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SPECIAL ISSUE ARTICLE

Agricultural Intensification and Soil Fertility in Atlantic Spain, 1750–1890

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Abstract

This article describes the intensification process of agriculture and its environmental limits regarding soil fertility in the rural community of Fonsagrada, in the inner region of Galicia in northwestern Spain. It addresses changes in land use, crops, and agricultural productivity between 1750 and 1890, framed within the theory of social metabolism and based on the method of nutrient balances. That technique measures nitrogen, phosphorus, and potassium flows across the landscape within a given agro-ecosystem to assess its biophysical functioning and to detect environmental constraints related to management. The intensification of cropland resulted in net losses of potassium in outlying rough grazing land and hay meadows that served as the sources of cropland nutrients. Agricultural intensification was possible due to the close stabling of livestock, which allowed for more manure availability. Doing so, however, deprived pastureland of nutrient recover through manure deposition, which created a metabolic rift in the agro-ecosystem.

Keywords: Environmental history; social metabolism; soil fertility; nutrient balances

Introduction

Between 1750 and 1890, farmers in Galicia, on northwestern Spain's cool, wet Atlantic coast, intensified their agricultural system and raised yields in the context of a growing human population. How did they manage to boost productivity on long-farmed soils prior to the advent of tractors, hybrid crops, synthetic fertilizers, and pesticides? How did communities reorganize agro-ecosystems to feed ever more people? The answer lies in soil fertility management. Employing a brushy, leguminous plant called gorse (*Ulex Europaeus*), villagers transferred soil nutrients from outlying bushland for deposition on their arable cropland. They also restructured their livestock management, with the aid of new crops imported from the Americas, to capture more manure. Those two strategies enabled increased fertilization of cropland, higher grain yields, and more food to feed more people. It was an ingenious adaptation to social and economic pressures and environmental possibilities, but it was unsustainable in the long run, as agro-ecosystems eventually depleted soil nutrients from outlying bushland. The analysis relies on the theory of social metabolism formulated by González de Molina and Toledo (2011, 2014), which studies the coevolution of social and natural systems according to the material and energy exchanges that occur between them. The methodology of nutrient balances in historical agro-ecosystems developed by García-Ruiz et al. (2012) reveals how nutrient cycles worked and how sustainable they were, with special attention to land management techniques focused on replenishing soil fertility. To test the theoretical limits of the agricultural system, the article employs a "forced local funds sustainability assumption," which considers the highest level of sustainability that might be reached within the constraints of an agro-ecosystem (Marco et al., 2018). The village of Fonsagrada serves as a case study, reconstructed for three time points (1752, 1852, 1887) from taxation and statistical sources and an imperial cadaster. Hardly an ignorant or unchanging peasantry, farmers in Fonsagrada responded to global events and social and demographic pressures, innovated their land management, raised productivity, and over a century and a half utterly remade their farm system. They accomplished those transformations by manipulating soil nutrients in ingenious ways across a varied landscape.

An Extensive Territory

The municipality of Fonsagrada lies in the interior province of Lugo, with an area of 439 square kilometers.[1] It is located in the eastern mountains of Galicia, in the northwestern corner of the Iberian Peninsula. Two river basins frame this municipality: the Eo valley on the West and the Navia valley on the East. Two minor rivers divide the area into northern and southern parts: the Rodil, which flows into the Eo River, and the Lamas-Villabol, which flows into the Navia River. The average elevation in the municipality is between 700 and 800 meters above the sea level (López Fernández, 1986).

The eastern mountains of Lugo form a nexus with the Cantabric Mountains, creating a biogeographic frontier with the rest of the territory (Terra Chá, Sarria-Lemos) and blocking winds from the coast. An oceanic climate predominates, although with continental influence. Average annual precipitation ranges between 1750 and 2100 mm, and there is no dry season (Giménez de Azcárate, 1993). Winters are cold and snow is common, as are frosts through most of the year. Temperature and rainfall conditions favor certain weathering processes that do not modify soil chemistry very much (Martínez Cortizas et al., 1999). Average annual rainfall at the nearby meteorological station of Pedrafita reaches 1,900 mm, with an annual precipitation deficit of 122 mm during June through August. Mean annual temperature is 8.3 ºC. These average data inform the nutrient balance analysis in the following text[2] (Gil Sotres and Díaz-Fierros, 1979).

By the Middle Ages, traditional land use in mountainous regions was characterized by an integration of crops, livestock grazing, and forestry, with micro-adaptations to the diverse ecological environments. Low-lying land in valley bottoms received

[1]See http://ige.eu/igebdt/selector.jsp?COD=77&paxina=001&c=0101001002 (accessed October 2011).

[2]These data belong to the weather station at Pedrafita do Cebreiro, a mountain village with similar geographical and climatic conditions as Fonsagrada and within 50 km of it. They refer to the period 1931–60. However this station is situated 300 m higher than the average height in Fonsagrada.

deposits of dissolved nutrients washed down from uplands, as well as manure applications, and were intensely cropped. Human habitations concentrated on sunny slopes or at the bottom of the valleys. Vegetable gardens were spread among the houses and surrounding the village. Nearby were the *soutos* (chestnut groves) and *labradío* (cropland, mostly rye). Further away from the village there was *monte*, mostly composed of shrubland, especially gorse, and generally defined as uncultivated land. Villagers occasionally burned *monte* to regenerate shrub and pasture, and very occasionally cultivated it for a short period in a unique form of shifting agriculture referred to as *estivadas*. It was this *monte* that served as a crucial nutrient reserve for cropland. Hay meadows were located at the floor of the valleys and along water streams (Guitián, 1993).

Population in Fonsagrada

Demographic growth was likely the driving force behind agricultural intensification in Fonsagrada, where population doubled between the 1750s and 1860s. Such a rapid increase created a real challenge in the context of an isolated agrarian society with an unfavorable environment embedded in feudal relationships that extracted an important part of the agricultural produce from producers (Saavedra, 1979). According to Saavedra, the increase in population was tightly connected with the introduction of potatoes, an American crop that arrived in Fonsagrada after 1788. The spread of this tuber was a partial solution to previous agrarian crises that had been responsible for population stagnation during the middle decades of the eighteenth century. With the introduction of potatoes, yields increased and rotations became more complex. Mortality rates fell due to more diverse and abundant nutrition (Saavedra, 1979). After the 1860s, however, migration away from Galicia was responsible for a reduction in the rate of population growth (Table 1).

A key argument here is that the out-migration of the nineteenth century in Fonsagrada resulted from an agricultural intensification process that was very successful, but that had reached its biophysical limits under the specific historical and cultural practices of an organic metabolism. After a period of remarkable agricultural growth, there was no further opportunity for population to continue increasing on the same soil base. Between 1750 and 1890 Fonsagrada underwent changes that have been described elsewhere as the "First Agricultural Revolution." Other terminology refers to these changes as the "First Wave of the Socio-Ecological Transition" (SET), recognizing that it was just the beginning of a long-term process that would not conclude until the twentieth century, with a massive incorporation of fossil fuels into agriculture. The process of SET in this case refers to the change from an organic or agrarian metabolism into an industrial one as it has been described by Fischer-Kowalski and Haberl (2007) or González de Molina and Toledo (2014). The second wave, which mainly refers to the use of inorganic fertilizers, happened in Fonsagrada and across Galicia and all of Spain in the 1940s, following the Spanish Civil War (Fernández Prieto 1992; Soto, 2006). That second wave of the SET is well documented, but this article focuses on an important transformation that happened earlier, in the century and a half before the onset of the twentieth century. Prior to the better-known modernization of agriculture, changes related

Table 1. Fonsagrada. Population changes between 1753–1900

	De facto population	**Inhabitants/km^2**
1753*	9,099	20.75
1787*	11,067	25.24
1826*	14,242	32.48
1857	17,368	39.61
1860	18,014	41.08
1877	15,903	36.27
1887	16,419	37.44
1897	17,163	39.14
1900	17,294	39.44

Source: Saavedra* (1979) and INEbase population censuses (http://www.ine.es/inebaseweb/libros.do?tntp=71807).

with the first wave were the result of an optimization of agrarian production and changes in cultural practices within an organic metabolism. Those changes were rooted in soil nutrient management, and they are the focus of this article.

Changes in Land Use, Rotations, and Yields

In the case of Fonsagrada, as in most interior regions of Lugo, changes related with the first wave of the SET appeared first as experiments in *cortiñas*, small enclosed plots with intensive management that Saavedra documented as early as the thirteenth century. Legumes were cultivated in *cortiñas* at the time, and by the sixteenth and seventeenth centuries every *aldea* had *cortiñas*, where turnips, flax, millet, and other crops grew. Farmers applied manure abundantly in these plots, which produced at least one harvest a year. With such intensive management, *cortiñas* were similar to vegetable gardens, which also used to be near the houses (Bouhier and Vila, 2001; López Fernández et al., 1986; Saavedra, 1979). However, it is difficult to track changes in *cortiñas* with detail, especially regarding their area. In Ensenada's Cadaster of 1752, data are not very specific about this type of land use, and its accounted area reached only 20 hectares out of 2,105 hectares of total cropland. Beyond 1752, *cortiñas* cannot be tracked in available sources. Thus, they are not included in the soil nutrient balances presented in the following text. However, they do appear in general descriptions of the agro-ecosystem toward the middle of the eighteenth century due to their qualitative importance. This should not imply significant changes in the nutrient balances because *cortiñas* surface was not relevant in quantitative terms but only as experimental plots. However, we cannot provide further detail due to the lack of information in the sources.

A first goal is to present a general picture of the whole agro-ecosystems revealed by the sources, and then proceed to an analysis at crop scale. Some crops such as wheat, oats, or maize were very important in qualitative terms but occupied a very small area that was not representative of the agro-ecosystem, as in 1752, or not even recorded at all in the nineteenth century. These crops are excluded from the

Table 2. Fonsagrada. Changes in cultivated area: 1752, 1852, and 1887 (ha)

	1752	1852	1887
Vegetable gardens	*33	101	69
Nonirrigated cropland	1,603	3,041	3,379
Meadows	238	1,068	4,318
Vineyards	5	24	897
Chestnut groves	124	213	608
Estivada	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 statistics from 1887, APHL, Facenda, C14491.
*Includes *cortiñas*.

aggregated scale and the nutrient balances, although they appear in a more detailed description and general analysis due to their agronomic significance.

A structured description of the agro-ecosystem includes the following categories: vegetable gardens and *cortiñas*, cereal or nonirrigated crops, hay meadows (both irrigated and not), chestnut groves, vineyard, woodland, *monte* bushland, and *estivada* swidden. The most common and abundant crop throughout the period was rye: either in a biannual rye-fallow rotation or, progressively through the nineteenth century, associated with potatoes and turnips but without fallow. Table 2 shows changes in areas of each of these land use types.

Vegetable gardens decreased between 1852 and 1887, accompanying the reduction of population connected with active migration to America. Vineyard and chestnut groves must have been considerably underestimated in 1752, however their increase between 1852 and 1887 is very remarkable. *Estivada* area, which provided an extra cereal crop, also saw a large increase through the period, from 101 hectares in 1752 to 1,194 in 1887. Finally, the biggest increase was that of meadows, which grew from 238 hectares to 4,318 at the end of the period, when their area was larger than that of cropland (3,879 hectares) and had replaced *monte* surface as the agro-ecosystem's main soil nutrient provider.

Average land productivity for these different types of land uses is showed in table 3 and figure 1, which indicate a decreasing trend and stagnation in most categories. Overall productivity in cropland remained more or less the same all through the period, although with a slight increase from 2.55 tons per hectare in 1752 to 2.57 in 1852, and 2.76 in 1887. However, note that the same yields have been applied to some crops in all three time points. Growth in productivity was mostly a result of changes in the quality of cultivated soils and especially the increase of cropped area. In the case of meadows, decreases can be explained by a larger proportion of non-irrigated meadows, which had lower yields. The same average yields were applied to vegetable gardens all through the period, and variations in production are only related with different distributions of soil qualities. The decrease in the productivity of *soutos* (chestnut groves) in 1887 was mainly due to the fact that first quality soils disappeared from the declarations of this year, and area increased considerably in

Table 3. Fonsagrada. Average productivity and annual domestic extraction in nonirrigated cropland (dry matter): 1752, 1852, and 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 Domestic Extraction (t/year dry matter)	**3,012**	**5,488**	**6,034**
Area Domestic Extraction (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 statistics of 1887, APHL, Facenda, C14491.

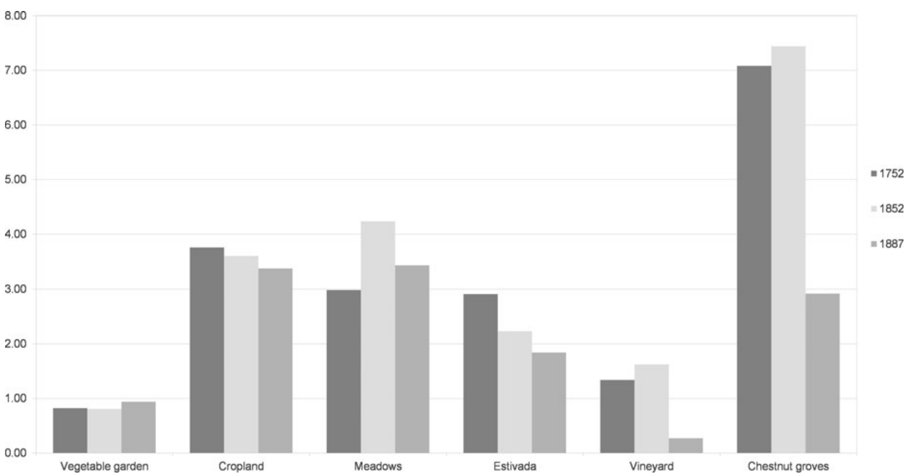

Figure 1. *Fonsagrada. Land productivity in 1752, 1852, and 1887 (t/ha, dry matter).*
Sources: Respuestas Generales of Ensenada's Cadastre, 1752, (http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0); cartillas of Fonsagrada from 1852 and 1886, APHL, Facenda, C14491 and C14992, respectively, and agricultural statistics from 1887, APHL, Facenda, C14491.

the other two soil qualities. It is unclear whether this was a deliberate fraud in the taxation sources or if it represented real changes, which would seem too drastic. Chestnut yields are specific for 1752, but in the nineteenth century they come from the neighbor village of Rendar.[3] Productivity was generally so high in *soutos* because wood and firewood extractions are included, but chestnut yields varied between 596 kilograms per hectare in 1752, 880 in 1852, and 623 in 1887 (in dry matter

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

equivalents). Changes in the productivity of vineyard were also related with a different soil quality distribution in the sources from the nineteenth century. An initial increase of productivity from 1.34 tons per hectare to 1.62 between 1752 and 1852, which was accompanied by a slight area expansion, grew to 1.66 tons per hectare in 1887, when the surface expanded immensely, especially in first quality soils.

The nonirrigated cropland included only rye in 1752, mostly in a biannual rotation with fallow. Farmers grew rye, potatoes, and turnips in 1852 and 1887, but without fallow. The elimination of fallow and the addition of root crops was the most significant example of intensification in Fonsagrada. Net production in cropland doubled by the end of the period, in part because of a considerable expansion of its total area. But overall yields (production per area) decreased slightly, which was certainly connected with this process of more intensive cropping and a higher level of soil nutrient extractions. This strategy fed more people but drained nutrients from other parts of the landscape by means of livestock conversion, mainly from extensive *monte* at the beginning of the period, and then increasingly from hay meadows too. The most reliable indication of nutrient exhaustion resulting from this intensification pattern is the gradual decrease in productivity in both cropland and *estivadas* between 1752 and 1852. These were the main sources of food provision for the community, and the most intensively managed after vegetable gardens and *cortiñas*.

The nonirrigated cropland was one of the most important and widespread land uses in the region, with rye as the staple crop. Here one can best appreciate the intensification process: fallow disappeared progressively between 1752 and 1852, cropped area grew, new crops were introduced, and total production increased. In 1752, the 21 percent of *labradío* was cropped annually with rye. The remaining 79 percent could not produce without a year of fallow. By 1852, there was no fallow at all, and a biannual rotation had emerged, in which rye was cropped in the first year, and alternated with potatoes or turnips in the second. It is important to mention that in 1887, more surface was cultivated with potatoes and turnips than with rye. The introduction of potatoes from the New World was associated with the suppression of fallow but also with changes in techniques and tools. The cultivation of this tuber required deeper tillage and was more demanding in terms of nutrients than rye, thus increasing manure requirements. As shown in table 3, cropland produced in 1887 twice as much food as it did in 1752, but yields drifted downward from 1.88 tons per hectare 1752 to 1.80 in 1852, and to 1.79 in 1887. In the case of *estivadas*, as detailed in table 4, rye yields also declined, from 2.86 tons per hectare in 1752 to 2.19 at the end of the period.

These changes in land uses, which implied an increasing prominence of meadows and estivada and an increase in cropped surface, were accompanied by adaptations in the management of livestock. Its numbers were dramatically reduced between 1752 and 1852 to secure a more intensive management that provided crops with manure, as we will see in this article. But again by 1897 livestock head had increased to satisfy higher manure demands.

However, agricultural intensification also kept in step with the demographic evolution. Population grew from 9,099 inhabitants in 1753 to 18,014 in 1860. By the time the next census was made in 1877 population had decreased to 15,903

Table 4. Fonsagrada. Average yields and land productivity in estivada: 1752, 1852, and 1887 (dry matter)

Rye *estivada*		1752	1852	1887
Rye grain (kg/ha)		785	612	601
By-products (kg/ha)		2,079	1,621	1,591
Total Domestic Extraction (t/year)		271.57	2,032	2,618
Area Domestic Extraction (t/ha)		**2.86**	**2.23**	**2.19**
Wheat *estivada*		**1752**	**1852**	**1887**
Wheat grain (kg/ha)		1,121	–	–
By-products (kg/ha)		3,142	–	–
Total Domestic Extraction (t/year)		2.98	–	–
Area Domestic Extraction (t/ha)		**4.26**	–	–
Rye/oats *estivada*		**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	–	–
Total Domestic Extraction (t/year)		12	–	–
Area Domestic Extraction (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 statistics from 1887, APHL, Facenda, C14491.

inhabitants, thus indicating an exhaustion in the intensification pattern. However, it would recover slightly with 16,419 inhabitants in 1887 and 17,163 in 1897. Migration should be considered as a structural phenomenon in the region, with seasonal movements to other regions within the Iberian Peninsula until the middle of the nineteenth century, when it headed mostly toward America (Villares and Fernández, 1996).

Changes in *Monte* and *Estivadas*

Due to their specificities when compared with cultivated land, the uncultivated gorse shrublands, *monte* and *estivadas*, deserve special attention. In Fonsagrada, access to *monte* resources was determined by descent or lineage. These were called *montes de varas*, and were characteristic of the northern half of Galicia, whereas common lands, or *montes en man común*, where access was determined by locality, were predominant in the southern half. Co-owners in *montes de varas* could sell their plots and, apart from the common appropriation of pasture or firewood, most other uses were individual (Balboa, 1990; Bouhier and Vila, 2001; Saavedra Fernández, 1979).

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Table 5. Fonsagrada. Monte area (ha): 1752, 1852, and 1887

	1752	1852	1887
Unreported area	35,921	5,644	285
Reported *monte* area	1,914	15,360	*10,222
Total *monte* area	41,554	38,300	33,194
Required *monte* area	9,168	4,138	2,847
Cropland area	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 statistics from 1887, APHL, Facenda, C14491.
*Estimated according to the increase in cropland in 1887 when compared with 1852 and its declared *monte* surface.

Monte satisfied three important needs in this organic metabolism: firewood, pasture, and bedding for stabled livestock. In doing so, they were also the primary soil nutrient supplier for cropland. Here "pasture" does not refer to cultivated grazing land, but rather to the multifunctional rough grazing in shrubland areas, where it was common for animals to range widely. This pasture was composed of both spontaneous plants and those shrubs that were planted in *estivadas*, namely gorse, which has been characterized both as the "*support*" (Bouhier and Vila, 2001) and as the "*motor*" (Soto, 2006) of the agrarian system. According to Bouhier, the diverse functions of *monte* remained the same during the intensification process, apart from a progressive decline of *estivadas*. According to Soto, however, changes in the appropriation of *monte* resources was the precondition of intensification. Nutrient balances reveal how this process occurred in Fonsagrada, where *monte* appropriation adapted to changes in the management of soil fertility. Table 5 reflects changes in the area of this essential resource and its proportion compared to cropland.

"Unreported area" has been estimated by deducting total reported area in the sources (7,929 ha in 1752; 38,206 ha in 1852; and 43,565 ha in 1887) from the current area of the Fonsagrada municipality (43,850 ha), as previous researchers have done in other case studies (Villares, 1982). In 1887 unreported area was much lower, but that year includes estimated *monte* surface as reported. *Estivadas* are reported area too, both their yearly cropped area, and their corresponding fallow extent, obtained by multiplying total cropped *estivada* area by the number of years in which the soil is left fallow. The result is the maximum possible area requirements for *estivada*, although actual area must have been less. Reported surface was less than is indicated here because it includes fallow area requirements as well, which comes directly from the sources. Besides, the sources from 1752 included other areas: 105 hectares of oakwood and 86 hectares of urban and other unproductive areas such as paths or streams, which are also accounted for in 1852 and 1887.

The datum of "reported *monte* area" has been obtained from the accounts in the sources. In the 1880s *monte* area was not reported but annually cultivated *estivada* was. Therefore *monte* area for this year has been estimated according to the assumption that cropland expansion after 1852 occurred at the expense of *monte*. Thus, we deducted this increase in cropland area that occurred between 1852 and 1880s from the total *monte* area as declared in 1852 and obtained an estimated total of 10,222 ha of *monte* in this decade.[4]

"Total *monte* area" represents the total current area of the municipality minus all reported area that is not *monte*. The result approximates the maximum possible *monte* area and is not included in the biophysical estimations because a considerable portion was unavailable due to steepness, rocks, rivers, and so forth. Fallow *estivada* area has been accounted for as *monte* as well because that is its actual use when not being cultivated by following a long-fallow strategy.

"Required *monte* area" has been estimated according to biophysical criteria by taking into account firewood, pasture, and stable bedding needs of the population and livestock present in the community in each year. Firewood needs were at least 2 kilograms per person per day, according to Infante-Amate et al. (2014). Firewood availability includes both woodland and chestnut groves. *Estivadas* area is not included because of its different treatment in nutrient balances. Although resource extraction took place on this land during fallow years, the management was completely different in the year of cultivation. Therefore, *estivadas* area did not follow such strict biophysical requirements and took place whenever peasants deemed it necessary in for shrub regeneration or food supply.

Finally, "cropland area" refers to the rest of the managed land: vegetable gardens, nonirrigated cropland, meadows, vineyard, chestnut groves, and yearly cropped *estivada*, all as reported in our sources. This combination of land uses has been described as "Used Agricultural Area"[5] by Soto (2006) or López Iglesias (1995). The sum of cropland, total *monte* area, and urban land and oakwood as reported in 1752 represent the total of the municipality in all three time points.

The estimation of total required area allows comparison between sources and analysis of shrubland appropriation, but it does not correspond with actual surface, which was obviously much larger. This also means that the limits to intensification were not exclusively dependent on the amount of shrubland area available, which was more than enough in all three periods. The quality of *monte*, its distance, transport conditions, and labor availability were limitations on its appropriation and nutrient mobilization.

Limits to cropland intensification emerged mainly because the role of *monte* within the agro-system changed once villagers began to keep livestock in stables. Doing so meant that they mobilized soil nutrients in a different way. Livestock stabling suppressed an important form of direct fertilization, through fresh manure dropped on pastureland, both on *monte* and hay meadows. In Fonsagrada, the appropriation of *monte* surface to sustain livestock declined toward the end of the period specifically because of this change in livestock management.

Agricultural intensification was only possible by expanding cropland into former *monte* lands in a kind of frontier expansion. Thus soil nutrient stocks were mobilized from *monte* land that had never been intensively cultivated, and increasingly from hay meadows too. Cropland expansion into *monte* eventually exceeded sustainable limits due to nutrient scarcity and the increasing demand for fertilizer, which drained nutrients from meadows, but also from *monte* through *estivadas*.

[4] 15,360 – (1,194 – 910) – (4,318 – 1,068) – (897 – 24) – (608 – 213) – (3,379 – 3,041) = 10,222 ha.
[5] *Superficie Agraria Útil* (SAU).

Table 6. *Fonsagrada.* Estivadas*: yearly cropped area (ha) and fallow duration (years) in 1752, 1852, and 1887*

	1752	1852	1887
	3 crops	**Rye**	**Rye**
Annually cropped area	101	910	1,194
Fallow area	3,719	17,296	22,687
Total *estivada* area	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 statistics from 1887, APHL, Facenda, C14491.

Estivada, the practice of shifting agriculture in the rough grazing lands, intensified as a result of a decreasing relative food availability in the community. This significant expansion of cultivated surface destroyed the previous land equilibrium. How could farmers sustain cropland fertility without extracting soil nutrients from extensive meadows and *monte*? This change was the origin of the "metabolic rift" between society and nature, and eventually created a land scarcity for the replenishment of soil fertility in a sustainable way.

Intensification of Estivadas

Estivada was a form of shifting agriculture that took place on *monte bushland.* It had a long fallow that allowed the soil to recover after the harvest. This could last between 30 and 50 years in 1752, depending on soil quality, and about 20 years in the second half of the nineteenth century. However, according to Saavedra, these numbers represent a maximum threshold, and the land could have been ploughed with greater or lesser frequency (Saavedra, 1979). Table 6 shows the remarkable increase in *estivada* area, from 101 hectares in 1752 to 1,194 in 1887.

Estivadas had several phases. In a first step, farmers cut shrubs and broke the land. Then they piled shrubs and clods together and burned them. Scattering the ashes over the whole surface returned some nutrients to the soil and slightly improved its acidity. Fire accelerates the process of mineralization in the soil, making nutrients more readily available to plants. Reducing soil acidity also increases the availability of some nutrients, such as nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium. In a next phase, farmers plowed the land and prepared for cultivation with the first rains of the fall. At best, two crops were possible (Balboa, 1990; Bouhier and Vila, 2001). However, in Fonsagrada most *estivadas* produced only one harvest. Only one case of a double harvest in *estivada* was described in 1752, which consisted of rye in the first year and oats in the second. The total cultivated area under this form of swidden reached 5.9 hectares annually in 1752, whereas 94.8 hectares were dedicated to rye under nonirrigated cropland, and 0.7 hectares to wheat. In the other two periods, *estivadas* were only composed of a single harvest of rye.

According to García Fernández, *estivadas* were already rising in the eighteenth century, as a result of increasing demographic pressure throughout the territory and the need for extra crops (García Fernández, 1975). However, this author misses the purpose of *estivadas*, which have been described by Bouhier as a way of regenerating shrub growth, namely gorse, in support of an increasing demand for fertilizers (Bouhier and Vila, 2001). This explanation makes sense in agronomic terms because gorse grows better after fire (Sineiro, 1978). Cropland intensification was accompanied by a parallel *monte* intensification as well, which was usually only identified with the disappearance of *estivadas* in favor of more intensive gorse extractions. Farmers sold gorse seeds, and even selected for their improvement, and intensely cultivated the shrub. The span of time between gorse cuttings was more strictly observed in privatized lands, which also explains why they were more productive. Bouhier describes the general disappearance of *estivadas* in Galicia during the eighteenth and nineteenth centuries as a consequence of more intense uses over *monte* for gorse production. Pérez García, who describes this process for the southeastern coast of Galicia and Balboa, also confirm these main conclusions (Balboa, 1990; Bouhier and Vila, 2001; Pérez García, 2000). However, in Fonsagrada there was also a parallel process of intensification of *estivadas*, a phenomenon that has not been studied so far. According to Bouhier, *estivadas* were intensified when required, but always attending to soil quality to sustain its fertility. In fact, according this author, they were progressively abandoned in Galicia. Fonsagrada is an exception, and perhaps there were other cases as well. Bouhier emphasizes the empirical knowledge of peasants in their management of land, affirming that gorse production was crucial. Besides, Bouhier contradicted modern prejudice against the supposed destructive and backward character of *estivadas*, a common misperception of swidden farming methods around the world. Farmers usually avoided establishing *estivada* on steep slopes, thus reducing soil erosion to the average for other cropland areas, and fire had a positive impact on soils by reducing acidity and favoring mineralization. Their main goal was to regenerate the growth of plants such as gorse and brooms, leguminous plants that increase nitrogen availability in the soil. By encouraging young gorse plants, symbiotic nitrogen fixation rates were also higher than with older plants (Bouhier, 1984; Bouhier and Sila, 2001; Sineiro, 1982). Besides, the role of *estivadas* as extra food supplier with the cultivation of rye should not be discounted because in Fonsagrada they provided an important share of nutritional requirements in the most critical moments of the nineteenth century, when population struggled with relative food scarcity. Without the supply of cereal from *estivadas*, the nutritional security of the population in both 1852 and 1887 would have been much diminished, as shown in table 7. According to Cussó's estimates on the minimum nutritional requirements of the Spanish population in 1860, an average diet should supply with at least 2,270 kilocalories per person per day (Cussó, 2005).

In Fonsagrada, without the contribution of *estivadas* in 1852 and 1887, food availability would have been only 1,720.5 and 1,701.7 kilocalories per person per day instead of 1,998.6 and 2,078.7, respectively, that the entire agro-ecosystem delivered. *Estivadas* contributed between 250 and 400 kilocalories to the diet of the inhabitants of Fonsagrada in these critical moments of the second half of the nineteenth century, with a slight increase toward the 1880s that was related to a further expansion in cropland area and its intensification. The intensification of *estivadas*

Table 7. *Fonsagrada.* Estivadas *contribution to human diets (kcal/pers/day) in 1752, 1852, and 1887*

	1752	1852	1887
Total kcal/pers/day	2,518.8	1,998.6	2,078.7
Kcal/pers/day contributed by *estivada*	78.6	278.1	377.0

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

must have been driven by food scarcity, while also leading to fertility depletion and decreasing productivity in the long term.

The role of *estivadas* changed through time in direct relation with the intensification process and its eventual exhaustion. Thus, in 1752, when *estivada* mainly served to regenerate shrub production, *monte* mostly supported an extensively grazing livestock population. Farmers cultivated cereal on *estivada* because they had to carry out the labor either way to regenerate pasture. The grain harvest was a bonus, but clearly not the primary target of the *estivada*. Later on, this shrub regeneration was also necessary because *monte* had to supply ever more livestock bedding. Although these extractions were not higher than those of pasture, by the nineteenth century *estivadas* were mainly necessary to supply an extra crop to feed the community, despite the fact that it required a great deal of labor. These tasks did not require as much labor or land as did the process of increased manure production and the further expansion and intensification of cropland. Both depended on an increase in livestock numbers, daily gorse cuttings, frequent renewals of stable bedding, and manure distribution onto cropland. The intensification of *estivadas* can be interpreted as a result of reaching the physical limits of cropland appropriation.

However, the role of *estivadas* as food supplier in 1752 was irrelevant because *estivada* contributed only with 79 kilocalories per person per day at a time when the rest of agro-ecosystem provided 2,440, which was more than enough according to Cussó's estimates.

As grazing pressure on *monte* pasture decreased during the nineteenth century, with livestock stabling and the expansion of hay meadows, there was a wider margin for intensification in *estivadas*, which increased their frequency to every 20 years by 1850. These *monte* crops were especially necessary toward the middle of the century with an increase in population and relative food scarcity. However, as a result of this increasing use of *monte*, nutrient imbalances worsened, with a parallel decrease in cropland yields. The nutrient balances confirm this trend also. Land availability had been overtaken by the requirements of soil fertility, and there were not enough resources to restore nutrients to cropland soils in a sustainable way. The expansion of cropland and more intensive land use alongside increasing demographic pressure created a metabolic rift. Besides, the reorientation in livestock management to produce manure in stables resulted in soil depletion in hay meadows and *monte* pastures, where nutrients were extracted but no longer replenished due to the relocation of animals to stables.

Similar conclusions regarding this metabolic rift have been obtained for case studies in Austria (Gingrich et al., 2015) and in the Mediterranean Spain (Galán et al., 2012; González de Molina 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), as well as the relation between these processes and the institutional changes derived from liberal revolutions such as the reform of land property and the integration of markets.

Livestock: From Free-Range Animals to Stabled Cattle in Less Than a Century

Livestock fulfill functions that affect the entire agro-ecosystem, integrating its various elements and allowing matter and energy to flow within its boundaries. Domestic animals speed up the cycle of nutrients by means of their manure. They optimize farm production by consuming certain feed that is inedible to humans. And they provide transportation, labor, and ready cash when sold at the market (Martínez López, 2000).

However, livestock are inefficient energy converters (Cussó et al., 2006). They represent a costly option within an agro-ecosystem, especially when—as in our case—it meant switching from an extensive form of animal husbandry to an intensive one that required keeping animals in stables, mowing hay crops, and cultivating feed such as turnips. This strategy required a great deal of human labor, but also much land. However, it was worth the effort due to livestock's essential contributions in the form of manure and labor, allowing cropland intensification in turn. Livestock intensification led to stall feeding because the goal was to obtain more manure. Farmers had to collect gorse and bedding materials daily to refresh stables regularly, but also for feed. Gorse could be cut all year round, and especially in spring and summer. This operation, combined with transport, manure production, and manure application on the fields occupy as much as 19 percent of the time required for all agricultural tasks (Bouhier and Vila, 2001). Producing animal feed also competed with human food crops, which made it a costly land use option as well. It was the stabling of cattle that required both the expansion of meadows and the introduction of turnip and maize crops, which were used almost entirely for livestock feeding.

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 entire Crown of Castile, including all the parishes that belonged to Fonsagrada at the time. For 1852 and 1887 data come from two documents: a livestock *cartilla* from 1855 and agricultural statistics from 1876, respectively.[6]

Livestock census data were converted into live weight measures with converters from *Estudio de la ganadería en España*, referred to the year 1917 (Ministerio de Fomento, 1920), and then total weight was transformed into standard Livestock Units of 500 kg each (LU-500 kg).[7] These data are represented in figure 2, which shows changes in livestock numbers through the study period. Livestock density was 20 animals per square kilometer in 1752, 8 in 1852, and 10 in 1887. This abrupt reduction by 1852 corresponds with the intensification of livestock management,

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

[7] For more detail on estimations, see the methodological appendix (Table A1).

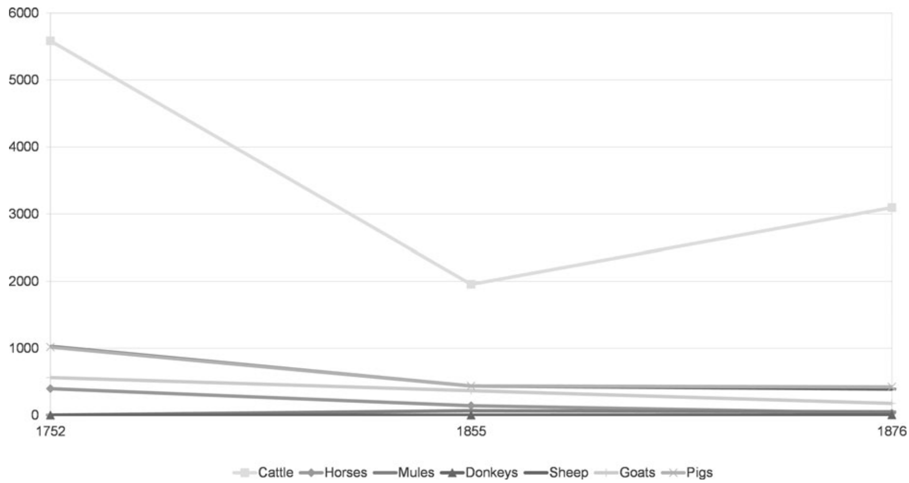

Figure 2. *Fonsagrada. Changes in livestock numbers: 1752, 1855, and 1876 (LU-500 kg).*
Source: Censo ganadero de la Corona de Castilla (INE, 1996), livestock cartilla, Fonsagrada, 1855, AHPL, Facenda, C14205; "Estadística Agrícola. Provincia de Lugo. Partido Judicial de Fonsagrada," 1876, AHPL, Facenda, C14491; Estudio de la ganadería en España (Ministerio de Fomento, 1920)

when the whole system introduced adaptative changes in crops and land use. The small increase by 1876 was related to a further advance in the intensive management of livestock and was accompanied by an important increase in hay meadows as well.

The abundant livestock of 1752, namely cattle and swine, could not have been kept in stables; it would have been physically impossible. Livestock would have outnumbered people in the villages. To shelter livestock, it was necessary to reduce their numbers. This must have been a gradual process, and implied that livestock stopped spending most of their time grazing freely on *monte* and started to be stabled on the ground floor of peasant houses. The chronology of the process is still uncertain, but it occurred after the 1760s and it was completed by the 1850s.[8]

The emphasis on cattle was directly related to their multifunctional character within the agro-ecosystem: cows provided milk, meat, labor, and calve production for the market. However, this specialization was not market driven. Cattle were not oriented solely to either labor, milk, or meat production, but supplied all of them at

[8]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 fertilizers (superphosphates) and *guano* from Peru and, later on, from Chile, started to be incorporated to the soil after the 1840s, although farmyard manure was the main source of nutrients in British farming between 1830–1930 (Grigg, 1989). 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 the ecological imperialism of the colonial era, partially driven by a soil shortage in Europe. Cushman has linked industrialization with guano and similar fertilizing substances that were imported to Europe, favoring the ecological conditions of an input-intensive agriculture and the related growth of population and industrial economies in the nineteenth century. The nutrient bottleneck was overcome by importing nutrients (soil) from the colonies in the Pacific World (Crosby, 1986; Cushman, 2013). This is another story, but to some extent it helps explain the different rythms in European industrialization.

Table 8. Fonsagrada. Manure requirements in 1752, 1852, and 1887 (t/ha, fresh matter)

		1752	1852	1887
Vegetable gardens	Nitrogen requirements	4	1.3	1.3
	Phosphorus requirements	13	14.8	14.2
	Potassium requirements	−2.94	−3.89	−3.75
	Manure availability	**13.0**	**14.8**	**14.2**
	Manure deficit	**0**	**0**	**0**
Nonirrigated cropland	Nitrogen requirements	2.39	6.42	6.59
	Phosphorus requirements	1.33	2.34	2.21
	Potassium requirements	2.39	6.87	6.96
	Manure availability	**1.34**	**4.26**	**4.80**
	Manure 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, 1920).

the same time, as was common in preindustrial agricultural metabolisms (Krausmann, 2004).

This change in livestock management aimed primarily at increasing manure availability for cropland, drawing on the livestock numbers reported in the previously mentioned sources. Specific converters for the corresponding amounts of manures deposited by different animals and nutrient contents of those manures come from ASAE (2003), and bedding amounts from Soroa (1953). Total manure availability reached 2,332 tons in 1752, 14,465 in 1852, and 17,193 in 1887. Soil nutrient requirements for the two land uses that received manure, gardens, and nonirrigated cropland, appear in table 8.

Estimated availability refers to manure in stables, excluding manure dropped on pastureland. Availability in 1852 and 1876 has been estimated assuming that all cattle were permanently held in the stable to optimize manure collection. Such intensive stabling has been described by previous literature, but that assumption seems too extreme for Fonsagrada. Still, it is a conservative assumption to estimate the maximum manure and the most soil nutrients that could possibly have been collected. This would be an ideal situation or the upper limit of the agro-ecosystem for cropland nutrient availability. This might seem like a questionable decision but without any further information in the sources that allow us to estimate an accurate percentage of outdoors excreta we opted to approach the optimal situation. The aim of such decision is to show that even with that amount of manure the situation was still unsustainable in the long term.

Nitrogen must have never been a problem in vegetable gardens in Fonsagrada, but manure was not enough as to replenish it fully in the nonirrigated cropland already in 1752. This deficit increased significantly in 1852, when it was more than twice that of 1752, but it declined again by 1887 to about half a ton per hectare in comparison with the deficit of 1852. Peasant knowledge innovated further adaptations in the management of livestock and land uses to increase manure availability. Part of the solution was a larger number of livestock by 1887, which served to connect more hay meadow and cropland area.

Phosphorus was the most limiting nutrient in vegetable gardens, but there must have been enough manure to keep its soil balanced during the entire study period considering the logical hierarchy in the distribution of manure, which always favored the most intensive rotations. In the case of nonirrigated cropland, phosphorus was also balanced. Problems might have arisen with potassium, which was already scarce at the beginning of the period and in especially short supply toward the middle of the nineteenth century. However, potassium was not a problem at all in vegetable gardens because potential replenishment exceeded requirements (represented by negative values in table 8). Because vegetable gardens were very small compared to cropland, a transfer of all the manure from the former to the latter would not have solved the cropland deficits. This analysis assumes that logic would have aimed to guarantee a complete replenishment of nutrients in vegetable gardens instead of allowing imbalances in both vegetable and cereal land, especially considering the more intensive cropping of orchards.

Regarding total manure availability, amounts rose from 2,333 tons per year in 1752 to 14,465 in 1855 and 17,193 in 1887. This was equivalent to an average manure availability of 1.4, 4.6, and 5 tons per hectare, respectively, considering both types of fertilized land as a whole, disregarding their particular requirements. The general low availability for 1752 is explained by the fact that soil fertility relied not only on manure for nutrient replenishment but also on fallow. Nitrogen requirements in the nonirrigated cropland was replenished up to a 50 percent by fallow, while manure supplied 30 percent, and there was a deficit of 20 percent. At that time, potassium was the most limiting nutrient, with the following replenishment supplies: manure provided the 30 percent, fallow 47 percent, and there was still a 23 percent deficit. In the case of phosphorus, manure provided most of it, up to a 68 percent, and fallow replenished the remaining 32 percent. The management of soil fertility relied considerably on fallow for nutrient replenishment in the mid-eighteenth century. These results are similar to those that Krausmann found for preindustrial Austrian agriculture (Krausmann, 2004).

Nutrient Balances in Fonsagrada and Agricultural Management of Soil Fertility

It is also useful to consider soil nutrient balances at land use scale to assess the functioning of the agro-ecosystem. These estimations have a margin of error considering the methodology, the sources, and the assumptions required to replace missing data. 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 to sustain the soil fertility in cropland, at the expense of other areas, namely *monte* and hay meadows (Tables 9–11).

Table 9. Nitrogen balances in Fonsagrada: 1752, 1852, and 1887 (kg/ha)

	1752	1852	1887
Vegetable garden	30.4	44.2	42.4
Nonirrigated cropland	−3.5	−6.4	−4.6
Meadows	−38.5	−30.0	−26.1
Nonirrigated 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, 1920).

Table 10. Phosphorus balances in Fonsagrada: 1752, 1852, and 1887 (kg/ha)

	1752	1852	1887
Vegetable garden	0	0	0
Nonirrigated cropland	0	2.2	3.2
Meadows	0.4	1.7	2.4
Nonirrigated 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, 1920).

In the case of vegetable gardens, manure availability was enough to ensure the complete replenishment of these three main nutrients in all three periods. There was a conscious effort to optimize the management of soil fertility between the 1850s and the 1880s, which can be observed in the general improvement of balances. However, this pattern of intensification with a livestock specialization was not sustainable in the long term because nitrogen and potassium were clearly being depleted in some parts of the agro-ecosystem, especially in meadows and in cropland in the case of potassium, and in meadows and woodland (including *soutos*) in the case of nitrogen. This result was due to the expansion of an agriculture frontier over *monte* surfaces. The nutrient stocks of these soils were invested in the process

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Table 11. Potassium balances in Fonsagrada: 1752, 1852, and 1887 (kg/ha)

	1752	1852	1887
Vegetable garden	95.7	111.9	107.6
Nonirrigated cropland	−6.3	−15.6	−13
Meadows	−35.2	−23.3	−17.8
Nonirrigated 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, 1920).

of both intensification and extensification, thus widening the metabolic rift. By contrast, the combination of an unsustainable pattern and the lower suitability of such soils for crop production was evident in both the nutrient balances and in the trend toward yield stagnation. Despite the acknowledged margin of error in these results, a coherent picture emerges of this agro-ecosystem and its transformation through intensification.

Table 12 shows the nutrient balances in *monte*, which has been disaggregated from the rest because of its specific characteristics, including the long duration of the *estivada* fallow cycle, and the multifunctional role of this land use within the agro-ecosystem. Besides, the use of fire in *estivadas* made them distinctive.

In 1752, an average of 40 years of fallow allowed for all nutrients to be fully replenished by nature. Over that time span, natural deposition in *monte* occurred at an average rate of 58 kilograms per hectare for nitrogen, 2 for phosphorus, and 31 for potassium. In 1852 and 1887, sources[9] confirm that all types of *monte* were cultivated under *estivada* every 20 years. For that time span, deposition rates decreased to 54, 1, and 27 kilograms per hectare, respectively, in 1852, a consequence of the intensification of this land use. Then problems with potassium began to become evident. In 1887, deposition rates recovered to similar values as in 1752 because of the reduction in grazing pressure on *monte* pastures after the stabling of livestock and the increasing reliance on hay meadows as nutrient suppliers for cropland. At that time, nitrogen and phosphorus were still fully replenished, but net losses of potassium became evident, indicating a nutrient mining process directly linked to the intensification of *estivadas*.

[9] *Cartilla* of Fonsagrada from 1852 and agricultural statistics from 1887, both in AHPL, Facenda, C14491.

Table 12. *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, 1920).

Conclusions

The agricultural innovations in Fonsagrada related to the first wave of the SET included the introduction of new crops such as maize, potatoes, and turnips, and a parallel intensification of cropland by eliminating fallow. Those changes meant a new approach to nutrient management, which performed adaptations in livestock management to provide cropland with more manure.

There was a clear connection between an increasing demographic pressure on the land and agricultural intensification between 1752 and 1852, when population doubled. But by the middle of the nineteenth century the distribution in land uses reached its limits, as it is evident in the decrease of food availability per person in 1852, and the beginning of significant migration to the Americas, which eventually contributed to relieve pressure on the territory and allowed to save nutrients and soil. Data allow us to hypothesize that there was still some margin for further intensification, at least until the 1880s. Livestock statistics from 1876 and land use distribution from 1888 show how both livestock numbers and cropland increased when compared with those of the 1850s, which resulted in a consequent growth in manure availability. More balanced soils in terms of nutrients at the end of the period confirm such a trend, which must have been partially enabled by migration as suggested by its chronology. However, other unknown driving factors must have been involved too, such as institutional changes or innovation, but sources do not provide any further information at this respect and we cannot be more conclusive.

However, balanced soils in cropland had an important downside. Sustaining the expansion of cropland and the increase of nutrient supplies could only be accomplished at the expense of nutrient reserves in *monte* areas and, especially, in meadows. There is evidence of a nutrient mining process of potassium in these parts of the landscape, which resulted from livestock stabling. Phosphorus stocks also decreased through the whole period. As Fernández Prieto (2000) shows, the good response in yields to the application of industrial phosphate fertilizers throughout Galicia after 1900 indicates that phosphorus availability must have been problematic too. The comparison with current potassium levels in the soil would be misleading due to the general overfertilization with slurry and the abundant application of chemical fertilizers after the 1970s in regions with a livestock specialization

(Fernández Marcos et al., 1994; Guitián, 1993; Rubio and Gil Sotres, 1995). However, research indicates that potassium availability is usually low in Galician soils (Calvo et al., 1992; Fernández Marcos et al. 1994) but the most determinant limitation is that of phosphorus (Gil-Sotres and Díaz-Fierros, 1979).

In conclusion, more nutrient balances are required for the period after 1890 to assess whether the nutrient bottleneck was a driver of the second wave of the SET in the twentieth century. Even with continuing out-migration, the high productivity agricultural system established by the late nineteenth century in Fonsagrada could only have continued for a few decades more.

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Appendix

Table A1. Data used in estimations

	1752	1852	1887
Population	Ensenada's Cadastre[1]	INEbase population census, 1857[2]	INEbase population census, 1887
Area	Ensenada's Cadastre	*Cartilla*, 1852, AHPL, Facenda, C14491	*"Riqueza rústica y pecuaria,"* AHPL[3] Facenda, C14491
Land uses	Ensenada's Cadastre	*Cartilla*, 1852, AHPL, Facenda, C14491	*Cartilla*, 1852, AHPL, Facenda, C14491
Yields	Ensenada's Cadastre	*Cartilla*, 1852, AHPL, Facenda, C14491	*Cartilla*, 1852, AHPL, Facenda, C14491; *Cartilla* from Rendar, 1852, AHPL, Facenda, C14491; Ministerio de Agricultura, 1905, 1904, and 1892; Ministerio de Fomento, 1913; Soroa, 1953
Livestock	INE, 1996	Livestock *cartilla*, 1855, AHPL, Sección Facenda, C14205	*"Estadística Agraria. Provincia de Lugo. Partido Judicial de Fonsagrada,"* 1876, AHPL, Facenda, C14491; Ministerio de Agricultura, 1892; Ministerio de Fomento, 1920.
Dry matter content and residue indexes	Guzmán et al., 2014	Guzmán et al., 2014	Guzmán et al., 2014

[1]http://pares.mcu.es/Catastro/servlets/ServletController?ini=0&accion=0&mapas=0&tipo=0.
[2]http://www.ine.es/inebaseweb/libros.do?tntp=71807.
[3]Arquivo Histórico Provincial de Lugo.

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