used this ratio in order to obtain grape productivity in kg/ha according to wine yields as declared in the sources, which are those of Ensenada's Cadastre and the *cartilla* from 1852. For vine shoots and pomace estimations we have used the residue ratio in Guzmán et al. (2014).

Dry matter content for pomace is available in Guzmán et al. (2014), but for dry content of vineshoots and leaves we have used Phyllis biomass and waste database elaborated by the Energy research Centre of the Netherlands (ECN)[145]. Data regarding production in kg/ha for vine shoots and vineyard leaves come from Soroa (1953), who collected these data from a field study on a common variety of red grapevines in a farm in Castilla *la Nueva*. We know this is not the most appropriate option but it is the closest we can get.

Chestnut groves

In chestnut groves, the main yearly extraction detailed in the sources are chestnuts. Yields and surface are consigned in Ensenada's Cadastre as well as in the cartilla from 1852. However, the latter consigns very low yields for a region where chestnut was among the main foodstuff at the time, especially before the expansion of potatoes: 756, 504 and 126 kg/ha, according to soil quality. These yields are also abnormally low when taking into account those stated in 1752: 1,616; 1,321; and 817 kg/ha. Therefore we have used yields from the *cartilla* of 1852 from the municipality of Rendar, within 100 km from Fonsagrada, which are more coherent for the region and the period. 2,772, 1,848 and 924 kg/ha[146]. As mentioned before, in the absence of specific yields for the decade of 1880, we apply these same data to both years.

Other products extracted from chestnut groves are wood, firewood and leaves. The latter were used as animal bedding according to *cartillas* from the 19th century. The amount of extracted leaves is obviously not accounted for in our sources. Our production data come from Ford & Newbould (1970): 2,250 kg/ha. We have considered that only 25% of this production was extracted since not all leaves are available and it is also not convenient to do so (Pfeiffer, 2004). This same criteria has been applied to leaf extraction in oakwoods.

For chestnut leaves we have used dry content of oak leaf as well because we could not find a more specific datum (Gond et al., 1999). For *Castanea Sativa* nutrient content see Borges et al., 2008. NPK in chestnut fruit is from Soroa (1953). For wood and leaves nutrient content of

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145 https://www.ecn.nl/phyllis2/, consulted in October 2015.
146 All in fresh matter content.

Castanea Sativa see Santa Regina et al., 2001. For dry matter content we consulted University of Córdoba Food Data Base[147].

Our data of wood production in chestnut groves is from Cabrera and Ochoa (1997). We have taken the values of the lowest qualitites. Average value of chestnut wood production according to this reference is 446.09 m3. With a wood density of 500 kg/m3 (Vega et al., 2011) productions reach the following values:

- first quality soils: 9.519 m3/ha/year or 4,759.5 kg/ha/year
- second quality soils: 6.319 m3/ha/year or 3,159.5 kg/ha/year
- third quality soils: 3.866 m3/ha/year or 1,933 kg/ha/year

Humidity has been added to these values. In the case of wood, production data are used as extraction rates since it is very likely that all wood produced was used for building. Finally, firewood productions have been taken from the *cartilla* of the municipality of Cebreiro from the year 1888: 1,500; 1,000 and 800 kg/ha. However, for the balances we consider extraction equal to production for both wood and firewood.

Pasture in the province of Lugo comprised a wide variety of products, from grass to bushes such as gorse, heather or *ericacea* species, and was available in different rotations: *"dehesas de roble, tojales, monte bajo (matorral formado por brezo, carpazo, tojo, retama, jara, madroño y otras plantas forestales)"* (Ministerio de Fomento, 1915: 168). For the types of pasture which were not cropland, grass composition in our estimations comes from Reiné (2009, p. 60). Extractions by livestock grazing are also estimated according to this author, thus being 71% by harvest and 29% by grazing. Grazed extractions are calculated according to production data from Ministerio de Agricultura, 1905, as we already mentioned.

Woodland

The datum of firewood extraction in oakwoods comes from the neighbor municipality of Castroverde, (*cartilla* 1888). However, for the balances we consider that extraction equals production for both wood and firewood. Acorn production is from Kilchenmann (2004); wood production has been estimated in 2,078 kg/ha/año according to Diéguez-Aranda et al. (2009). Sources from Castroverde (*cartilla*, 1888) consign oak firewood (*leña*) extractions of 7,210; 5,948 and 4,600 kg/ha. Since these values would be too high for only firewood taking into account biomass expansion factors, we assume they include both wood and firewood. *Quercus Robur* leaf production has been estimated in 2,202-2,476 kg/ha/year in dry matter according to Carlisle et al., 1966. For wood nutrient content see Balboa-Murias et al. (2006),

[147] http://www.uco.es/sia/banco_de_datos/, consulted in October 2015.

and for dry matter content we consulted the University of Córdoba Food Data Base[148]. Oakwood density is 0.59 with a 12% of humid content according to Centre de la Propietat Forestal (2004). For nutrient content of acorns, we have used data from Rácik et al. (2004), and Lema and Mora (2013). Dry matter content is again from the University of Córdoba Food Data Base[149].

Regarding estimates on wood and firewood consumption, we have assumed that all produced wood was eventually used, therefore we take production rates as extraction values. For firewood, however, we take into account household and population numbers and contrast them with available productions from declared surfaces in order to evaluate the accuracy of our sources and estimate the most suitable value. We consider that consumption of firewood was of an average of 2kg/cap/day (Infante-Amate et al., 2014b).

Shrubland

When surface values are not disaggregated according to soil quality in the sources, we have assigned one third for each. The main extractions are pasture, firewood and *esquilmo*[150].

Shrubland provided livestock bedding which, once fermented with their excreta, formed a high quality manure. One of the most appreciated shrubs was a leguminous plant called *toxo,* gorse (*Ulex* species), the Net Primay Production of which has been estimated by Sineiro (1982) in 4,120 kg/ha (dry matter) for Galicia. The following data have served as contrast to confirm Sineiro's research:

- Egunjobi (1971, p. 35): 9,800 kg/ha (fresh matter) NPP
- Hernández Robredo (1936) adds some insight in extractions of shrub in *monte*, which can sum up to 10 carts/ha/year with woody and more spiky gorse, and 16 carts when used for livestock bedding. The same author mentions that tender gorse was used as livestock feedstuff as well, grinded when for bovines.
- Other sources offer similar data: *cartilla* from Cebreiro (1888).

However, there are higher values which we have not considered. According to research based on general statistics from the end of the 19th century, a hectare of *monte* produced up 15 tons of gorse a year (fresh matter). However, in private *monte,* production could reach up to 40 tons/year (Fernández Prieto and Balboa, 2000: 287). This second datum would certainly refer to the most intensive agricultures of the south-eastern coast of Galicia.

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[148] http://www.uco.es/sia/banco_de_datos/, consulted in October 2015.
[149] http://www.uco.es/sia/banco_de_datos/, consulted in October 2015.
[150] Non-woody parts of shrubs which served mainly as livestock bedding.

Dry matter content of *Ulex* has been determined by González González and Cosín Álvarez (1986). For nutrient content of *Ulex E.* see Iglesias Pérez (1985). Data for shrubland composition in terms of species are from Soto et al. (1997), who conducted a study on the Pedroso in Santiago de Compostela (A Coruña). Composition in this case resulted in 8% of E*ricaceae* varieties and 92% of *Ulex*. We aplied these percentages for our case studies as well as nutrient content of shrub ashes given by this authors, which are as follows:

- 1.19 % of N
- 0.60% of P
- 2.41% of K

These values match our type of soils, which are mostly acidic. Ash residue of *Ulex Europaeus* is 1.97% according to Iglesias Pérez (1985). González González and Cosín Álvarez (1985) confirm this percentage. Other phytomass data are from Soto et al. (1997) as well. As contrasting data for NPK content in shrub ashes we have also consulted Fernández Fernández et al., 2015.

Livestock and available foodstuff

Our sources are not very accurate regarding livestock data but in the absence of better information we have used what is available without further correction since it is not possible to know the exact percentage of concealed information at local scale. We assume that these are the most conservative data, which is also an interesting perspective for the study of the exhaustion of the intensification process.

For the year we study in the 18th century, the publication *Censo ganadero de la Corona de Castilla, año de 1752* (INE, 1996) offers all livestock data available in Ensenada's Cadastre for the whole of Castilla. We collected data of all the parishes that belonged to Fonsagrada at the time. For 1852 and 1887 we used data from two municipal livestock censuses (1855 and 1876, respectively).

Livestock numbers from the sources were converted into live weight and then Livestock Units of 500 kg each (LU-500 kg). Live weight data have been taken from *Avance de la ganadería* (Ministerio de Fomento, 1920). This document collects average weight for different types of animals. The average cow, horse and mule would weight 300 kg; donkeys, 150 kg; sheep, 25; goats; 30 kg; and pigs, 60 kg. These average weights are multiplied by the corresponding number of animals and results are then summed up and, eventually, divided by 500 in order to obtain uniform livestock units. By converting livestock head in LU our data become comparable with other case studies where these units are also used. In order to estimate available meat and milk for human consumption, we take have used average weight and applied different percentages and conversion factors from González de Molina et al., 2014b.

Available foodstuff for livestock changes in the different moments of the period we are studying. In 1752, with a huge amount of livestock which was not stabled, we assume that most of their foodstuff was provided by shrubland in *monte* areas, where animals spent most of their life. Besides, we have asigned all meadow productions for bovines and all domestic residues for swines.

In the 19th century there is a reduction in the size of livestock head and, at some point, bovines start to be stabled and better looked after. Pastureland surface has increased, and new crops such as fodder, corn, potatos, and turnips start to be cultivated. This foodstuff has been distributed between both bovines and pigs.

We have assigned different products for livestock according to the dietary needs that cannot be covered with the declared productions in our sources. Sheep and goats graze in shrubland. Bovine, equine and mule livestock graze in both irrigated and non-irrigated meadows. According to FEDNA (2010), swines can eat up to 1 kg of roots for each 10 kg of live weight. Home residues as well as pomace from grapes are given to swines. Home organic residues nutrient content (dry matter) comes from Espinosa Lloréns et al., 2007.

For metabolizable energy of ruminants, which we need in order to estimate livestock dietary needs, we have used data from Blair (2011): 13 MJ/kg, that is to say 3.11 Mcal/kg. Data regarding food comes from FEDNA tables (2010) and, because potatoes were not included we used data from sweet potatoes, which for swines is 15.15 MJ/kg or 3.66 Mcal/kg. Other data regarding estimates of dietary needs in kcal/day have been generously provided by members of the SFS project at the University of Barcelona[151].

Livestock: bedding and manure production

Precise manure and bedding data are not provided in sources for Fonsagrada. Livestock bedding is only mentioned once in the *cartilla* from 1852, where chestnut leaves and straw are said to be used for this purpose. Using the same criteria, we assume that leaves from oakwoods had the same end but we only computed them when bedding materials were scarce.

Fortunately, *cartillas* from neighbor municipalities provided contrast data on manure doses for the two main rotations that were fertilized according to our sources: vegetable gardens and potatoes-turnip-rye rotation. As mentioned before, for vegetable gardens in all three moments we have used data from the *cartilla* of Cebreiro (1888), and for the manure applied to the potatoes-turnip-rye rotation (documented both in 1852 and 1887) we have used the most

[151] Marco et al., forthcoming.

similar one in requirements, a barley-turnip rotation from the *cartilla* of Castroverde (1888). These data have been contrasted by taking into account soil requirements. In the following paragraphs we describe how we proceeded in order to obtain manure and bedding amounts.

For livestock bedding we have considered the following materials: shrub (*esquilmo*, mainly gorse), straw, and oak and chestnut leaves (only 25% of the total production of leaves). Average consumption of bedding (straw) in kg/day per head for all different types of livestock comes from Soroa (1953, p. 427):

- donkeys: 1 kg/day (365 kg/year)
- horses: 3 kg/day (1,095 kg/year)
- mules: 2 kg/day (730 kg/year)
- bovines (labor): 3.5 kg/day (1,277.5 kg/year)
- bovines (milk): 4.5 kg/day (1,642.5 kg/year)
- sheep: 0.2 kg/day (73 kg/year)
- pigs: 1-2 kg/day (547.5 kg/year)

As contrast information we have current bedding data from Urbano Terrón (1995, pp. 385-388), which are in the same order of magnitude as Soroa's numbers. From Urbano Terrón we have also taken manure and livestock excreta NPK content, as well as supporting evidence for weight live converters from Ministerio de Fomento, 1920. Robredo (1936, p. 297) estimates aggregated yearly consumption of gorse for both bovine bedding and firewood in Galicia at the beginning of the 20th century in 8,000,000 kg/day (fresh matter). With a bovine head of 2,113,583 individuals, as he consigns, an average of 3.7 kg/day of gorse would be consumed, which is equivalent to 1,381.5 kg/year per cow, including gorse for firewood. Cascón (1918) estimates bedding consumption in 1,213.8 kg/year. All data are in the same order of magnitude as Soroa's, which validates our decision. In this case we have not used the local data from Robredo because his values include firewood consumption as well but proportion is not specified, thus opting as well for the most conservative data.

According to the *cartilla* of Cebreiro (1888), anual extraction of shrub firewood (which includes other plants apart from gorse such as heather or broom) would reach up to 3,000, 2,500 and 2,000 kg/ha depending on soil quality. Therefore, 2,500 kg average in 1,914 ha of declared shrubland surface in Fonsagrada would result in 4,785,000 kg of shrub being extracted yearly. Besides, 6,000,000 kg of straw were available for bedding as well. Both amounts are summed and then divided by the number of bovines declared in 1752, which results in 570 kg/year. We assume that much more surface was used although not declared and, besides, livestock was not sheltered at that time which means that the needs for bedding materials was not relevant at the moment. For 1852 and 1887, straw availability is much higher, and livestock numbers much lower. Besides, in all cases, there is always a wide shrubland surface which provided most of the bedding.

Dry matter and nutrient composition of manure is from ASAE (2003). Data on daily livestock excreta are from the same source, although they have been adapted to livestock diet in Fonsagrada in every moment, therefore we have different values as shown in the following chart. Data are in similar magnitudes as those from Ministerio de Fomento (1920) for the province of Lugo although considerably higher in the case of horses and donkeys, which are however not numerous in Fonsagrada.

Chart 59. Data on livestock excreta (kg/year, fresh matter)

	M. Fomento, 1918	ASAE, 2003 (1752)	ASAE, 2003 (1852)	ASAE, 2003 (1887)
Cow	6,000	6,145	6,594	6,524
Horse	2,500	4,760	5,508	5,146
Mule	2,500	3,107	3,545	3,471
Donkey	1,250	0	0	3,738
Goat	483	455	455	460
Sheep	483	492	492	492
Pig	2,000	2,189	2,245	2,290

For estimations related with manure availability in the 19th century we have assumed that the whole bovine head is held in stables. This was necessary in order to satisfy manure demand towards 1852.

Human nutrition and wood consumption

Population data for estimations have been obtained from local sources. In 1752, according to Ensenada's Cadastre, 1,816 "neighbors" (*vecinos*) lived in Fonsagrada, being "neighbors" an equivalent to homestead in that period in most of the cases. For this region, an average of 5.01 people lived in every house, which means 9,099 inhabitants (Saavedra, 1979). For the 19th century, we have used the statistical records of the Instituto Nacional de Estadística (INE). From these censuses, we have used the datum of population who were present at the time of the headcount by subtracting passers-by ("*transeúntes*"), who had also been accounted for. In the census of 1857, the first available one, passers-by in Fonsagrada were a total of 33 people, whom we have excluded from our study thus having a population of 17,368. In 1887 more people were registered in Fonsagrada as *de jure* inhabitants (16,919) than the actual population present, which is our final datum: 16,419 inhabitants. This means that about 500 people were absent at the moment in which the census was elaborated, athough most of them were not passers-by they have been excluded too. These inhabitants had the right to live in Fonsagrada and their absence is related with migration.

For estimations on food availability per capita we have used the minimum nutritional requirements estimated by Cussó for 1860: 2,270 kcal/cap/day (Cussó, 2005). This type of estimations also serve as a way to evaluate the degree of accuracy of the sources and to determine whether cropland surface or had been concealed in land registries and cadastres.

Human diets have been estimated according to the declared surfaces and rotations in our sources. Only a datum from the beginning of the 20th century regarding hunt and pouldry consumption has been added: 4.4 kg/cap/year, as recorded by the *Asociación General de Ganaderos* in *Estadística del consumo de carnes en España*. *Año 1925* and compiled by the GEHR (GEHR, 1991: 91). Therefore, eggs have also been included assuming consumption estimates by Marco et al. for Sentmenat (forthcoming). Even though this datum is from a Catalonian agroecosystem, it seems conservative enough as to export it to our cases: 2.14 kg/cap/year, assuming every household had at least 2 hens. This issue is not essential in our estimations but allows to check if the scarcity of kcal could be filled with other productions and extractions which we cannot account for such as fish, or wild harvesting. Imports and exports should also be taken into account but sources do not provide any data at this respect.

Coefficients for meat and milk availability estimations have been kindly provided by David Soto, co-author of "Crecimiento agrario en España y cambios en la oferta alimentaria: 1900-1933" (González de Molina et al., 2014b). These average coefficients have been obtained from livestock reports by the Ministerio de Agricultura (1892) and Ministerio de Fomento (1920).

For nutrient content of meat, milk and eggs we have used data from the Farran et al. (2004). Meat content in this compilation is classified according to the type of animal and the part of its body, as well as raw and processed forms. For all of them we have used raw values and the medium nutrient content from the different parts, excluding the most extreme ones, as shown in the following chart.

Chart 60. Nutrient content in meat, milk and eggs

	N (gr)	K (gr)	P (gr)
Beef meat (brisket, 100 gr)	3.13	0.32	0.2
Lamb meat (shoulder blade, 100 gr)	2.64	0.27	0.16
Pork (rib, 100 gr)	2.74	0.26	0.24
Chicken (whole without skin, 100 gr)	3.552	0.30	0.19
Eggs (100 gr)	2.032	0.125	0.188
Milk (all types, 100 gr)	0.512	0.148	0.086

Source: own elaboration with data from Farran et al. (2004) and FAO (2012).

Milk density (1.03) is the same for all types of milk and has been taken from FAO INFOODS Density Database (FAO, 2012). In the case of game, since it is impossible to know which types were hunted, we have used porc values assuming wild boars were common at the time. However, this flow is not relevant and this datum will not have an impact on material flows. Its main relevance is regarding human dietary needs.

Other products such as lard or butter have not been accounted for since they are contained in the final product, which is the maximun nutrient availability. Transformation processes imply a loss of nutrients which we have not accounted for.

Funds and material flows

We have considered six main funds, two of which are represented together but also have some independent accountancy as we will explain. The established funds are:

- shrubland + *estivada*
- cropland
- livestock
- pastureland
- woodland

Estivada is a form of shifting agriculture which is done on shrubland surface with an increased periodicity along the studied period. Therefore is part of the shrubland, on which it relies, but it is a rotation by itself as well. We have considered that ashes are a contribution from shrubland to *estivadas*. However, seeds from both cereal and gorse come from the *estivada* itself and are considered as reused biomass.

Appendix 2. Methodology of nutrient balances

Once we have determined the biomass flows of each crop and livestock average nutrition, we can estimate nutrient balances. We have proceeded as detailed in the following sections, which are illustrated with data for the year 1752. The spreadsheets with the calculation of nutrient balances for all three years can be found in the attached CD.

Nutrient extractions with harvest in 1752

The first step is to estimate harvest extractions for each type of soil quality. Surface and most production data are from Ensenada's Cadastre. By-products such as straw, husk or stubble must have been included. The following charts collect the N, P and K content of the main products, by-products and total extraction values for each nutrient according to land use.

Mineral composition of pasture is from Muslera and Ratera (1991), and *Quercus robur* wood nutrient content from Balboa-Murias et al. (2006). Average extractions in shrubland surface in *monte* are estimated over the total of the surface and not just the declared one in the sources. Leave extraction for livestock bedding in *soutos* and oakwood has been estimated in a 25%.

Chart 61. Fonsagrada. Nutrient extractions in main products according to land use in 1752

		N	P	K	N	P	K
		---------- % fresh matter --------			----------------- kg/ha ------------		
Vegetable gardens	Collards	2.40	3.23	5.23	11.19	15.06	24.38
	Lettuce	2.20	0.44	3.24	1.36	0.27	2.00
	Cabbage	2.40	3.23	5.23	1.36	1.83	2.97
	Onions	2.70	0.57	2.08	1.50	0.32	1.16
Irrigated cropland	Meadows	3.25	0.40	3.64	109.70	13.50	122.87
Non-irrigated cropland	Rye	17.60	3.71	4.81	17.13	3.61	4.68
	Fallow				0.00	0.00	0.00
	Meadow	3.25	0.40	3.64	46.88	5.77	52.50
Estivada	Wheat	20.80	3.45	4.32	26.52	4.40	5.51
	Rye	17.60	3.71	4.81	15.77	3.32	4.31
	Associated rye	17.60	3.71	4.81	16.79	3.54	4.59
	Associated oats	17.60	2.97	3.98	6.13	1.04	1.39
Woody crops	Vineyard	0.20	0.13	0.83	0.10	0.07	0.42
	Souto	6.90	1.18	5.89	8.23	1.41	7.02
Oakwoods	Wood	1.93	0.16	1.18	11.39	0.93	6.96
Monte	*Esquilmo*	5.79	0.52	1.78	51.93	4.66	15.96

Chart 62. Fonsagrada. Nutrient extractions in by-products according to land use in 1752

		N	P	K	N	P	K
		--------- % (fresh matter) ---------			-------------- kg/ha ----------------		
Collards	Residues	2.40	3.23	5.23	2.80	3.76	6.10
Lettuce	Residues	2.20	0.44	3.24	0.38	0.08	0.56
Cabbage	Residues	2.40	3.23	5.23	1.68	2.26	3.65
Onion	Residues	2.70	0.57	2.08	0.92	0.19	0.71
Non-irrigated cereal	Straw	5.60	1.22	9.71	10.90	2.37	18.90
	Husk	5.80	2.44	4.32	2.48	1.04	1.85
	Stubble	5.30	1.05	5.23	0.37	0.07	0.37
Wheat *estivada*	Straw	4.80	0.96	5.23	14.26	2.85	15.54
	Husk	7.20	1.75	6.97	4.04	0.98	3.91
	Stubble	3.70	0.57	4.65	0.34	0.05	0.43
Rye *estivada*	Straw	5.60	1.22	9.71	10.03	2.19	17.40
	Husk	5.80	2.44	4.32	2.29	0.96	1.70
	Stubble	5.30	1.05	5.23	0.34	0.07	0.34
Associated rye *estivada*	Straw	5.60	1.22	9.71	10.69	2.33	18.53
	Husk	5.80	2.44	4.32	2.43	1.02	1.81
	Stubble	5.30	1.05	5.23	0.36	0.07	0.36
Associated oats *estivada*	Straw	5.60	1.22	13.53	3.51	0.77	8.49
	Husk	6.40	0.57	3.74	0.98	0.09	0.57
	Stubble	3.70	0.57	4.65	0.09	0.01	0.12
Vineyard	Shoots	2.00	0.17	2.49	1.92	0.16	2.39
	Leaves	8.00	0.70	2.32	11.66	1.02	3.38
	Pomace	10.00	1.31	4.15	3.08	0.40	1.28
Souto	Firewood	3.68	0.46	1.88	3.87	0.48	1.97
	Wood	0.45	0.11	0.20	3.04	0.76	1.37
	Leaves	6.21	1.00	3.16	13.98	2.26	7.11
Oakwood	Leaves	10.53	0.55	2.49	54.76	2.88	12.96
	Acorns	4.03	0.55	4.57	0.97	0.13	1.10
Monte	Firewood	5.79	0.52	1.78	17.99	1.62	5.53

Chart 63. Fonsagrada. Total nutrient extractions according to land use in 1752

		Surface	Nitrogen	Phosphorus	Potassium
		ha	---------------------	kg/ha	--------------------
Irrigated cropland	Collards	13.73	13.99	18.82	30.48
	Lettuce	2.29	1.74	0.35	2.56
	Cabbage	2.29	3.04	4.09	6.62
	Onions	4.58	2.42	0.51	1.86
	Meadow	114.65	109.70	13.50	122.87
Non-irrigated cropland	Rye	968.12	30.88	7.10	25.79
	Fallow	635.36	0	0	0
	Meadow	122.91	46.88	5.77	52.50
Estivada	Wheat	0.70	45.17	8.29	25.39
	Rye	94.81	28.43	6.54	23.75
	Rye associated	2.95	30.28	6.96	25.29
	Oats associated	2.95	10.72	1.90	10.56
Woody crops	Vineyard	5.34	16.76	1.65	7.47
	Souto	123.80	29.11	4.91	17.48
Oakwood		104.50	67.11	3.94	21.01
Monte		1,914.24	69.92	6.28	21.49

2. Soil characteristics in Fonsagrada

For some estimates on nutrient flows it is necessary to determine the soil typology where land uses were. We have sorted this out with the use of a study on soils in Galicia by Guitián Ojea (1974). Our decisions are presented in the following chart. We have established the distribution of slate and granite soils through the territory in a 60% and 40%, aproximately, according to the geological map of the region[152].

[152] Instituto Geológico y Minero de España, 1976, "Mapa geológico de España: Fonsagrada", Madrid.

Chart 64. Fonsagrada. Soil composition according to land use

Land use	Soil type	Proportion	Clay	pH	N	Co	C/N	P_2O_5	K_2O	Al
		%	%		%	%		mg/100 g		%
Vegetable garden	Alluvial soil	100	23.55	5.4	0.625	5.69	9.10	0.6	10	0.6
Meadows	Slate soils with gentle slope	100	16.50	5.3	0.43	5.5	13	0.4	7.5	0.36
Non-irrigated cereal	Slate soils, low descent	100	9.67	4.95	0.597	7.83	13.11	0.4	5	0.7
Other	Clay soil	60	19.42	5.38	0.503	7.15	14.21	0.8	7.5	1.6
	Granite soil	40	12.32	4.30	0.740	7.80	10.54	1.6	15	0.6

Both irrigated and non-irrigated meadows. Data from Paz-Ferreiro et al. (2010) except for P_2O_5 y de K_2O, which are from Guitián (1974).

Data of phosphorus and potassium do not refer to total content but to availability and serve to determine the level of soil fertility. On the contrary, nitrogen datum has been obtained with Kjeldahl methodology, which means that it is total content in the soil.

Erosion

Erosion affects all elements in the soil and is a relevant issue at constructing nutrient balances. Since historical data are not available, we have calculated laminar erosion by using references in literature and perceptive estimations.

Slopes have been estimated according to the geotechnical characteristics of Fonsagrada as especified in the Precedo Ledo and Figueroa (1997). This study distinguishes three main groups of soils according to slope but data are presented in percentages but without surface information.

- group 1: flat areas with slope under the 7%
- group 2: undulating terrain with slopes between the 7% and 15%
- group 3: abrupt and mountainious areas with slopes over the 15%

Vegetable gardens

According to García-Ruiz (2010) gardens are usually in alluvial areas, where both sedimentation and erosion occur. Therefore, a net balance of 0 t/ha of erosion is considered.

Monte **(shrubland)**

According to Soto et al. (1997), control areas in their research have losses of 1.4 t/ha/year. Vega et al. (2011) conclude that erosion losses in shrubland areas are only of 0.096 t/ha/year. We have used an average datum of 0.75 t/ha/year.

Estivada

Soto et al. (1997) indicate losses of 57.8 and 46.2 t/ha/year with practices such as slash and burn in areas with gorse. The average is of 52 t/ha/year.

Vineyard

We have used data from from González-Prieto et al. (1996) for unprotected soils with a slope of about the 30%. We have used an average datum of 11.55 t/ha/year according to data in this study, which are 9.69 and 13.42 t/ha/year.

Other crop rotations

For the rest of rotations we have estimated erosion values according to the map of potential laminar erosion of the province of Lugo for the year 2002[153], and also considering the usual or logic location of such crops as well as common practices to avoid soil losses through erosion (vegetation cover, shrubland or bare and plowed soils). Therefore, we have estimated an erosion of 2.5 t/ha/year in meadows, of 5 t/ha·year in *soutos* and oakwoods, and 35 t/ha/year in vineyard, since we have assumed that soils were uncovered.

3. Manure doses

Nutrient content of manure and animal excreta have been estimated according to livestock intake. For this purpose, we have reviewed especialized literature and extracted average values for each type of animal according to diet. This information is collected in the following chart.

[153] Ministerio de Medio Ambiente, 2003, *Inventario Nacional de Erosión de Suelos 2002-2012. Galicia. Lugo 2002*, Madrid, Dirección General de Conservación de la Naturaleza.

Chart 65. Review of animal excreta in % of N, P and K

	Percentage of excretion (% excreted g/intaken g)			
	N	**P**	**K**[154]	
Hutton et al., 1961	71	66	91	Dairy cattle, pasture
Brito, 2006	65.6			Dairy cattle, stabled
Jorgensen et al., 2013	59.3	60.3		Stabled pigs
Wu et al., 2003		66.6		Dairy cows, stabled
Kebreab et al., 2008		62		Dairy cows, stabled
Shalit et al., 1991			80.3	Dairy cows, stabled
Joyce et al., 1970			91.6	Stabled lamb
Reffet et al., 1985			89.4	Stabled lamb
Average	65.3	63.7	88.0	

These conversion factors have been applied to the intake in order to estimate the content in N, P and K of fresh excreta deposited on the fields, when animals are not in the stable. Besides, it is necessary to consider that in the case of nitrogen there are also associated losses through ammonia volatilization, thus resulting that the final contribution of nitrogen to the soil in this case is only about the 80% of the excreted. On the other hand, of all consumption on meadows and pasture in oakwoods and *monte* we assume that a 45% of the nutrients are recovered during the night in the stable, either at the village or in stables in *monte*.

For instance, in the case of cows, about 594,698 kg of pasture are intaken (dry matter), which is about 2,973,490 kg (fresh matter) at an 80% of humid content. Assuming a nitrogen composition of 3.25 g/kg, about 9,663.8 kg of nitrogen are ingested, which at an excretion rate of the 28.67% of the total consumed, means that direct excreta on the field will achieve only about 1,809.1 kg of this nutrient. Besides, the weight of meadow in the total of a cow intake is about the 2.48%, thus the 28.67% of the excretion takes place on meadows. With 9,308 cows, which excrete an average of 6,000 kg/year, this means a total o 397,088 kg of fresh excreta. Therefore, the content of nitrogen in the excreta on meadows will have a 0.45% of nitrogen, which is slightly lower than the 0.52% of the average manure. The application of the 1,809.1 kg of nitrogen in the 114.65 ha of meadow translate into 15.77 kg N/ha. But assuming that ammonia volatilization losses reach the 20%, this value is reduced to 12.62 kg N/ha. If we add horse excreta on meadow, this rate increases to the 13.10 kg N/ha indicated in the balance.

On the other hand, and in order to simplify the construction of the balance, in the case of manure we keep the proposal of the previous chart for content in N, P and K. Manure available in stables includes all excreta that is not deposited on meadows (either irrigated or

[154] We have not used the same procedure with potassium in order to avoid too high values. The percentage of its excretion has been estimated in order not to exceed the 0.6% of content of this nutrient, which implies an excretion of the 35.9%. This is coherent since potassium is mostly concentrated in urine, which is not easily retained even with bedding.

not), *monte* and oakwoods. According to animal, type, the following chart shows manure availability in stables and excreta according to land use.

Chart 66. Fonsagrada. Excreta distribution according to land use and livestock type in 1752 (kg)

	Meadow	Non-irrig. Meadow	Oakwood	*Monte*	Stables
Cows	223,279	367,938	0	52,383,473	4,218,751
Horses	9,937	0	0	2,930,760	210,658
Mules	0	0	0	9,320	0
Donkeys	0	0	0	0	0
Sheep	0	0	0	9,356,767	0
Goats	0	0	0	4,610,934	0
Pigs	0	0	35,475	18,125,812	402,634
Total	**233,216**	**367,938**	**35,475**	**87,417,067**	**4,832,043**

4. Nitrogen balance

4.1 Natural inputs

Once the extractions according to land uses have been estimated, we can proceeded to calculate the natural inputs of nitrogen in the soil. There are three main natural inputs: atmospheric deposition, non-symbiotic fixation, which depends also on the type of soil management, and symbiotic fixation, which depends mostly on the type of crop and adventitius plants.

4.1.1 Atmospheric deposition

Atmospheric deposition depends, firstly, on the composition of rainfall water. At this respect, we have used the datum from Macías Vázquez and Calvo de Anta (2003) for regions with low atmospheric pollution in Galicia, which is 0.57 g N-(NO_3^-+NH_4^+) for each m^3 of water. Average rainfall is from the municipality of Pedrafita, where it achieves 1,900 mm per year, as indicated in Díaz-Fierros (1971). This means that for each hectare, there is a nitrogen input of 10.83 kg/year. Most of data regarding nutrient flows refer to real hectares. Therefore, for rotations that include more than one harvest a year such as vegetable gardens, these values should only be applied to one of the crops. In this case, for instance, we have applied all detailed values to collards, which is a winter crop.

4.1.2 Non-symbiotic fixation

Non-symbiotic fixation proceeds from autotrophic and heterotrophic organisms in the soil. We have used the datum from Boring et al. (1988), who offer an average value of 4 kg N/ha but with variations depending on the soil management. Thus, following the remarks by García-Ruiz et al. (2012), we have estimated the following average values: 1.5 kg N/ha in vegetable gardens, potatoes and turnips; 3 kg N/ha in cereal crops (non-irrigated and *estivadas*), and 4 kg N/ha for vineyards, *soutos*, fallow, meadows, shrubland and woodland.

4.1.3 Symbiotic fixation

For symbiotic fixation we have used the factor $1.14*N_{ext}$, which results from the application of the factors proposed by García-Ruiz et al. (2012) in leguminous crops. In shrubland areas, where gorse is abundant, we have applied a factor of 1.16 over the total of extracted nitrogen, as indicated by Reid (1973) for acidic soils in the United Kingdom. According to his research, fixed nitrogen represents the 71.9% of total nitrogen which, considering that total nitrogen is $1.61N_{ext}$, results in 1.16 times the extracted nitrogen. For shrubland we have also applied a factor of 0.92 that represents gorse biomass regarding other type of plants (such as *Ericaceae*) as indicated by Soto et al. (1997). We need to consider that this is not properly a crop and therefore the value of symbiotic fixation will depend on production, but not on extraction. Thus the estimation is applied to the production of aerial biomass, and not only to the extracted one. Our resulting value is coherent with estimates for New Zealand, where symbiotic fixation is over 100 kg N/ha/year (Magesan et al., 2012), and with data from de Augusto et al. (2005), who indicate that fixed N varies between 60 and 100%. Regarding meadows, we have assumed there is a 19.4% of leguminous plants (Oliveira-Prendes et al., 2013), and we have applied a factor of 0.20 in order to estimate extracted nitrogen in these surfaces.

For crops with adventitious plants, we have applied values from García-Ruiz et al. (2012), which are 5.4 kg N/ha in vegetable gardens (plus the corresponding in the case of beans), potatoes and turnips; 8.33 kg N/ha in cereal crops, and 20 kg N/ha in fallow and vineyards.

In *soutos* and oakwoods we have considered a pasture production of 8,000 kg/ha and 9,000 kg/ha (dry matter), respectively, according to González-Hernández et al. (2008). Assuming leguminous plants are present up to an 8% in this pasture (Olea et al., 1990)[155], this allows to estimate symbiotic fixation by applying the factor $1.14N_{ext}$.

4.2 Anthropogenic inputs

4.2.1 Irrigation

Irrigation data are as indicated by Ministerio de Fomento (1918) for the province of Lugo, assuming that irrigation requirements remained more or less the same between 1752 and 1918, and that the technique did also not change much, which was mostly surface or flood

[155] We have not found a local datum, but this could be improved since this study refers to Extremadura (Spain).

irrigation[156]. Data are as follows: 688 m^3/ha for summer garden crops, and 20.760 m^3/ha in irrigated meadows. Finally, we applied the nitrogen factor of 2 mg/L from García-Ruiz et al. (2012), which results in an input of 1.38 Kg N/ha in gardens and 41.52 kg N/ha in meadows.

4.2.2 Seeds

Seed requirements are from Soroa (1953), and indicate that 160 kg/ha are needed in vegetable gardens and 150 kg/ha in cereal crops. We applied the nitrogen content of each type of crop and obtained values between 0.38 and 0.47 kg N/ha in gardens; 2.64 kg N/ha in oats and barley, and 3.12 kg N/ha in wheat.

4.2.3 Ashes

This refers to the case of *estivadas*, which means that land is broken, burned, and then sowed. Therefore, ashes are incorporated to the soil as the first organic matter contribution after the impact of erosion in the initial phases of the *estivada*. Estimates according to Soto et al. (1998) indicate that about 53,537 kg of biomass are burned. Ashes are the 1.97% over fresh biomass according to Iglesias Pérez (1985) and contain a 1.16% of nitrogen, which results in an input of 12.23 kg N/ha.

4.2.4 Reused biomass

In some crop rotations biomass reuses are common, as it is the case in *estivadas*[157], where two processes take place in the same period. Firstly, ashes are incorporated to the soil and nitrogen inputs are as indicated in the previous paragraph. Secondly, after the harvest of the main product (cereal grain), by-products such as straw were returned to the soil. This represents an input of 18.64 kg N/ha in the case of wheat; 12.66 kg N/ha in the case of rye; and 13.48 and 4.59 kg N/ha in the rye/oats biannual rotation, respectively.

4.3 Nutrient outputs

4.3.1 Denitrification

Denitrification refers to the change of nitrate into gaseous state that are into the atmosphere. It can occur in two different ways: basal denitrification in the soil and denitrification associated to fertilization. We have used the model by Vinther (2005) for both processes. This author estimates basal emision values of N_2/N_2O according to clay content in the soil. Thus total

[156] *Riego a manta*.

[157] This is indicated in Ensenada's Cadastre, at least in the case of Padrón. We assume this must have been the norm since it seems coherent with the management of *estivadas*. See http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0, sheet 11,274 (verso).

emision is estimated with the following equation, where N_{Ef} is 2.5% as recommended by Kasimir-Klemedtsson and Klemedtsson (2002):

$$N_{DE} = (N_{BD} + N_F \cdot N_{EF}) \cdot N_{RATIO} \quad \text{(Eq. 1)}$$[158]

Equations 2 and 3 show how we have estimated basal losses and the factor N_2/N_2O.

$$N_{DB} = \frac{-0.256+0.259 \cdot \%}{1+0.074\%} \qquad \text{(Eq. 2)}$$

$$N_{Ratio} = \frac{0.189+1.171 \cdot \%}{1+0.136\%} \qquad \text{(Eq. 3)}$$[159]

With these equations, we obtained the values collected in the following chart.

Chart 67. Fonsagrada. N_{DB}, N_{RATIO}, basal emissions and percentage of losses in fertilizer through denitrification

Land use	Proportion	Clay	N_{BD}	N_{RATIO}	N_{BD}	$\%_D$
	%	%	Kg N_2O/ha		Kg N/ha	%
Vegetable garden	-	23.55	2.13	6.60	14.07	16.50
Irrigated meadows	-	16.50	1.80	6.01	10.80	15.03
Non-irrigated rotations	-	9.67	1.31	4.97	6.51	12.43
	60	19.42	1.96	6.30	12.35	15.75
Other	40	12.32	1.54	5.46	8.41	13.65
	100				10.77	14.91

4.3.2 Volatilization

This process refers to nitrogen losses as a result of the transformation of ammonium into ammonia. As in denitrification, there are two types of losses: the basal one and the related to fertilization. The second has been considered in the process of manure compost, therefore we will now estimate the basal loss.

Considering the criteria in García-Ruiz et al. (2012), we have used data from Holtan-Hartwig and Bockman (1994), who indicate basal losses between 1 and 2 kg N/ha. Since this is a low value, we decided to apply the average to all land uses, that is to say 1.5 kg N/ha.

[158] Where N_{DE} refers to total denitrification in kg N/ha; N_{BD} is basal denitrification in kg N_2O/ha; N_F is the nitrogen input in fertilization in kg N/ha; N_{EF} is the emision factor of N_2O in fertilizer, and N_{RATIO} is the ratio between kg N_2 / kg N_2O.

[159] N_{BD} refers to losses of nitrogen through basal denitrification in kg N_2O/ha, "%" refers to the percentage of clay in soil, and N_{RATIO} to the ratio between kg N_2 / kg N_2O.

4.3.3 Erosion

Erosion data have already been specified in section 2.1. of this appendix. Chart 68 collects the nitrogen content in the soil according to land use. Losses of this nutrient through erosion can be estimated with this information.

4.4 Nitrogen balance

Once we have defined all nitrogen flows, we can present the resulting values of the balance. The following data show the nitrogen balance before fertilization with manure.

Chart 68. Fonsagrada. Nitrogen balance before fertilization and according to land use in 1752 (kg/ha)

											Denitrification		Volatilization		
		N_{EXT}	Rainfall	Non-Symbiotic Fixation	Symbiotic Fixation	Irrigation	Seeds	Ash	Buried biomass	Animal excreta	Basal	Fertilized (%)	Basal	Erosion	Balance
Irrigated	Veg. Garden	21.18	10.83	1.5	5.4	4.1	1.69				14.07	16.5	1.5	0	14.89
	Meadow	109.70	10.83	4	24.26	41.5				7.20	10.8	15.03	1.5	3.2	38.49
Non-irrigated	Rye	30.88	10.83	3	8.33		2.64				6.57	12.43	1.5	14.9	29.08
	Fallow	0.00	10.83	4	20						6.57	12.43	1.5	4.5	-22.28
	Meadow	46.88	10.83	4	10.37					10.67	6.57	12.43	1.5	3.2	23.63
Estivada	Wheat	45.17	10.83	3	8.33		3.12	12.23	14.60		10.77	14.91	1.5	307.6	316.89
	Rye	28.43	10.83	3	8.33		2.64	12.23	10.38		10.77	14.91	1.5	307.6	304.23
	Associated rye	30.28	10.83	3	8.33		2.64	12.23	11.05		10.77	14.91	1.5	307.6	305.51
	Associated oats	10.72	10.83	3	8.33		2.64	12.23	3.61		10.77	14.91	1.5	307.6	292.28
Woody crops	Vineyard	4.74	10.83	3	20						10.77	14.91	1.5	8.4	-8.44
	Souto	17.44	10.83	4	2.37						10.77	14.91	1.5	4.5	17.00
Oakwoods		25.93	10.83	4	2.67					0.51	10.77	14.91	1.5	4.5	24.76
Monte		13.16	10.83	4	74.62					5.90	10.77	14.91	1.5	4.5	-64.55

5. Phosphorus balance

Processes related to phosphorus flows are less numerous than in the case of nitrogen due to its higher insolubility and its more stable ways of retention. In the following sections we present our flow estimation according to the proposal by García-Ruiz et al. (2012).

5.1 Natural inputs

5.1.1 Rainfall

Rainfall water has phosphorus content, which is deposited in the soil through atmospheric deposition. Rainfall datum is as indicated in the case of nitrogen, and phosphorus content in rainfall water is 0.1 g P/m^3 according to Macías Vázquez and Calvo de Anta (2003). This corresponds to an input flow of 1.9 Kg P/ha.

5.1.2 Soil formation

Contrary to what happens with nitrogen, both phosphorus and potassium are highly present in geological materials. Firstly, we need to estimate the formation rate of new soil. García-Ruiz et al. (2012) propose values between 0.5 to 1 t/ha/year for places with low-medium to medium-high ratio of soil weathering. Since average rainfall reaches the 1,900 mm yearly in the case of Fonsagrada and there is an oceanic climate, we take the higher value (1 t/ha/year), which is coherent with values observed by Alexander (1988). Then, we estimate the amount of phosphorus in original materials. We assume that most of the soil in the region, as indicated by the geological map[160], are mostly composed of slate and granite. According to Cárdenes et al. (2012), the composition of slates in Fonsagrada is of 0.21% of P_2O_5, which corresponds to a final content of 0.092% of phosphorus. On the other hand, Taboada Rodríguez and García Paz (1997) offer granite composition data for different places in Galicia and obtain an average content of 0.18% of P_2O_5 in the original soil materials, which corresponds to a 0.079% of total phosphorus. This results in contributions of phosphorus of 0.92 kg P/ha in slate soils, and 0.87 kg P/ha in mixed soils of slate and granite.

5.2 Anthropogenic inputs

5.2.1 Irrigation

We use the same irrigation data as specified for nitrogen (Ministerio de Fomento, 1918) and criteria as proposed by García-Ruiz et al. (2012). This results in a phosphorus concentration in

[160] Instituto Geológico y Minero de España, 1976, “Mapa geológico de España: Fonsagrada”, Madrid.

irrigation water of about 0.5 mg/L. Phosphorus inputs in irrigation reach 0.34 kg P/ha in vegetable gardens with lettuce, cabbage and onions, and 10.38 kg P/ha in irrigated meadows.

5.2.2 Seeds

Phosphorus inputs in seeds are also estimated according to Soroa (1953), which vary between 0.08 and 0.56 kg P/ha in vegetable gardens; 0.56 kg P/ha in non-irrigated rye; 0.45 kg P/ha in associated rye and oats, and 0.52 kg P/ha in wheat.

5.2.3 Ashes

We keep the same criteria as with nitrogen regarding the amount of ash resulting from burning biomass. Content in phosphorus in this case is 0.54 % according to Soto et al. (1997), which corresponds an input of 5.70 kg P/ha.

5.2.4 Reused biomass

Again, we consider that there are biomass reuses in the case of *estivada*, since only grain is harvested and by-products are left in the soil. Besides, in this case, we need to account for phosphorus in the ashes as well, which have a composition of 0.6% of this nutrient. This results in a mobilization of 6.33 kg P/ha. On the other hand, the return of phosphorus in biomass represents 3.89 kg P/ha in the case of wheat, and 3.22; 3.42; and 0.87 kg P/ha for rye, associated rye, and associated oats, respectively.

5.3 Outputs

5.3.1 Erosion

For nitrogen we used data from Guitián Ojea (1974) but this is not possible with phosphorus nor potassium since bioavailability of these nutrients cannot be extrapolated to total content. Therefore, our erosion data for phosphorus and potassium are from Soto et al. (1997). The value for phosphorus is 0.0496% of its total.

5.4 Balance

The following chart presents estimated flows prior to the calculation of manure requirements.

Chart 69. Fonsagrada. Phosphorus balance before fertilization and according to land use in 1752 (kg/ha)

		P_{EXT}	Rainfall	New soil	Irrigation	Seeds	Ash	Buried biomass	Animal excreta	Erosion	Balance
Irrigated	Vegetable garden	23.77	1.9	0.92	1.032	1.30				0	19.92
	Meadow	13.50	1.9	0.92	10.38				1.08	0.37	-0.41
Non-irrigated	Rye	7.10	1.9	0.92		0.56				1.24	4.97
	Fallow	0.00	1.9	0.92						0.37	-2.45
	Meadow	5.77	1.9	0.92					1.60	0.37	1.72
Estivada	Wheat	8.29	1.9	0.87		0.52	5.70	2.90		25.52	21.92
	Rye	6.54	1.9	0.87		0.56	5.70	2.25		25.52	20.79
	Associated rye	6.96	1.9	0.87		0.56	5.70	2.40		25.52	21.06
	Associated oats	1.90	1.9	0.87		0.45	5.70	0.78		25.52	17.73
Woody crops	Vineyard	0.59	1.9	0.87						0.69	-1.49
	Souto	4.61	1.9	0.87						0.37	2.21
Oakwoods		3.93	1.9	0.87					0.08	0.37	1.45
Monte		1.17	1.9	0.87					0.64	0.37	-1.87

6. Potassium balance

Potassium flows within an agroecosystem are very similar to those of phosphorus. In the following sections we present our estimations according to García-Ruiz et al. (2012).

6.1 Natural inputs

6.1.1 Rainfall

Considering an annual average precipitation of 1,900 mm of and a potassium concentration in rainfall water of 0.5 g K/m^3 (Bellot and Escarré, 1988), atmospheric deposition reaches 9.5 kg K/ha.

6.1.2 Soil formation

Cárdenes et al. (2012) indicate a potassium content in slate soils in Fonsagrada of 4.84% in K_2O, whereas granite is of 4.71% according to Taboada Rodríguez and García Paz (1997), also in K_2O. For these estimations we follow the criteria specified in section 4.1.2. of this appendix. Therefore, total potassium reaches 40.2% kg/ha in slate soils and 39.8% in mixed soils.

6.2 Anthropogenic inputs

6.2.1 Irrigation

Potassium content in water is 2 mg/L (García-Ruiz et al., 2012), this results in a total potassium supply of 4.13 kg K/ha/year in vegetable gardens and 41.5 kg K/ha/year in irrigated meadows.

6.2.2 Seeds

Potassium supply in seeds is from Soroa (1953), which varies between 0.36 and 0.91 kg/ha in vegetable gardens; 0.72 kg/ha in rye; 0.60 kg/ha in oats, and 0.65 kg/ha in wheat.

6.2.3 Ashes

Criteria regarding total burned biomass and the corresponding amount of ash is the same in all three balances, as it is logic. Potassium content in ashes is 2.47% according to Soto et al. (1997), which means an input of 26.05 kg K/ha.

6.2.4 Reused biomass

We follow the same criteria indicated in section 4.2.3. Potassium supply in ashes is as specified in the previous section, and the return of by-products to the soil after the *estivada* contributes with 19.88 kg K/ha in the case of wheat; 19.44 kg/ha rye; 20.70 kg/ha with associated rye, and 9.18 kg/ha with associated oats.

6.3 Output

6.3.1 Erosion

We applied the same criteria as with phosphorus but considering that, in this case, total potassium content in the soil has been estimated in a 3%.

6.4 Balance

Once we have estimated all inputs and outputs, except for manure because requirements have not been estimated yet, we obtain a preliminar balance which is presented in the following chart.

Chart 70. Fonsagrada. Potassium balance before fertilization and according to land use in 1752 (kg/ha)

		K_{ext}	Rainfall	New soil	Irrigation	Seeds	Ash	Buried biomass	Animal excreta	Erosion	Balance
Irrigated	Vegetable garden	41.52	14.82	40.2	4.12	2.75				0	-17.63
	Meadow	122.87	14.82	40.2	41.52				13.59	22.05	35.24
Non-irrigated	Rye	25.79	14.82	40.2		0.72				75.00	45.05
	Fallow	0.00	14.82	40.2						22.50	-32.52
	Meadow	52.50	14.82	40.2					20.13	22.50	-0.15
Estivada	Wheat	25.39	14.82	39.8		0.65	26.05	15.97		1,543.50	1,471.64
	Rye	23.75	14.82	39.8		0.72	26.05	17.74		1,543.50	1,468.16
	Associated rye	25.29	14.82	39.8		0.72	26.05	18.89		1,543.50	1,468.55
	Associated oats	10.56	14.82	39.8		0.60	26.05	8.60		1,543.50	1,464.23
Woody crops	Vineyard	3.95	14.82	39.8						42.00	-8.63
	Souto	16.94	14.82	39.8						22.50	-15.14
Oakwood		20.94	14.82	39.8					0.96	22.50	-12.10
Monte		4.76	14.82	39.8					3.60	22.50	-30.92

7. Fertilization requirements

Once we have defined the nutrient requirements prior to the application of manure, we proceed to analyze the rotations that were fertilized with manure.

7.1 Available manure and nutrient balances

According to our sources, the only fertilized rotations were vegetable gardens and the non-irrigated rotation. Unfortunately, there is no information on manure doses in the sources for 1750s. Therefore we test whether nutrient requirements can be satisfied with estimated manure availability. For this purpose, we firstly compared all the previous balances in order to determine the most limiting nutrient in each rotation.

The nutrient composition of manure has been estimated by following these steps:

1. Firstly, we estimated available excreta in stables, which amounts to 2,332,857 kg. This is the 5.2% of the total excreta since it was mostly deposited on *monte* and meadows due to an extensive management. Nutrient composition of excreta is as explained in section 3.

2. Secondly, we estimated the nutrient composition of livestock bedding, which was contained different shrubs, especially gorse, and both chestnut and oak leaves. We have accounted for standard nutrient losses through the process of compost according to IPCC (2006). Thus the final content in manure is 0.47% of nitrogen; 0.16% of phosphorus, and 1.57% of potassium. Results are collected in the following chart.

Chart 71. Fonsagrada. Composition of livestock bedding in stables

		Composition (g/kg fresh matter)		
	%	N	P	K
Gorse	82.29	6.30	0.56	2.28
Oak leaves	11.71	10.53	0.55	2.49
Chestnut leaves	6.00	6.21	1.00	3.16
Total (losses deducted)	100.00	3.40	0.59	2.36

7.2 Manure distribution

Once we had the preliminar balances and nutrient composition of manure in nitrogen, phosphorus and potassium, we identified the most limiting nutrient according to the fertilizing potential of manure. This means that we accounted for fresh kg of required manure instead of kg of required nutrients. Results for the two fertilized rotations are collected in the following chart.

Chart 72. Fonsagrada. Manure requirements in order to achieve balanced nutrients

	Manure (kg/ha)			
	N	P	K	Limiting nutrient
Vegetable garden	3,960.31	13,011.57	-2,938.59	P
Non-irrigated cereal	7,372.90	3,244.24	7,510.32	K

The final distribution of available manure between these two rotations has been done according to the most limiting nutrient in each one.

7.3 Nitrogen lixiviation

For the estimation of nitrogen lixiviation we have used Di and Cameron's (2000) formula because it does not considere losses through volatilization and denitrification, which had already been estimated.

$$N_L = 0.000082 \cdot (N_{PL})^2 - 0.0104 \cdot N_{PL} \quad \text{(Eq. 4)}$$

N_L refers to lixiviated nitrogen in kg N/ha·100mm and N_{PL} to potentially lixiviated nitrogen, which results from the previous balance, the supply of nitrogen in manure, and mineralization.

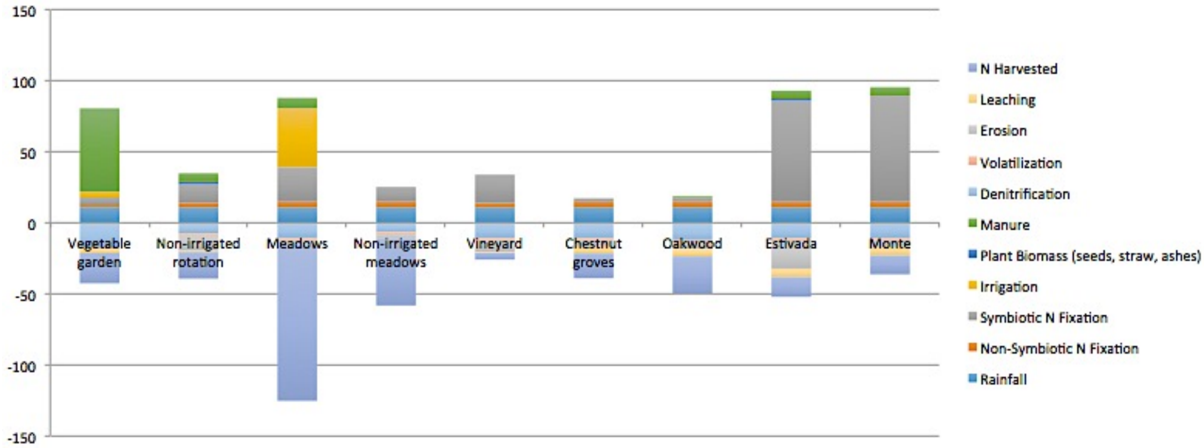
Mineralization has been estimated according data in section 2 and to González-Prieto et al. (1996), who determine the percentage of mineralized nitrogen for different soils and land uses in Galicia. Results for N_{PL} and N_L are collected in the following chart.

Chart 73. Fonsagrada. Estimation of nitrogen lixiviation in 1752 (kg/ha)

		Balance	Manure	Mineralization	N_{PL}	N_L
Irrigated	Vegetable garden	14.89	58.59	139.39	183.09	13.27
	Meadow	38.49	0.00	68.27	29.77	0.00
Non-irrigated	Rye	29.08	10.00	117.35	98.29	0.00
	Fallow	-22.28	0.00	117.35	139.63	2.00
	Meadow	23.63	0.00	68.27	44.64	0.00
Estivada	Wheat	316.89	0.00	122.02	-194.87	0.00
	Rye	304.23	0.00	122.02	-182.21	0.00
	Associated rye	305.51	0.00	122.02	-183.48	0.00
	Associated oats	292.28	0.00	122.02	-170.26	0.00
Woody crops	Vineyard	-8.44	0.00	122.02	130.47	0.53
	Souto	17.00	0.00	171.74	154.74	4.83
Oakwoods		24.76	0.00	171.74	146.97	3.31
Monte		-64.55	0.00	97.17	161.72	6.31

Levels over 120 kg N/ha of potentially leached nitrogen impact on nitrogen loss through lixiviation. The most remarkable value is found in vegetable gardens, with nitrogen losses that reach 13 kg/ha. The following graph represents the final balance with all inputs and outputs.

Graph 19. Fonsagrada. Nitrogen balance in 1752 (kg/ha)



Appendix 3. Nutrient flows within the agroecosystem of Fonsagrada

Nutrient flows for the years 1752, 1852 and 1887 have been represented with diagrams in order to analyze the functioning of the agroecosystem in terms of nutrient flows in the different moments of the period. This serves to illustrate the structure of the agroecosystem and how it changed through time according to adaptations in the management of soil fertility. The concepts of funds and flows as initially proposed by Georgescu-Roegen (1971) have been integrated in the theoretical framework of social metabolism in order to describe and analyze the functioning of an agroecosystem in metabolic terms. González de Molina and Toledo (2014) have used Giampietro's definition of both concepts, according to whom "funds" refer to

> *"elements whose identity remains "the same" during the analytical representation (they reflect the choice made by the analyst when deciding "what the system is" and "what the system is made of")".*

Flows can refer to energy, information or any kind of material such as nutrients or water and can be described as

> *"elements which are either produced or consumed during the analytical representation (they reflect the choice made by the analyst when deciding "what the system does" and "how it interacts with its context")"*, (Giampietro, 2012: 384).

In this case, we deal with nutrient flows, which are measured in total tons and represented at scale, attending to their proportional volume within the agroecosystem. Funds supply or receive nutrients, and in our case we have identified the following elements: society, livestock, cropland, *monte*, *estivadas,* meadows, and woodland (including *soutos*). Flows are represented by lines, and funds by squares. When lines are located at the bottom of a square, they represent an output flow, whereas input flows are located either on top of the square or on its sides. Society has been represented according to population size, and livestock according to LU-500 kg. Yearly cropped *estivada*, woodland, meadows and cropland have been represented according to surface data from our sources. In the case of *monte* we have used our own estimations according to current extension of the municipality and considering all other declared surfaces in each moment. Since it occupies a huge part of the territory, we have represented its actual size with a shadowed square underneath. This is only for visual purposes, otherwise the rest of the funds and flows would be difficult to represent.

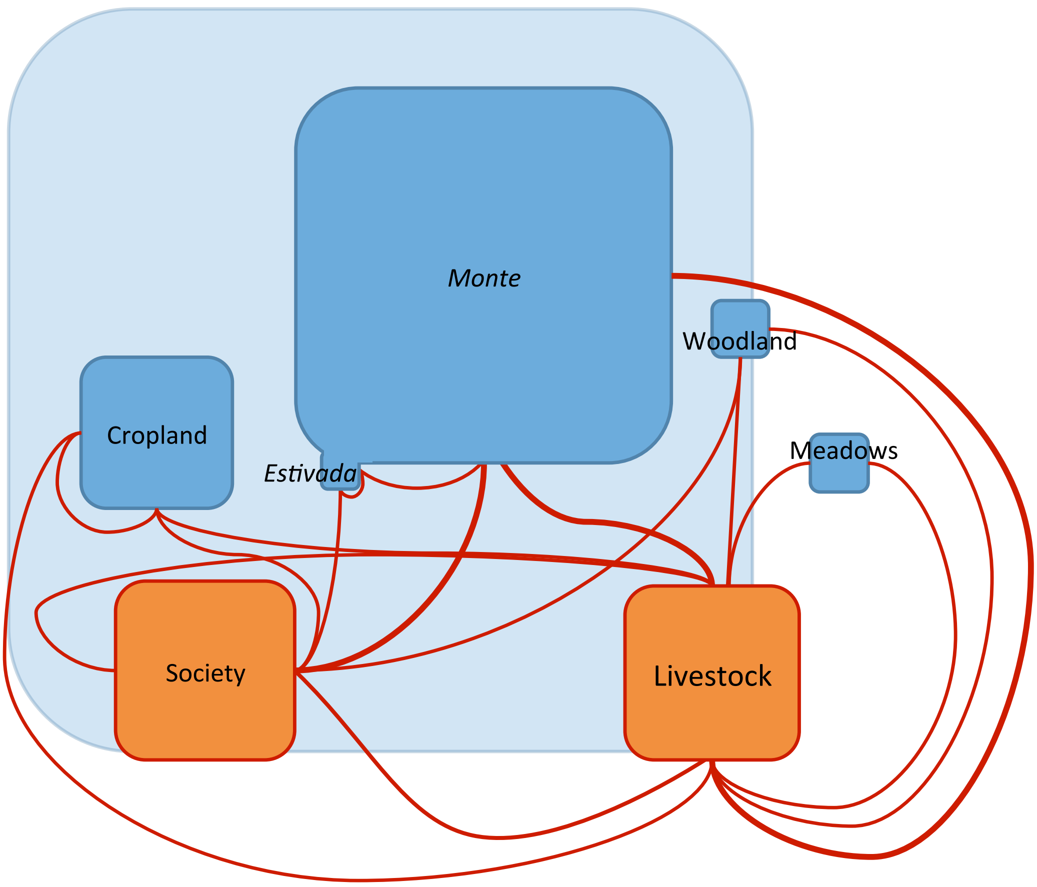
Finally, flows have been distributed according to the main needs within the agrarian system: food for society and livestock, manure for vegetable gardens and cereal crops, etc. This has been done according to our sources and, when required, to previous research on Galician agrarian history. After each diagram we include a chart with the amounts of the corresponding nutrient assigned to each flow. The funds in the left column of the chart receive flows from the funds listed on the upper row.

Nutrient flows in 1752

In this moment, diagrams reflect the extensive character of the agricultural practices. Most of nitrogen, phosphorus and potassium circulate between *monte* and livestock. This reflects the fact that a numerous livestock head is kept on this surface, where it returns the greatest part of the nutrients consumed. This ensures nutrient replenishment in *monte* surface and guarantees enough manure for cropland, which occupies now a relatively small surface and incorporates fallow as a replenishment technique too. Since extractions in *monte* surface are higher than returns by livestock, natural fixation processes are also very relevant for nutrient replenishment. Meadows are appropriated with a similar logic. Other extractions of nutrients from *monte* go directly to society in the form of firewood and cereal from *estivada*[161]. Woodland provides society with wood, and livestock with pasture, thus receiving part of the nutrients back when animals are grazing. Some leaves are also removed from under the trees to be used as livestock bedding. Cropland feeds both humans and livestock. There are no output flows from society because we have not accounted for human excreta, but this could be done in the future in order to obtain more accurate balances.

[161] Wild harvesting and fishing have not been accounted for.

Diagram 1. Nitrogen flows in Fonsagrada in 1752



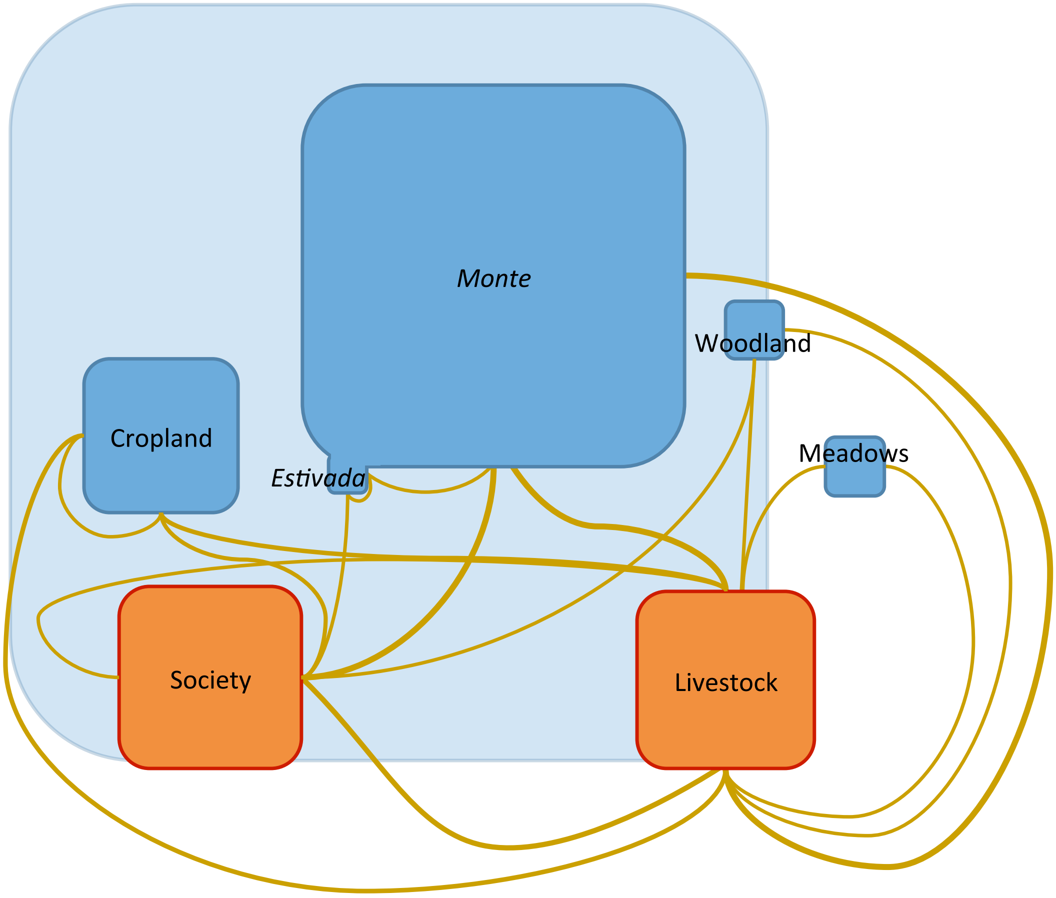
Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Chart 74. Nitrogen flows in Fonsagrada in 1752 (total kg)

	Monte	***Estivada***	**Woodland**	**Meadows**	**Cropland**	**Livestock**	**Society**
Monte						245,400	
Estivada	1,241	1,305					
Woodland						53	
Meadows						2,138	
Cropland					2,556	10,323	
Livestock	475,770		1,964	18,339	13,408		2,848
Society	73,865	1,313	3,182		14,247	35,000	

Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Diagram 2. Phosphorus flows in Fonsagrada in 1752



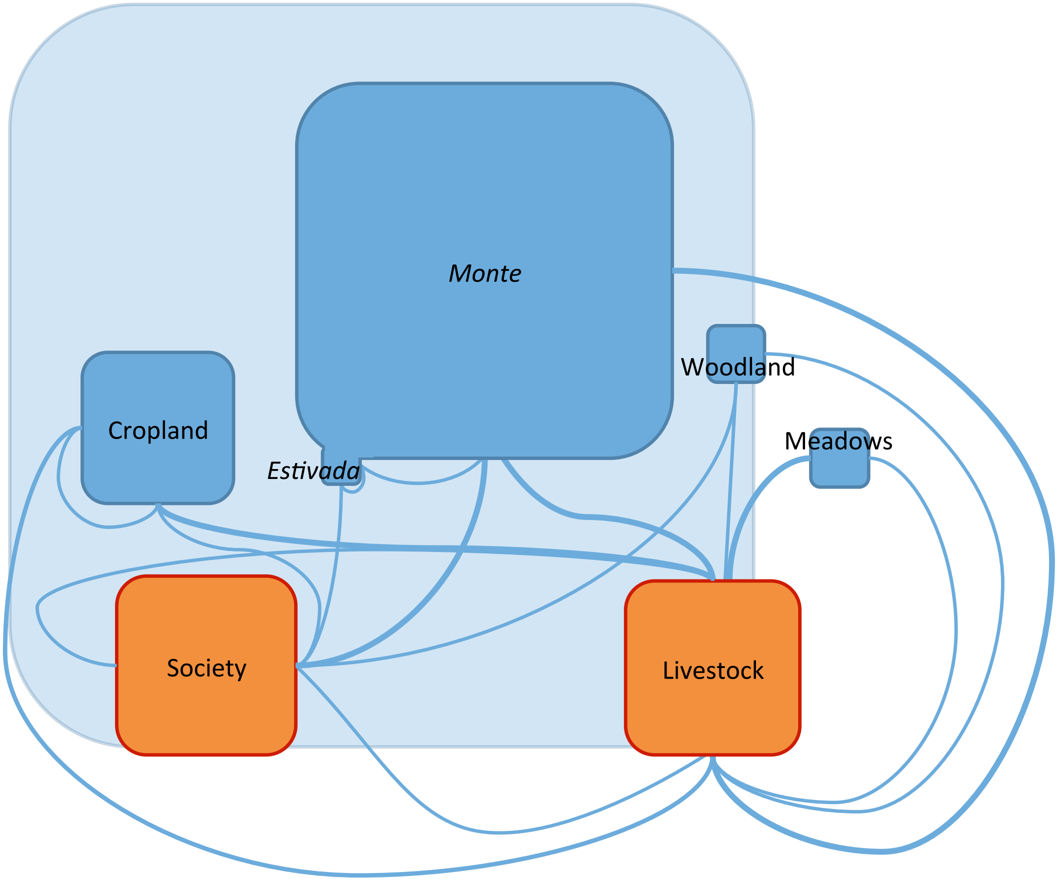
Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Chart 75. Phosphorus flows in Fonsagrada in 1752 (total kg)

	Monte	***Estivada***	**Woodland**	**Meadows**	**Cropland**	**Livestock**	**Society**
Monte						26,599	
Estivada	578	281					
Woodland						9	
Meadows						321	
Cropland					539	3,571	
Livestock	42,291		159	2,257	3,469		487
Society	6,566	276	412		3,198	4,053	

Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Diagram 3. Potassium flows in Fonsagrada in 1752



Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Chart 76. Potassium flows in Fonsagrada in 1752 (total kg)

	Monte	*Estivada*	Woodland	Meadows	Cropland	Livestock	Society
Monte						149,605	
Estivada	2,642	1,847					
Woodland						101	
Meadows						4,033	
Cropland					698	13,994	
Livestock	172,183		673	20,540	20,598		4,413
Society	26,732	357	1,963		4,267	6,483	

Source: *Respuestas Generales* of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); *Censo ganadero de la Corona de Castilla* (INE, 1996); Saavedra (1979) for population datum of 1752; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

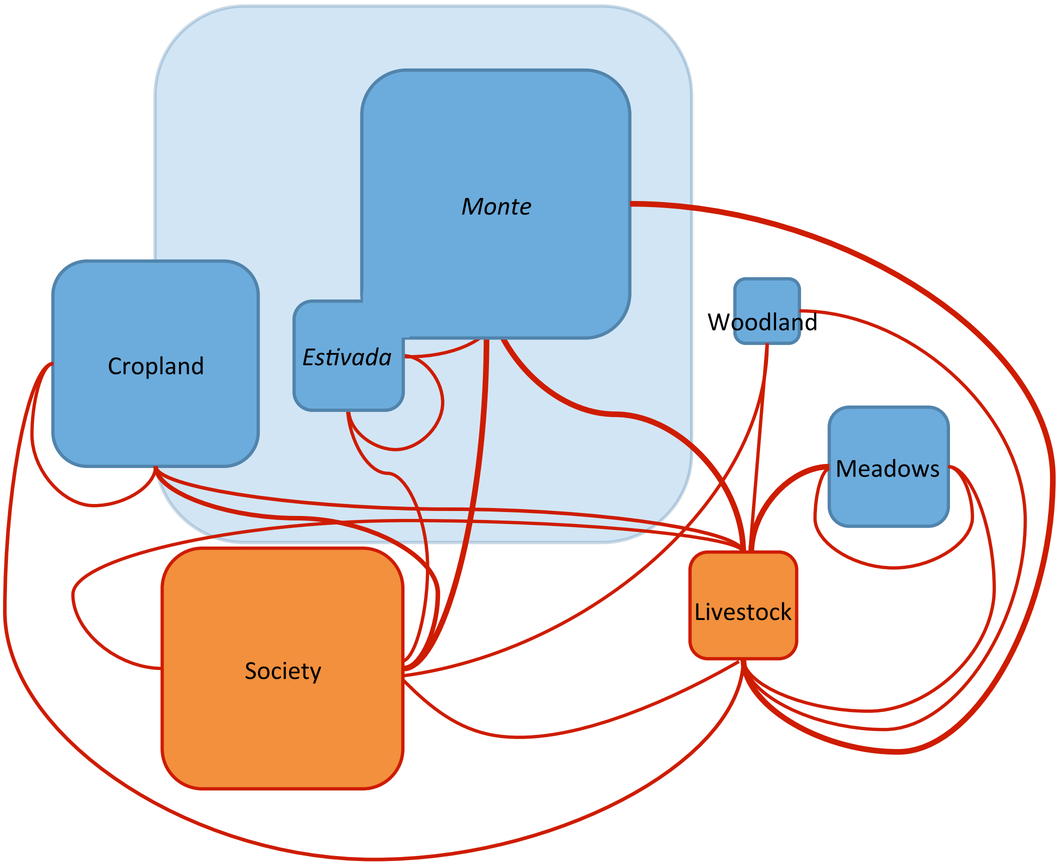
Nutrient flows in 1852

In this moment, in order to obtain the maximum manure possible, we have considered that livestock was kept permanently in the stables. We are aware that both goats and sheep were still being kept in *monte* surface. But this assumption allows to obtain the best possible results regarding soil fertility in cropland with the existing resources in the agroeosystem. An actual and accurate flow distribution is impossible to determine with the available sources. Therefore, the situation we describe is the best possible scenario of agricultural optimization within an organic metabolism in Fonsagrada. This means that, from this moment on, we have not accounted for any nutrient contribution from livestock to *monte*. We assigned part of the cattle's excreta to meadows (both irrigated and non) according to their more unsustainable situation. This means that cows still spent some time grazing. Distribution of excreta according to land use is collected in Chart 38.

Either way, our aim with this virtual model is to remark that the distribution of nutrients among the different funds could be changed but this would not affect their total availability. Nutrients are circulating within the agroecosystem boundaries and there are no external inputs of fertilizers at this moment. Therefore, nutrient imbalances can be seen in our data and already in 1852, which is related with the process of keeping livestock in stables in order to increase manure availability. We cannot know which of the two funds was more affected by nutrient mining, whether *monte* or meadows, but it is clear that agricultural intensification and livestock specialization in order to sustain cropland fertility were very costly in terms of nutrients for both surfaces.

Therefore, the following diagrams and charts show the new structure of the agroecosystem, where the protagonism of *monte* as nutrient provider for cropland diminishes and starts to be shared with meadows. Finally, the flow of nutrients from livestock to cropland has also increased when compared with the previous moment. Population growth is evident, as the paralel increase in cropland surface. Potassium mining is now evident, especially in meadows.

Diagram 4. Nitrogen flows in Fonsagrada in 1852



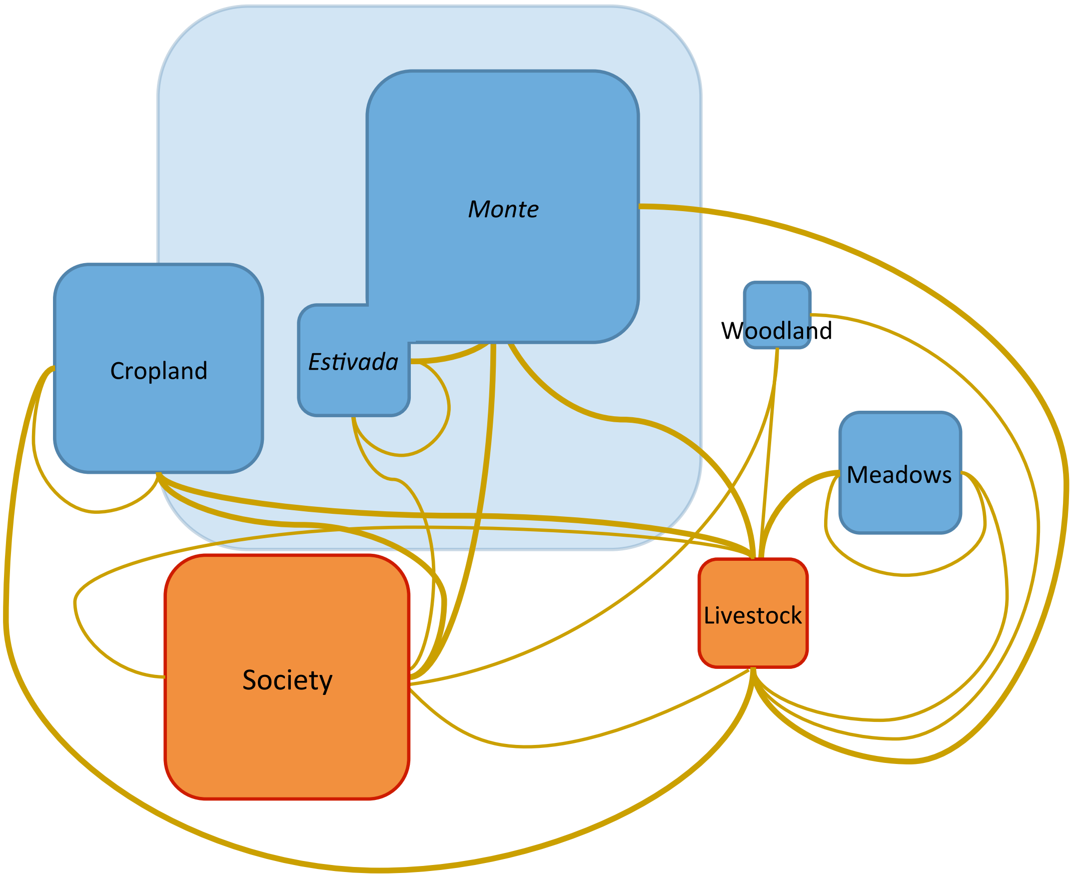
Source: INEbase population census from 1857 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartilla* from 1852, Fonsagrada, APHL, Facenda, C14491; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Chart 77. Nitrogen flows in Fonsagrada in 1852 (total kg)

	Monte	***Estivada***	**Woodland**	**Meadows**	**Cropland**	**Livestock**	**Society**
Monte						0	
Estivada	11,137	9,765					
Woodland						53	
Meadows						9,618	
Cropland					6,287	65,912	
Livestock	132,519		2,276	73,525	32,752		5,437
Society	149,779	8,784	5,534		40,973	17,037	

Source: INEbase population census from 1857 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartilla* from 1852, Fonsagrada, APHL, Facenda, C14491; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Diagram 5. Phosphorus flows in Fonsagrada in 1852



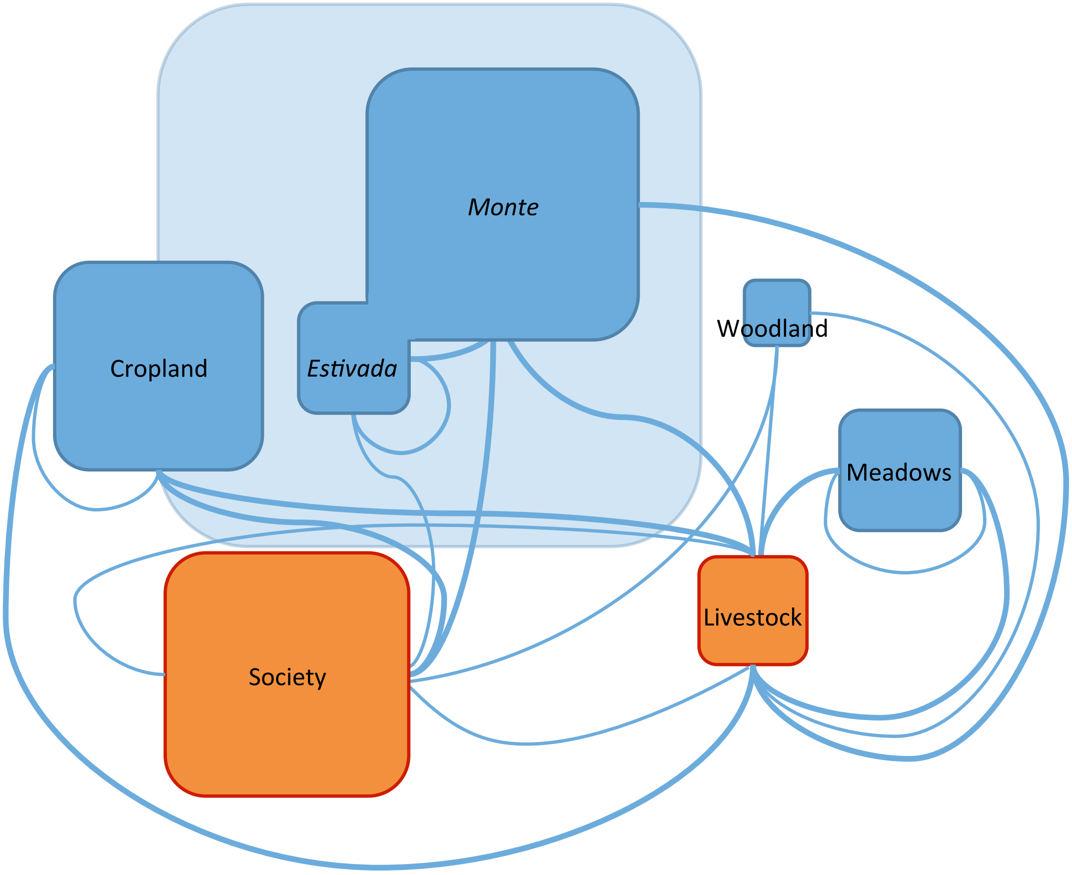
Source: INEbase population census from 1857 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartilla* from 1852, Fonsagrada, APHL, Facenda, C14491; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Chart 78. Phosphorus flows in Fonsagrada in 1852 (total kg)

	Monte	*Estivada*	Woodland	Meadows	Cropland	Livestock	Society
Monte						0	
Estivada	5,184	2,106					
Woodland						9	
Meadows						1,443	
Cropland					1,242	16,717	
Livestock	11,779		209	9,049	7,280		931
Society	13,314	1,852	790		8,087	1,907	

Source: INEbase population census from 1857 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartilla* from 1852, Fonsagrada, APHL, Facenda, C14491; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Diagram 6. Potassium flows in Fonsagrada in 1852



Source: INEbase population census from 1857 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartilla* from 1852, Fonsagrada, APHL, Facenda, C14491; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Chart 79. Potassium flows in Fonsagrada in 1852 (total kg)

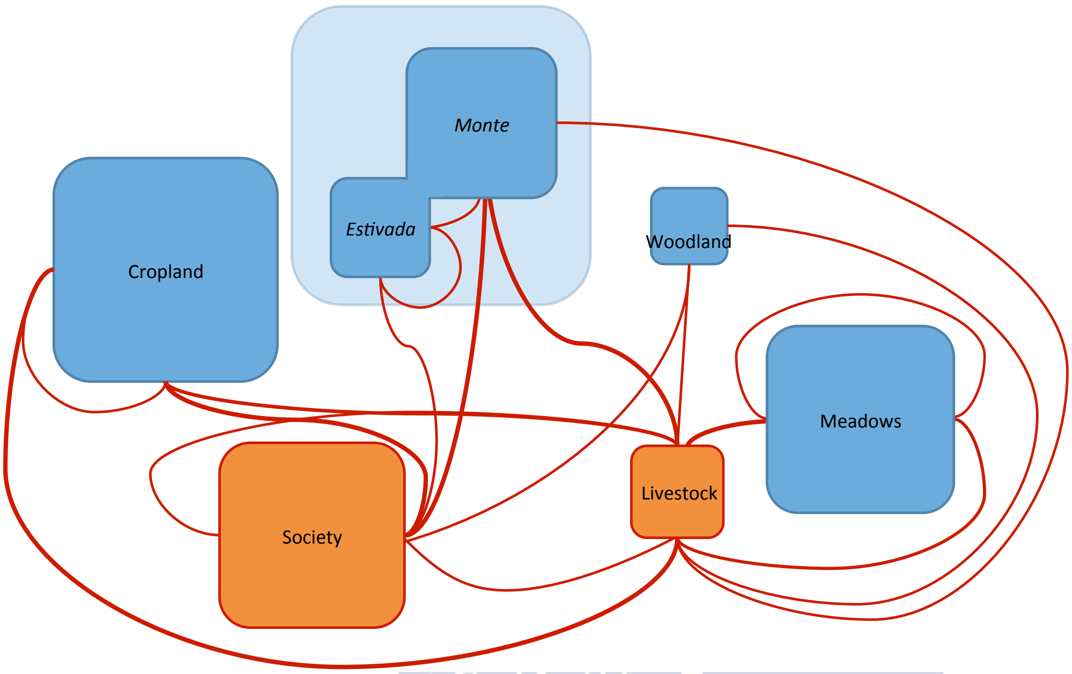
	Monte	***Estivada***	**Woodland**	**Meadows**	**Cropland**	**Livestock**	**Society**
Monte						0	
Estivada	23,714	13,240					
Woodland						101	
Meadows						18,146	
Cropland					3,549	86,146	
Livestock	47,959		832	82,348	43,670		8,424
Society	54,206	2,401	3,586		25,349	3,006	

Source: INEbase population census from 1857 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartilla* from 1852, Fonsagrada, APHL, Facenda, C14491; livestock *cartilla,* Fonsagrada, 1855, AHPL, Facenda, C14205; *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Nutrient flows in 1887

These last diagrams show the structure of the agroecosystem in a moment of definitive livestock specialization, where meadows are clearly under a process of nutrient mining and the role of *monte* as nutrient supplier is less relevant. Its surface has also decreased considerably due to the expansion of cropland and *estivadas*.

Diagram 7. Nitrogen flows in Fonsagrada in 1887



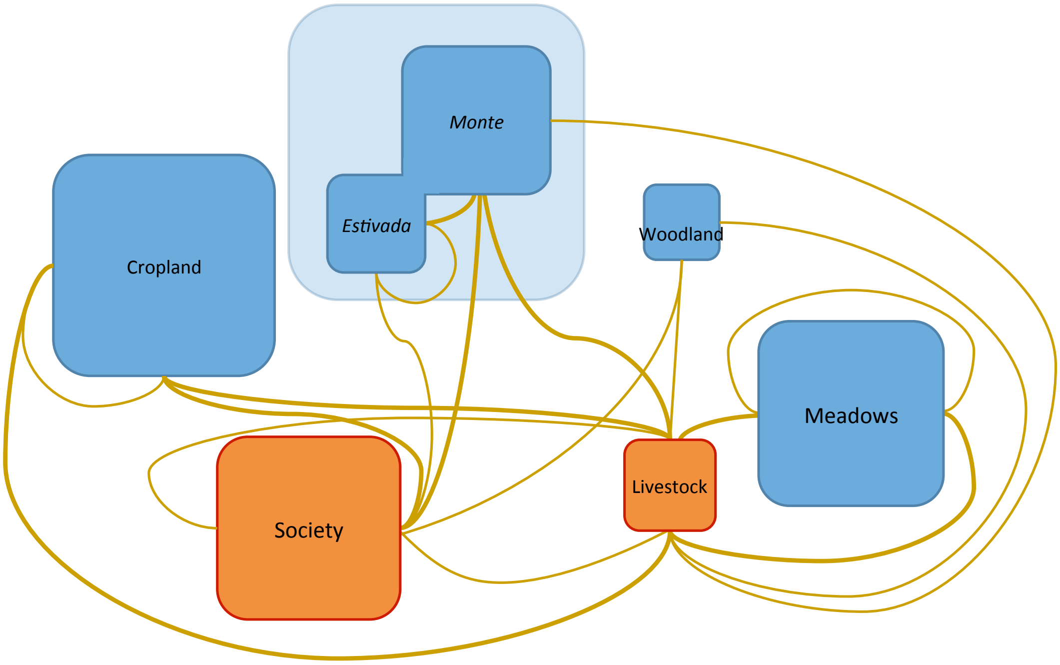
Source: INEbase population censuses from 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartilla* 1886, Fonsagrada, APHL, Facenda, C14992; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Chart 80. Nitrogen flows in Fonsagrada in 1887 (total kg)

	Monte	*Estivada*	Woodland	Meadows	Cropland	Livestock	Society
Monte						0	
Estivada	14,608	12,635					
Woodland						53	
Meadows						41,077	
Cropland					8,401	88,522	
Livestock	79,721		3,656	241,228	49,268		5,139
Society	115,726	11,258	9,722		78,796	18,600	

Source: INEbase population censuses from 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartilla* 1886, Fonsagrada, APHL, Facenda, C14992; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Diagram 8. Phosphorus flows in Fonsagrada in 1887 (total kg)



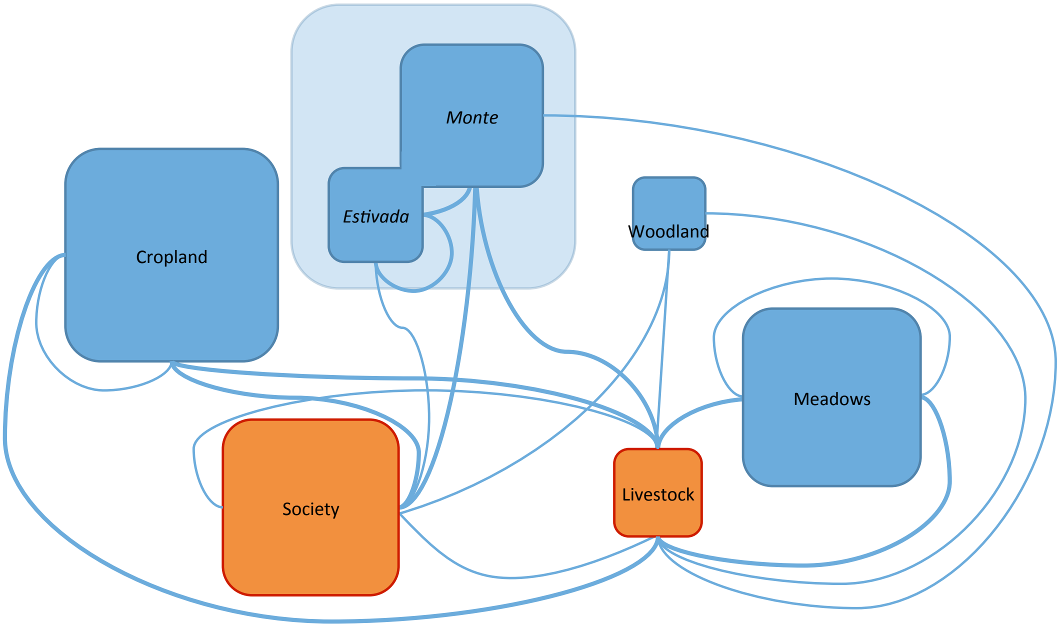
Source: INEbase population censuses from 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartilla* of Fonsagrada, 1886, APHL, Facenda, C14992; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Chart 81. Phosphorus flows in Fonsagrada in 1887 (total kg)

	Monte	*Estivada*	Woodland	Meadows	Cropland	Livestock	Society
Monte						0	
Estivada	6,800	2,724					
Woodland						9	
Meadows						6,165	
Cropland					1,700	23,824	
Livestock	7,086		432	29,690	10,104		880
Society	10,287	2,373	1,492		12,642	2,029	

Source: INEbase population censuses from 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartilla* of Fonsagrada, 1886, APHL, Facenda, C14992; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Diagram 9. Potassium flows in Fonsagrada in 1887



Source: INEbase population censuses from 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartilla* of Fonsagrada, 1886, APHL, Facenda, C14992; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Chart 82. Potassium flows in Fonsagrada in 1887 (total kg)

	Monte	*Estivada*	Woodland	Meadows	Cropland	Livestock	Society
Monte						0	
Estivada	31,106	17,070					
Woodland						101	
Meadows						77,499	
Cropland					6,688	108,054	
Livestock	28,851		1,534	270,176	64,578		7,964
Society	41,882	3,077	6,607		52,216	3,209	

Source: INEbase population censuses from 1887 (http://www.ine.es/inebaseweb/libros.do?tntp=71807#); *cartilla* of Fonsagrada, 1886, APHL, Facenda, C14992; *"Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada"*, 1876, AHPL, Facenda, C14491; agricultural statistics from 1887, APHL, Facenda, C14491; and *Estudio de la ganadería en España* (Ministerio de Fomento, 1918).

Appendix 4. Glossary

This glossary collects all the concepts either in Galician or Spanish that we have used through the text and for which it was difficult to find a suitable translation.

Agra: type of cropland organization that is organized in enclosed fields which, at the same time, are internally divided in smaller plots of different holders who develop a collective work discipline

Aldea: group of houses with its own agrarian area. These population nuclei functioned as the most basic territorial unit for landscape organization.

Amillaramiento: document elaborated through the 19th and 20th centuries that consisted in a list of owners and their properties in a given locality. Such documents were used to distribute the payment of taxes according to wealth.

Aparcería: type of share-farming contract between a moneylender or owner, who pays for the animal, and a peasant, who looks after it and benefits from milk, manure, and transport. When the brought up animal and offspring are sold, money is then shared between them, as well as losses if that were the case. Specific conditions depend on the type of animal, and the contract can also be applied to land, although this was not common in Galicia, where most of the land was under *foro* contracts.

Cartilla evaluatoria: wealth assessment that registered both productions and expenses per land unit according to soil quality. There were also livestock *cartillas* which assessed productions and expenses per animal type. These informations served to establish a tax burden for the locality, which was later distributed among the neighbors according to wealth declarations in the *amillaramientos*.

Cepas: vines which are tied to poles and prunned in such a way that they grow towards their sides and close to the ground. Also referred to as *viñas* or *viñedos* in the sources of Ribadavia.

Couto: manor territory that has been granted with its own justice administration by the king.

Cortiñas: type of rotation that is similar to vegetable gardens in its intensive management and its location near the houses but included also cereal and other crops such as turnips, especially for testing purposes before being introduced in cropland.

Esquilmo: in this case, it refers to shrub from *monte* surfaces when cut, which serves mostly as livestock bedding, but also as fuel or animal foodstuff depending on the type of shrub.

Generally, *esquilmo* is any kind of benefit obtained from land or animals such as crops, wool or milk.

Estivada: common agricultural practice within the Atlantic territory in the NW of Spain which consisted in breaking a portion of land in *monte* surface and preparing it for one or two cereal harvests. Clods and vegetation were let to dry for some time and then burned before sowing cereal. After the harvest, the soil was left fallow in order for vegetation to recover. As agricultural intensification advanced, gorse was also sowed along with cereal since it it had a slower growth rythm. Therefore such practice served both to provide extra cereal crops and to regenerate shrub production.

Fidalguía: lower nobility.

Foro: common type of contract used for land and labor exploitation.

Labradío: cropland.

Monte: uncultivated surfaces. However, *estivadas* took place on such surfaces and, in fact, they were completely integrated in the agrarian system and fulfiled numerous functions. *Monte* provided pasture and bedding for livestock, but also firewood, cereal crops in *estivadas*, game, and wild herbs and fruits for harvesting.

Parras: vines that are prunned to grow in height, thus forming vine arbours.

Souto: chestnut grove.

Toxo (*Ulex Europaeus*): Galician word for gorse. This leguminous plant is very abundant in Galician *montes* as a result of its historical cultivation, which is related with its main function within the agroecosystem as nutrient provider for cropland, either as pasture or as livestock bedding, although it was also an important supply of firewood when plants were old enough.

Appendix 5. Resumo. Intensificación agraria e fertilidade do solo nun territorio atlántico: Galicia, 1750-1900

Esta tese ten por obxecto describir e analizar o proceso de intensificación agraria e a súa relación coa fertilidade do solo nun territorio Atlántico como é Galicia entre 1750 e 1900. Con este obxectivo, escollemos dous casos de estudo complementarios en termos climáticos e bioxeográficos: Ribadavia, pola súa temperá especialización vitícola e influencia mediterránea, e Fonsagrada, polo seu maior grao de aillamento e autosuficiencia, e clima máis tipicamente oceánico. A investigación susténtase no marco teórico do metabolismo social e, no caso de Fonsagrada, aplícase tamén a metodoloxía de balances de nutrintes propia da agroecoloxía adaptada ó estudo da fertilidade dos solos no pasado. Polo tanto, o enfoque combina a aproximación histórica e a biofísica da historia ambiental.

Este enfoque multidisciplinar é habitual na historia ambiental española dos últimos anos, que ten estudado varios casos da agricultura mediterránea en Andalucía e Cataluña (González de Molina e Casado, 2006; González de Molina et al., 2010 e 2012; Tello et al., 2010 e 2012; Infante-Amate, 2014; Galán, 2015). Polo tanto, era preciso incluír casos de estudo dentro do territorio atlántico para acadar unha visión máis ampla e complexa do proceso de intensificación agraria na península e da súa conexión coa transición socioecolóxica. É neste contexto no que se entende a xénese desta tese, que se insire ademais nun proxecto internacional que aplica este enfoque teórico e metodolóxico en casos de estudo en Canadá, Estados Unidos, Colombia, Austria ou España.

A teoría do metabolismo social concibe o estudo das sociedades na súa coevolución coa natureza mediante a análise dos procesos materiais de intercambio que acontecen entre ambos sistemas: apropiación, circulación, transformación, consumo e excreción. Polo tanto, fálase de transición socioecolóxica cando este tipo de interacción se modifica substancialmente e o metabolismo muda noutro distinto. Neste caso, trátase do paso dun metabolismo agrario ou orgánico a un industrial, caracterizado pola incorporación das fontes de enerxía fósil nos procesos antes mencionados. Seguindo a proposta teórica de González de Molina e Toledo (2011 e 2014) dentro do marco xeral do metabolismo social, no canto de referirnos á intensificación agraria dos séculos XVIII e XIX como primeira revolución agrícola, falamos de primeira vaga da transición socioecolóxica. Esta primeira onda caracterízase por unha optimización do funcionamento do agroecosistema dentro das condicións do metabolismo orgánico, é dicir, co emprego exclusivo de enerxía solar e de forza de traballo humana e animal. Esta optimización comprende principalmente a introdución de novos cultivos (leguminosas en moitos casos), a supresión do barbeito e a intensificación das rotacións.

Para o estudo desta primeira fase da transición, cómpre polo tanto un achegamento biofísico ó agroecosistema correspondente. A nosa selección dos casos de estudo para esta investigación estivo condicionada tanto por cuestións xeográficas como pola dispoñibilidade de fontes. Os documentos empregados deben ofrecer información cuantitativa sobre variables coma os usos do solo e os rendementos dos diferentes cultivos, así como o funcionamento das rotacións, e deben amosar unha seriación satisfactoria para coñecer os cambios de dito agroecosistema no tempo. Polo tanto, as máis acaídas son normalmente as fontes de tipo fiscal. Para o século XVIII recorremos ó Catastro de Ensenada e ás súas comprobacións tamén no caso de Ribadavia e, para o XIX, empregamos fundamentalmente cartillas avaliatorias de produtos e gastos, tanto para producións agrícolas como para o gando, e documentos de tipo estatístico ou fiscal que forman parte dos intentos de construír unha fiscalidade uniforme por parte da Coroa ou dos diversos interrogatorios sobre a crise agraria finisecular (Pro, 1992). Polo tanto, en ambos casos analizamos tres momentos concretos dentro do período de estudo, situados nas décadas de 1750/60, 1850/60 e 1880.

Malia os problemas de fiabilidade inherentes ó tipo de fontes empregadas, que teñen sido abundantemente sinalados pola historiografía española e galega (Fontana, 1980; Pro, 1995; Pérez García, 1982; Camarero, 1999 e 2002; Saavedra, 2007 e 2011), certos estudos dentro da historia agraria teñen validado o uso destas fontes a escala local mediante a contrastación con outro tipo de fontes e informacións (Huetz de Lemps, 1967; Bouhier, 2001; Saavedra, 1979; Villares, 1982; Mata e Muñoz, 1999;). No noso caso, como xa se ten feito en Andalucía e Cataluña (González de Molina e Casado, 2006; Cussó et al., 2006; Infante-Amate, 2014), o enfoque biofísico permite a reconstrución da produción total de biomasa e o seu contraste cos requerimentos nutricionais da poboación e do gando, de maneira que se obtén unha avalización máis precisa das fontes e da súa coherencia interna. Esta aproximación detallada está feita nos tres momentos que estudamos para o caso de Fonsagrada e parcialmente para o ano 1860 en Ribadavia. O resultado é a validación das fontes empregadas, tanto pola súa consistencia interna como pola coherencia resultante tamén da comparación cos outros momentos do estudo e os procesos de cambio na agricultura do país sinalados previamente pola historiografía agraria galega (Bouhier, 2001; Pérez García, 1975, 1978 e 2000; Saavedra, 1990 e 1991; Sobrado, 2001).

No caso de Ribadavia, o Catastro de Ensenada non permite coñecer a situación en termos de usos do solo de todas as parroquias que conforman o municipio na actualidade e, na década de 1880, as cartillas dispoñibles recollen simplemente os datos de rendementos pero non os de superficie. Por esta razón, o ano estudado coas comprobacións de 1764 refírese unicamente ás parroquias de Ribadavia e Francelos e a súa escala non é comparable ós momentos posteriores. En 1888, as superficies empregadas son as especificadas na cartilla de 1860. No caso de Fonsagrada, as fontes son máis completas para os tres momentos, a excepción da cartilla de 1886, que é unha copia da cartilla de 1852. Neste caso empregamos case todos os mesmos rendementos de 1852, algúns de cartillas de municipios veciños, e a distribución dos usos do solo dun documento estatístico de 1887.

Ambos casos son, como diciamos, representativos do territorio galego pola súa complementariedade en termos bioxeográficos e climatolóxicos, xa que Fonsagrada está dentro da zona de clima oceánico e, Ribadavia, nunha zona de clara influencia mediterránea. Por outra banda, de cara ó futuro, cómpre engadir máis casos de estudo da franxa costeira, cunha pluviosidade en ocasións superior á de Fonsagrada e con procesos de intensificación agraria máis temperáns e diferenciados, especialmente no que atinxe á introdución e expansión do sistema millo-prado en certas comarcas das provincias de Coruña e Pontevedra.

Para a reconstrución da produción total de biomasa en ambos casos tivemos en conta os rendementos declarados nas fontes para os produtos principais e, trala conversión das unidades tradicionais ó sistema métrico decimal seguindo a proposta de Fernández Justo (1986), aplicamos diferentes índices e conversores para o cálculo dos subprodutos de cada cultivo: palla, casca, restrollos, etc. Estes conversores proceden de Guzmán et al. (2014), de onde tamén obtivemos os contidos en materia seca da maioría destas producións. A presentación de resultados en materia seca permite unha maior comparabilidade tanto entre as diferentes rotacións dos nosos casos como con outras investigacións similares. Por outra parte, a produtividade da terra calculouse tendo en conta todos os cultivos de cada rotación e a súa duración, computando o tempo de barbeito oportunamente. Os rendementos multiplicáronse pola superficie da calidade correspondente (nas fontes normalmente especifícanse tres calidades distintas), sumándose a continuación e dividindo finalmente pola superficie total de cada rotación. No caso de rotacións plurianuais, previamemente a estes cálculos, a superficie cultivada dividiuse polo número de anos correspondente. É importante ter en conta as rotacións neste tipo de cálculos dado que a asociación de cultivos inflúe tamén na fertilidade do solo, nos rendementos e na produtividade da terra. Por este motivo non podemos considerar os rendementos do millo aillados dos das fabas, que se cultivan ó mesmo tempo e na mesma superficie, do mesmo xeito que a súa asociación ten un impacto positivo na fertilidade do solo. Tamén é importante computar os subprodutos porque en ambos casos se empregan na alimentación ou na cama do gando, ou se enterran de novo no chan. No caso de Fonsagrada estas estimacións son máis precisas xa que inclúen tamén a casca e o restrollo dos cereais ó igual que toda a produción de superficies de monte e arboreda, incluíndo leña, madeiras e follas. Sen embargo, en ningún dos dous casos se computou a biomasa radicular. Finalmente, para a realización dos balances de nutrintes no caso de Fonsagrada aplicamos a metodoloxía desenvolvida por García-Ruiz et al. (2012), que especifica todas as entradas e saídas de nutrintes que hai que considerar.

En canto ós resultados da tese, confírmase no caso de Ribadavia a existencia dun proceso de intensificación agraria que determina un incremento considerable da produtividade da terra entre 1752 e 1860. Por outra parte, o barbeito xa non está presente nas declaracións de Ensenada, onde cultivos coma o millo miúdo ou paínzo e o liño son aínda abundantes. Estes produtos desaparecen progresivamente do agroecosistema e son substituídos polo millo procedende de América que, asociado coas fabas e en rotación co prado, ten uns rendementos moi superiores e permite compaxinar mellor os requerimentos alimenticios da poboación e do gando nunha rexión onde o viñedo limita e condiciona o resto de cultivos e tamén a cantidade de gando. Os rendementos da principal rotación de cereal en Ribadavia pasan de 4,51 t/ha en 1764, a 8,31 t/ha en 1860, cun lixeiro descenso cara finais da década de 1880, situándose en 7,58 t/ha de biomasa (materia seca). Isto, sumado ó feito de que a única rotación que incrementa significativamente os seus rendementos ata o final do período é a máis extensiva, a de centeo en secano e de colleita anual, indica claramente que as posibilidades de intensificación estaban esgotadas cara finais do século. Os cambios na produtividade media de todas as rotacións de cereais amosa esta tendencia cara ó estancamento, pasando de 3,88 t/ha a 7,59 t/ha na primeira centuria e descendendo a 7,29 t/ha en 1888 (materia seca). O viñedo, o cultivo protagonista na rexión, mantén unha produtividade lixeiramente estable cara finais do período, só superior en 0,3 t/ha con respecto á de 1860. Este cambio no manexo agrícola cara rotacións máis produtivas é parello a un crecemento demográfico considerable ó longo do período de estudo, especialmente na primeira metade, con crises demográficas puntuais que coinciden coas principais crises vitícolas e que se complementan cos movementos de poboación nas comarcas veciñas, como xa tiñan demostrado outros autores previamente (Saavedra, 1992c; Fernández Rodríguez, 1992a e 1992b). Por outra banda, as nosas estimacións preliminares sobre dispoñibilidade e requerimentos de esterco indican que, cara 1860, as necesidades de materias fertilizantes superan con moito ás existencias dentro dos límites do municipio, pero o alimento tamén debía de ser escaso nunha rexión densamente poboada, con 158,5 habitantes por km^2 e un 71% da súa superficie cultivada adicada a viñedo en 1860. A importación de alimentos está recollida en fontes cualitativas (Ministerio de Fomento, 1887, vol. II, p. 368) e indirectamente tamén en investigacións previas, que especifican que as importacións incluían toxo para fertilizar as viñas, herba para o gando e tamén cereal para consumo humano (de Juana e Limia Gardón, 1980; Rodríguez Troncoso, 2004, Domínguez Castro, 1992). Se a estas mencións cualitativas engadimos as nosas estimacións de dispoñibilidade de esterco e temos en conta un estancamento xeralizado dos rendementos cara a fin do XIX, semella bastante claro que o proceso de especialización vitícola e a intensificación agraria non eran sustentables dada a súa dependencia do exterior para pechar o ciclo de nutrintes. Así, Ribadavia exportaba ás comarcas circundantes a insustentabilidade das súas prácticas agrarias, ó tempo que podía suplir as carencias de nutrintes grazas ó retorno económico do cultivo comercial do viño. Malia todas estas evidencias, resta por aplicar a metodoloxía dos balances de nutrintes a este caso, e sería tamén interesante estudar algún concello veciño como, por exemplo, Melón, pola súa complementariedade económica e demográfica.

O caso de Fonsagrada é moi distinto polas condicións orográficas e climatolóxicas, o carácter en boa medida extensivo da súa agricultura, a especialización gandeira e a maior vocación de autosuficiencia malia á súa integración en mercados locais e mesmo rexionais con exportación de gando e manufacturas que podían chegar ata Castela (Saavedra, 1991). A densidade poboacional é ademais moi inferior e a alta dispoñibilidade de terra permitiu unha progresiva extensificación ó longo do período de estudo que, xunto con rotacións máis complexas, duplicou a dispoñibilidade de biomasa total producida entre 1752 e 1852. Malia todo, o proceso resultou insustentable no longo prazo cunha evidente minería de nutrintes, especialmente de potasio, nas rotacións máis extensivas, sobre todo nos prados pero tamén no monte. Isto debeuse ó incremento das necesidades de fertilización en relación a unha maior superficie cultivada e rotacións máis esixentes en materias fertilizantes, especialmente coa introdución da pataca e os nabos na rotación de centeo. A produtividade da terra nesta rotación non variou substancialmente no período de estudo, cun lixeiro descenso de 1,88 t/ha en 1752 a 1,79 t/ha en 1887 (materia seca). En xeral, neste caso, a produtividade da terra non varía moito entre 1750 e 1880, en boa medida polo carácter extensivo do manexo agrícola, aínda que amosa unha tendencia levemente ascendente se consideramos a escala agregada de toda a superficie cultivada, pasando de 2,55 t/ha en 1752 a 2,76 t/ha en 1887 (materia seca). Por outra parte, os datos das fontes non permiten moita concreción na maioría das rotacións xa que os rendementos da horta, os prados ou do monte só constan en carros ou en valor monetario e as nosas estimacións baseáronse noutras fontes máis ou menos coetáneas para os rendementos de herba (Ministerio de Fomento, 1915) e horta (cartilla de Castroverde, 1888), ou en investigacións especializadas e máis actuais para as producións do monte (Hernández Robredo, 1936; Sineiro, 1982; Egunjobi, 1971). Sen embargo, os datos de rendementos das estivadas son moi significativos xa a traxectoria é claramente descendente entre 1752 e 1852 como consecuencia da súa intensificación en termos de redución do período de descanso e pola súa maior superficie cultivada anualmente. No caso da estivada de centeo, a produtividade da terra cae de 2,86 t/ha en 1752 a 2,23 t/ha un século despois, mentres que en 1752 había estivadas doutros cereais como trigo (estivada dun ano) ou centeo e avea (de dous anos) que rendían ata 4,26 e 2 t/ha de materia seca, respectivamente, e que no século XIX xa non aparecen nas fontes. Esta intensificación das rozas está en relación cunha menor dispoñibilidade de alimentos por persoa na década de 1850 con respecto a 1750, o que indica un cambio tamén no papel que desempeñaba esta práctica agrícola, que pasa de empregarse principalmente para rexenerar a produción de pasto no século XVIII a ser un complemento esencial para a nutrición humana, aportando ata un 18% da dispoñibilidade de alimentos para consumo humano en 1887, cando en 1752 esta porcentaxe era unicamente do 3%. Por outra banda, esta intensificación das estivadas no monte foi posible tamén por un menor requerimento dos recursos desta superficie por parte do gando, que entre 1750 e 1850 pasaría a estar maiormente estabulado. O cambio no manexo do gando estivo motivado polos maiores requerimentos de esterco para a superficie cultivada, que aumenta de 2.105 ha en 1752 a máis do doble un século despois e aínda a 10.465 ha en 1887, cun maior peso dos prados e, en segundo lugar, da rotación de centeo, patacas e nabos. As estimacións respecto das dipoñibilidades de esterco neste caso establecen un máximo potencial ó considerar que se aplica maioritariamente unha estabulación permanente, o cal é pouco habitual na zona. Malia todo, nin con esta opción estaban totalmente satisfeitas as necesidades de esterco en 1852 e 1887. Polo tanto, isto indica que o incremento da superficie cultivada e a intensificación das rotacións sostense a costa de minar os nutrintes de superficies máis extensivas como monte e prados, que deixan de percibir unha parte importante de excreta animal e, polo tanto, non repón a súa fertilidade de xeito satisfactorio.

Finalmente, no caso de Fonsagrada, esta aproximación máis exhaustiva ás condicións biofísicas permite establecer un nexo co fenómeno migratorio, que torna definitivo e se acentúa despois de 1850 coa liberalización do tránsito de persoas cara América. Neste caso coincide cunha menor dispoñibilidade relativa de alimento por persoa, que varía ó longo do período de 2.519 kcal/persoa/día en 1752, a 1.998,8 en 1852, e 2.078,7 en 1887, estando o óptimo nutricional en 2.270 kcal/persoa/día para a media da poboación española en 1860 (Cussó, 2005). Detrás deste descenso relativo da dispoñibilidade de alimentos atópase o crecemento demográfico, especialmente a mediados do século XIX, momento no que a poboación se duplica con respecto a 1752. Pero, ademais, hai que contar tamén coa abrupta redución da cabana gandeira nese mesmo período como consecuencia do proceso de intensificación. Os alimentos de orixe animal contribuían cun 56% da dispoñibilidade media de alimentos en 1752, aproximadamente, e só cun 15,4% en 1852 e un 17,2% en 1887. Este último incremento está relacionado cun lixeiro aumento da cabana gandeira, a conseguinte nova ampliación da superficie de prados e tamén cunha menor presión demográfica, que pasa de 39,6 hab/km^2 a 37,4 hab/km^2, mentres que en 1752 acadábanse soamente 20,8 hab/km^2. Estes datos poñen en evidencia a competencia entre a sociedade e o gando polos usos do solo, e revelan a importancia da migración como mecanismo que permite aforrar solo e incrementar novamente a cabana gandeira en 1887, mellorando así tanto a dispoñibilidade absoluta e relativa de alimentos e os nutrintes da superficie cultivada cun aumento do esterco dispoñible.

En definitiva, e á luz dos resultados dos balances de nutrintes estimados para 1752, 1852, e 1887, o patrón de intensificación e extensificación agrícola da Fonsagrada permite manter a produtividade dos cultivos máis ou menos estable ó longo do período, sostendo unha maior presión demográfica, pero cun impacto negativo sobre a fertilidade do solo nas superficies máis extensivas que proveen de nutrintes ás colleitas, nomeadamente os prados e o monte. Isto foi posible tamén grazas ó proceso de intensificación gandeira, que permitiu aumentar as dispoñibilidades de esterco progresivamente ó longo do período, pasando de 2.333 t en 1752 a 17.193 t en 1887; é dicir, de 1,4 t por hectárea fertilizada a 5 en 1887. Como contrapartida, o crecemento poboacional sostido por estas prácticas agrarias rematou sendo superior ás capacidades de sustentación do solo. Isto dá lugar a unha "fenda metabólica[162]", a ruptura do equilibrio previo nos usos da terra e a intensificación do proceso migratorio.

En definitiva, os nosos resultados confirman a tendencia descrita pola historiografía ambiental española para o mediterráneo en termos de esgotamento do proceso de intensificación agrícola a finais do XIX pese ás amplas diferencias en canto á produtividade

[162] *Metabolic rift* (Foster, 1999).

da terra existentes entre os agroecosistemas atlánticos e os mediterráneos, que teñen sido explicadas con anterioridade (Fernández Prieto e Soto, 2010; González de Molina, 2010a). Por outra parte, este esgotamento está tamén vinculado á transferencia de nutrintes de rotacións máis extensivas ás máis intensivas, que ten sido documentado en xeral para toda Europa, onde a minaría de nutrintes, especialmente de fósforo, é algo habitual no presente como resultado destas prácticas históricas (Shiel, 2006a e 2006b; Sattari, 2014).

Finalmente, esta tese abre moitas outras cuestións que a investigación deberá abordar no futuro. En primeiro lugar, cómpre ampliar o marco cronolóxico e incluír o século XX no estudo de ambos casos, especialmente no da Fonsagrada. Así poderase comprobar se a minería de nutrintes continuou e se a escasez de fertilizantes orgánicos está na orixe da transición socioecolóxica, dado que nos casos mediterráneos esta escasez ten sido vinculada coa industrialización da agricultura polo papel dos fertilizantes industriais na superación da fenda metabólica aberta como consecuencia proceso de intensificación e especialización agraria (Foster, 1999; Schneider and McMichael, 2010). Non sabemos aínda como foi a difusión dos fertilizantes industriais na Fonsagrada, aínda que en todo caso non é anterior a 1900 (Fernández Prieto, 1992). Por outra parte, habería que incluír os balances de enerxía tamén na análise da agricultura deste caso de estudo para coñecer mellor o funcionamento do agroecosistema en termos de eficiencia, e contribuír a unha explicación máis satisfactoria dos procesos migratorios e da transición socioecolóxica. Por outra banda, a cuestión da desigualdade no acceso ós recursos debe de ser considerada tamén, xa que permitirá matizar estes resultados. De feito, a historiografía recente está a vincular o desenvolvemento de prácticas agrarias insustentables coa desigualdade (González de Molina e Toledo, 2011 e 2014; Neundlinger, 2017; Villa, 2017). Por último, é necesario incorporar máis casos de estudo e ampliar a escala para ver o que acontece a nivel rexional.

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