With the contribution of the LIFE financial instrument of the European Community

LIFE15 CCM/IT/000123

Report of the characterization of Sardinian dairy sheep production systems

A.1.3 Characterization of production systems

Language: EN

Authors

Agris Sardegna
Giovanni Molle
Mauro Decandia

CNR Ibimet
Laura Sanna
Enrico Vagnoni
Gian Valeriano Pintus
Pierpaolo Duce

CNR ISPAAM
Antonello Franca

Dipartimento di Agraria UNISS
Alberto S. Atzori

Laore Sardegna
Alberto Manca
Domenico Usai

Coordinated by:

Agris
Agenzia regionale per la ricerca in agricoltura
REGIONE AUTONOMA DELLA SARDEGNA

Acknowledgements

The authors wish to acknowledge Dr. Stefania Fanni of Agris Ricerca for her helpful advice on soil classification. Dr. Sandro Rolesu of Istituto Zooprofilattico Sperimentale della Sardegna is also thanked for providing the vectorial files of geo- referenced data of Sardinia sheep farms.

Executive summary

After an overview of Sardinian climate, soil features and dairy sheep sector, this report describes the methodology to distinguish and discriminate the main dairy sheep production systems in Sardinia. Finally this methodology is implemented on a wide database to characterize the sheep farms within the main production systems and to evaluate the most frequent values of key indicators of farm size, intensification level and performance and their variability within each production system.

Summary

Introduction

Sardinia is a Mediterranean island of about 24,000 km^2 traditionally devoted to livestock production and in particular to dairy sheep raising due to poor land capability which prevents the use of Sardinian soil as agricultural land. This report is aimed to provide an overview of the current status of Sardinian sheep production sector and to characterise the main sheep production systems in Sardinia. This is a pre-requisite for the following action of SheepToShip LIFE: i.e. the selection of representative sheep farms to be analysed in depth for their environmental impact, using the Life Cycle Assessment method.

Keeping in mind this objective, the following chapters are intended to give an overview of the island in terms of climate (Chapter 1) and soil (Chapter 2), to describe the Sardinian sheep dairy sector as a whole (Chapter 3), the methodology adopted to characterize its main dairy sheep production systems (Chapter 4), the application to this protocol to a wide database (Chapter 5) and the preliminary results of characterization process (Chapter 6).

1. The climate of Sardinia

The Sardinia climate is classified as Mediterranean type, group C of the Köppen system. The "Csa" category characterise most of the region, with the "Csb" category just in the inner areas above 800-1000 m of altitude (Secci et al., 2010). It is characterized by contrast between two seasons with relatively mild and rainy winters, hot-dry summers, and sharp transition periods among them (Chessa & Delitala, 1997). This large-scale pattern reflects the position of the island in the middle of Mediterranean Sea, at the boundary between the Tropical zone to the South and the Temperate zone to the North. In this transition area, large inter-seasonal variations on precipitation and temperature occur, due to the oscillation of the arid subtropical cells (the Azores Anticyclone) that migrate to North during the summers and regress toward the South during the winters. This leaves the island exposed to the penetration of the North Atlantic humid air masses (Delitala et al., 2000). At a regional scale, the inhomogeneous orographic distribution and the presence of the sea are the main sources of local climate variability that leads to the existence of several microclimates. Mediterranean types are widespread over 99.1% of the island while Temperate area, with its Sub-Mediterranean category, is confined to the mountain reliefs (Gennargentu, Limbara and Goceano) (Canu et al., 2015).

The aspects characterizing the Sardinian climate are the thermicity (thermal gradient and latitude), the aridity (precipitation regime) and the continentality (elevation and distance inland). The mean annual temperature ranges from 11.6 °C to 18.0 °C, allowing the presence of eight phytoclimatic horizons mainly correlated with altitude (Canu et al., 2015). Its spatial distribution is affected by the orographic structure of the island, distinguishing the plain landscapes (Campidano and Nurra) with the higher values, from the colder mountainous territories. The hottest month is August with extreme values (>45 °C) recorded in the Campidano plain and the coldest is January with low limit <-8 °C on the Gennargentu Massif (Chessa & Delitala, 1997).

Also the average annual temperatures of the maxima (from 16 °C up to 22 °C) follow the same spatial pattern, tracing two periods with steady mean values (July-August and December-February) and two transitional phases (March-April and September-November). During winter the regime of the maxima reveals the dominant effect of the sea, showing also altitudinal and latitudinal gradients (Figure 1). On the other hand, the mean annual temperatures of the minima (from 14 °C along the coast to 7 °C on the mountain zones) result more stable and their values are related to the inland distance with a slightly influence from latitudinal gradient, and to the position of the central-eastern mountain reliefs that dominates the spatial distribution of the days with temperature <0 °C (Chessa & Delitala, 1997).

The field of the minima temperature controls the maximum values of the humidity that reaches saturation (100%) during most of the nights and gives rise to condensation phenomena. Its mean annual minimum values range between 20% up to 75%. The concentration of water vapour is almost uniformly distributed over the island and has continental structure in summer. During the rainy season, the relative humidity decreases from West to East (except over Gennargentu Massif) due to the orographic effect that leaves the eastern coast lee respect to the main air mass fluxes. This last area also records the lower number of rainy days (Chessa & Delitala, 1997).

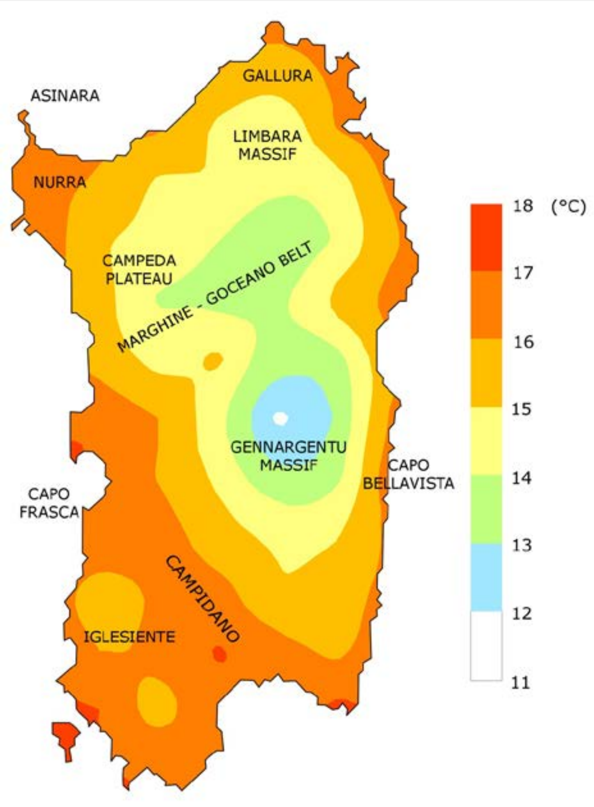

Figure 1. *Distribution of the mean annual temperature over Sardinia (modified from Chessa & Delitala, 1997).*

In Sardinia the total precipitation ranges from 411 mm to more than 1,215 mm in the inner mountain areas (Canu et al., 2015). Its regime is sporadic and particularly irregular, varying greatly from year to year without spatial correlation (Delitala et al., 2000). The seasonal precipitation is linked to large-scale atmospheric circulation structures which connect westward to the North Atlantic Oscillation and northward to the Artic Oscillation (Delitala, 2003). Based on the annual mean values, four different rainfall zones have been distinguished: (1) the area around the Gennargentu Massif, (2) the central part of Gallura, (3) the Campeda plateau and (4) the Iglesiente area. The Nurra and Campidano plains are the driest zones together with a stripe surrounding the Coghinas watershed (Chessa & Delitala, 1997). Among these zones, the highest rainfall fluctuations is recorded on the eastern coast, indicating that the meteorological phenomena that determine the precipitation in this area are different from those that manifest over the rest of the island (Figure 2).

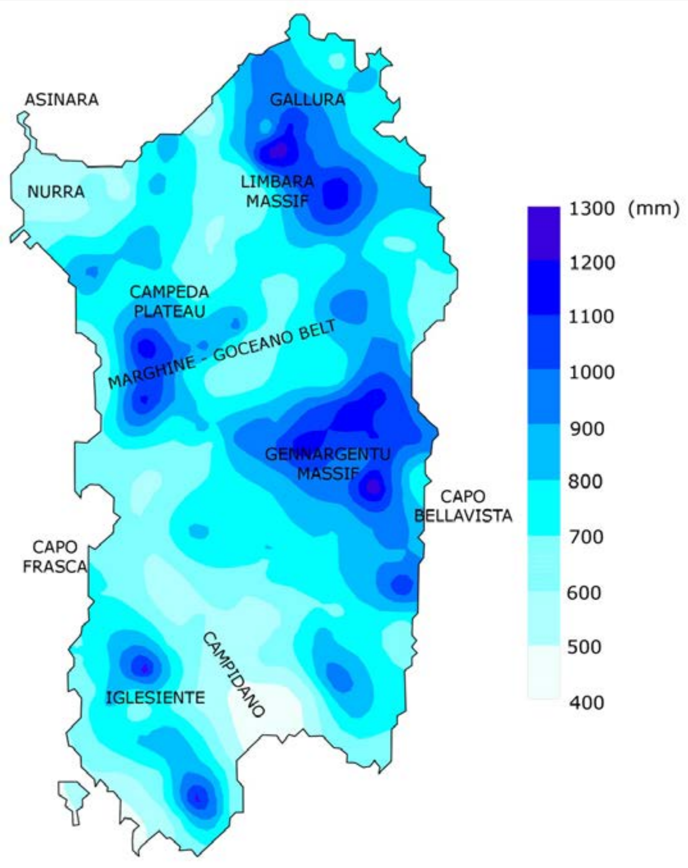

Figure 2. *Distribution of the mean annual precipitation over Sardinia (modified from Chessa & Delitala, 1997).*

In fact, exploring monthly data from 1946 to 1993, Delitala and co-authors (2000) recognised a rainy season from October to April, often related to Alpine cyclogenesis. The maximum cumulate is on December together with other months among the period from November to February. Conversely, during March and October rainfall events, often quite intense, concentrate on the East coast due to hot and moist currents coming from Africa (Bodini & Cossu, 2010). During summers, the occasional precipitations fall on the mountain reliefs. They show a North-South gradient in July and August, the driest mounts, and an East-West gradient in September.

The rainy days are always a small fraction of the year with a maximum rate of 80 days per year on Gennargentu Massif, Campeda plateau and Limbara mountain, that are the zones with the highest cumulate. The main rainy days have low values of mean daily intensity (between 1 and 10 mm), while the intermediate classes (10-25 mm and 25-50 mm) identify the driest areas: Campidano and Nurra plains. The extreme rainfalls (>50 mm) have a West-East gradient with a maximum value along the East coast (Chessa & Delitala, 1997).

The main precipitation fall at high elevations, but there is a clear contrast between rain frequency and intensity. The most frequent rainfalls have low intensity and are homogeneously widespread over the whole Sardinia, whereas the rare high intensity events privilege the East zones. The extreme events (>400 mm) occur in the Central-East and South-East Sardinia with the maximum historical value of 1,400 mm in four days in 1951. Such high intensities have never been documented on the north-western side of the island and do not occur simultaneously (Chessa & Delitala, 1997). Even though in the last decade few intense precipitations were recorded over the island, the relative frequency seems not to have increased the trend (Bodini & Cossu, 2008).

As regard the snowfall, it is an infrequent and irregular phenomenon that occurs just on the high-elevate areas (around Gennargentu Massif, on the Maghine-Goceano Belt and on Limbara Massif) and limited to the winter season, generally during the coldest months (January and February) for short periods (3-5 days) and with a mantle not very thick (a mean 45 cm of snow on top of the mountains).

Due to its orographic structure, another important aspect of Sardinia climate is its air masses circulation. It is very rare a day without wind, especially in winter and sea breezes characterize the region (Furberg et al., 2002). The dominant winds are from West and North-West and blow in the high intensity class reaching >13 m/s of speed at least one out the three days of the year. West and North-West winds are antagonist so the predominance of one direction avoids the prevalence of the other one. Some areas are also exposed to strong winds from East and South-East (Asinara), North-East (Capo Bellavista) and South-East (Capo Frasca) that are more frequent in winter (from 40% to 70%). For the middle-intensity flow dynamics, again West and North-West plus South, South-East and East sector are the most representative winds, whose regime is opposite to that of high intensity, with great frequency in summer. The low-intensity winds have a homogeneous distribution and are influenced by local factors as the inland distance (Chessa & Delitala, 1997).

2. The soils of Sardinia

Sardinian soils result from several cycles of deeply rooted pedogenetic processes of its substrate. The basement of the island is constituted by a sector of the Variscan metamorphic belt as part of the Southern European margin intruded by the granites (about 300 Ma ago) during late Paleozoic. After a period of intense erosion during Permian, Sardinia was part of the carbonate platform of the Tethys during Mesozoic and later affected by Cenozoic volcanism, related to the rotation of the Sardinia-Corse block. The volcanic activity gave rise to trachyte plateaux of Miocene age (30-18 Ma) and Quaternary basaltic flat highland (3-0.2 Ma) whose ridges typical shape the central western belts (Marghine-Planargia Belt) (Vardabasso, 1972). Moreover, fluvial and marine dynamic deposited a variety of continental and marine sediments over the whole island. Hence, Sardinian soils show diverse parental rocks and, according to them, they can be classified as follows (Figure 3):

- (S) Sedimentary soils: they feature most of the lowlands which stretch along the island from North to South with a break around the middle where the Marghine belt and Campeda plateau. They have a rather diverse composition depending on the presence of carbonate which can increase their fertility and pH.
- (I) Soils based on crystalline (intrusive) rocks, i.e. granite and metamorphic rocks. They basically feature all the eastern area of the island stretching again in the direction N-S. It is the basement of the Sardinia-Corse block.
- (E) Soils based on effusive rocks, mainly trachyte and basalt. They characterize the central part of the Island, with spots also in the south-western areas.

Figure 3. *The main source of Sardinian soils (modified from RAS, 2016; http://www.sardegnageoportale.it/).*

These three types of matrix provide specific physical-chemical characteristics to the derived soils, with a trend towards silt-clay texture with neutral-to sub-alkaline pH, particularly if rich of carbonate, and moderate to high fertility for sedimentary sandy textured soils with sub-acidic pH. Soils derived from granite or metamorphic rocks show moderate to poor fertility , while soils derived effusive matrix are usually with moderate fertility with loam texture and pH from sub-acidic to sub-alkaline (Aru et al., 1991). In this report, we refer to sedimentary, crystalline and effusive soils, respectively.

From a pedological point of view, a more detailed large scale classification has been suggested by a recent update Italian soils map (Costantini et al., 2012).

It groups Sardinian soils in four classes:

- Soils of the Southern alluvial plain of Campidano and Sulcis (SW) areas, characterized by soils with clay accumulation, , shallow water table and salt accumulation.
- Soils of hills zone on basic basalt and trachyte rocks. These soils cover an area approximately perpendicular to the main axis of the island and covers the hills and mountains surrounding Macomer (Marghine) towards the North plain (Nurra). They are often shallow but can be moderately fertile and contain relevant level of organic matter.

- Soils of the mountains and hills of Sardinia, on acid crystalline rocks which are often shallow soils with a weakly differentiated profile. They are often of poor fertility with high erosion risk due to slope, and often featured by stoniness and rockiness.
- Soils of mountains and hills of Sardinia based on metamorphic rocks. These soils are usually shallow and acidic.

Although this classification is probably more accurate, the land capability is not well discriminated: for instance the soils of southern and northern lowland or moderately sloped hills often falls in the same land capability classes (classes 2 and 4).

The simplified 3-class clustering of Sardinian soils has been proven sufficiently adequate to explain the variation occurring of natural vegetation between macro-areas (e.g. CORINE land cover map, http://www.sinanet.isprambiente.it). At a landscape-scale classification the project Lacope aimed at mapping the main Large Scale Grazing Systems (LSGS) in Europe (Caballero et al., 2009) the three main soil classes have been used. In this study, overlapping RAS (2017b) map to the distribution of the main livestock production systems in Sardinia four main LSGS were marked, which basically overlap the three soil classes with exception of Gennargentu Massif, which was distinguished from the remaining granite-metamorphic area only due to the presence of vast common land areas and a mixed grazing system including goats, cattle, and pigs, with a scattered modest presence of sheep.

Said that, it is noteworthy that soils of Sardinia, particularly those of the class I of land capability are prone to erosion being about 11.3% of Sardinia area deemed at risk of erosion (INEA, 2010). The content of C in the soil on average low (1.68%) but it is particularly low in the lowland arable soils submitted to frequent tillage (1.28%) (PSR Sardinia 2014-2020).

Climate changes will tend to exacerbate this phenomenon with a probable trend towards loss of soils, loss of soil biodiversity and fertility and at last desertification. About 46% of Sardinian land is at risk of desertification and almost 40% is regarded as fragile (PSR, Sardinia 2014-2020). This means that factors impinging on the dynamic of pedogenesis, such as intensive cultivation or abandonment (no cultivation and no grazing) can have catastrophic effects on these eco-systems. Another expected effect of climate change is soil salinization: it is already a problem in some areas of Sardinia due to the intrusion of sea water into water-tables adjacent to the coastline (INEA, 2010; Puddu et al., 2008). All these aspects are of course to be taken into consideration when envisaging adaptation and mitigation strategies against climate change.

3. Overview of sheep production sector in Sardinia

Sheep production has become the basis of rural economy in Sardinia since the second half of XIX century when the first cheese factories were settled by companies based in the Latium region of Italy, starting out the production of what is still the main sheep dairy product in Sardinia and Italy: the Pecorino Romano PDO (Protected Designation of Origin, European quality label) cheese. Since then, sheep production has undergone a manifold development with a dramatic raise of milk yield per ewe and per farm, an improvement of milk quality and animal welfare, an upgrading of cheese plant technologies and cheese marketing. However, there are still facets of the system, which remain tightly bound to the ancient *savoire faire (“su connottu” in Sardinian language)* of about two centuries ago. In particular, sheep nutrition is still based on grazing (natural pasture and cultivated forages) and the main dairy product (hard mature cheese) is still Pecorino Romano PDO cheese.

Nowadays dairy sheep production in Sardinia is widespread on all the regional area with a collection and processing of milk so developed and organized that can be considered as the most dynamic sector of Sardinia agriculture, accounting for about 25% of total agriculture income of Sardinia. With some 3 million sheep, 44% of national sheep stock (ISTAT, 2010) and about 3.5% of the EU total sheep stock (EUROSTAT, 2012) and a milk production of about 260,000 t year^{-1} (ISTAT, 2010), Sardinia is the top ranking EU region for sheep milk production, representing more than 12% of the total European production (EUROSTAT, 2012). The average flock size is 239 heads (Table 1).

Table 1. *Inventory of dairy sheep farms in Sardinia and Italy (ISTAT, 2010).*

	Sardinia (total)	**Sardinia** (% of Italy)	**Italy**
Total sheep farms (n.)	12,669	24.8	51,096
Total sheep (n. heads)	3,028,373	44.7	6,782,179
Average flock size (n. heads)	239		133
Total sheep milk** (t)	260,779	65.6	397,509

**Milk collected by cheese factories in year 2015 (ISTAT, 2016).

Total number of sheep and sheep farms vary annually with some relevant discrepancy among sources (National Database of Farm Animals, 2016; ISTAT, 2010). According to the National Database Farm Animals (year 2016) the geo-referenced farms are 12,058, partitioned in flock size classes as shown in Table 2.

Table 2. *Distribution of sheep farms on the basis of flock size (N. sheep heads/farm).*

Flock size class	N. sheep farms	% Tot. sheep farms	n. sheep heads	% Tot. sheep heads	Average flock size n. heads/farm
< 100	3,455	28.65	148,119	4.88	43
100-300	4,982	41.32	976,736	32.16	196
300-500	2,245	18.62	860,538	28.34	383
500-700	778	6.45	455,775	15.01	586
> 700	598	4.96	595,598	19.61	996
Total/Average	12,058		3,036,766		252

This table shows the wide variability of flock size. Interestingly, although only about 30% of farms have a flock size bigger than 300 sheep heads/farms, they include more than 60% of the total geo-referenced sheep stock. If we consider only the two top size classes (size bigger than 500 heads) they represent 15% of farms but 30% of total sheep stock.

Most of farms are managed directly by the land owners or their families (73.3%). The average farm size is 30.4 ha with huge variability within the region (ISTAT, 2010). In the last decades there has been a marked decrease in farm number and a consequent increase of farm size and number of heads per farm. Therefore the number of sheep per farm has been boosted from 121 heads in 1982 to 239 heads in 2015 (ISTAT 2015) and 252 heads in 2016 (National Database of Farms Animal, 2016) (Table 2).

Organic farms amount to 786 farms in 2010, in 65% of which dairy sheep are raised (208,000 heads) (ISTAT, 2010). These farms are located mainly in the inner areas of Nuoro province (46% of farms and heads) and based on natural pastures (101,000 ha as total of all Sardinian organic farms).

The whole milk production is processed into cheese factories (industries, cooperatives and mini-dairies). The number of cheese plants is estimated to be 71 in 2015, not including the mini-dairies (ISTAT, 2011). According to data by ISTAT (ISTAT, 2016) the total number of dairies is set to 111. The main products are the three PDO cheeses: "Pecorino Romano", "Pecorino Sardo" and "Fiore Sardo" (Table 3). "Pecorino Romano PDO" is one of the main Italian PDO products (ISMEA, 2012) and 95% of its production derives from Sardinian cheese factories (Idda et al., 2010).

Table 3. *PDO cheese production (t/year) (CLAL, 2016).*

Cheese type	2008	2009	2010	2011	2012	2013	2014	2015
Pecorino Romano[1]	29,461	26,746	27,477	25,335	25,099	24,778	24,117	30,167
Pecorino Sardo	196	186	1,935	1,989	2,031	1,783	1,720	1,414
Fiore Sardo	650	712	800	752	735	515	515	550
Totale	30,307	27,644	30,212	28,076	27,865	27,076	26,352	32,131

[1] About 95% of Pecorino Romano is produced in Sardinia.

Data on other types of dairy products are not validated. Total amount of PDO cheeses is approximately 55-60% of total dairy product production in Sardinia, which totalized approximately 55,000 t in 2015 (our estimate).

Meat (suckling lambs and culled sheep) represent around 20% of sheep farm total income. In 2010, 1,100,371 lambs were produced with an average live weight around 10 kg. Total meat production was 8,341 t, whereas lamb meat was 6,472 t. The greasy wool production is estimated around 1.5 kg/adult sheep corresponding to a total amount of about 3,470 t per year in 2015 (ISTAT 2016). The cost of shearing, usually made by professional shearers (around 1.2-1.7€ /adult head) is more than the corresponding income (around 0.6-1€/adult head).

The dairy sheep farming system in Sardinia is mainly grassland-based with a wide range of levels of input utilization and land uses. In fact, Sardinia is the Italian region with the highest share of land devoted to permanent grassland (Figure 4, ISTAT 2014).

In the last decade, there has been a decreasing trend of the area covered by permanent grassland basically due to the abandonment of utmost marginal areas, with bush encroachment or the replacement of permanent pastures with cultivated forages, which cover an area of about 230,000 ha, including double purpose cereals (oat, barley and triticale) (ISTAT 2010).

Conserved forages and concentrates are fed as supplements, particularly during late pregnancy-lactation period. The total amount annually offered varies among farms. According to a survey carried out in three consecutive years (2002-2004) in 40 farms, it averages around 70 kg of hay and 100 kg of concentrate per ewe per year (LEGGRAZE, data not published).

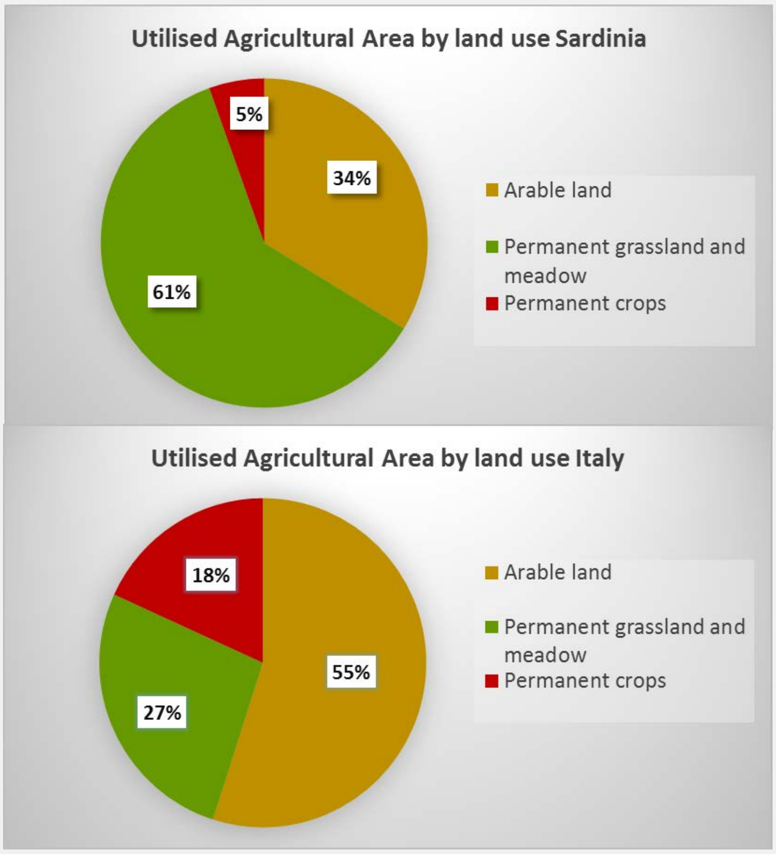

Figure 4. *Land use in Sardinia and Italy as % of utilised agricultural area (ISTAT, 2014).*

Economic data on dairy sheep farms are scanty. In a sample of 190 sheep farms (84,374 heads) the total income and gross margin per livestock standard unit (LSU) has been estimated as shown in Table 4.

Table 4. *Economic results of a sample of sheep farm (€/LSU per year) (INEA, 2013).*

Total income (€/LSU[1])		Gross margin (€/LSU[1])	
Sardinia	Italy	Sardinia	Italy
1,158	1,078	639	621

[1] Livestock standard unit: 1 LSU is equivalent to 10 adult sheep heads.

Although gross margin is positive, around 64 €/ewe per year, net margin can be negative as suggested by our analyses of survey data by Idda et al. (2010) in which average net margin was estimated to be 25 €/ewe, with almost 20% of farms displaying negative net margin values (G. Molle, unpublished data).

Fast variations of economic returns from dairy sheep farms are common. In fact, Sardinian sheep production sector have traditionally suffered for cyclic severe drops of revenue, in the past related to cyclic variations of the exchange ratio between US $ and Italian liras (Savona, 1983) now much more related to the cyclic increase of cheese offer following years of high milk price. In the last two years, after a peak of milk price up to 1.0-1.1 €/l of milk, there has been a marked increase (about. +50%) of milk and cheese production (particularly Pecorino Romano PDO) which in turn brought about a dramatic flop of milk price down to the current level (0.6-0.7 €/l of milk). Several internal (national and regional) factors exacerbate the negative impact of these ”swinging market conditions”, such as the high cost of energy (fuel), purchased forages (hay) and concentrates. Therefore, Sardinian sheep farms are currently realizing low or negative profit margins with dramatic consequences on Sardinian economy (Furesi et al., 2013). As a matter of fact, the economic sustainability of Sardinian sheep farms is nowadays based on the aids of Common Agricultural Policy payments, which account for more than 20% of sheep farm gross income (Idda et al., 2010).

4. Characterization of the of dairy sheep production system: A. methodology

The Sardinian sheep farms have a various degree of farming system intensification depending on the geographical location of farms, which affects key traits such as land capability (Caballero et al., 2009; Porqueddu, 2008). Land capability of soils ranging from class 2 to 8 and annual rainfall ranging between about 400 up to more than 800 mm make dairy sheep farms in Sardinia rather heterogeneous. The availability of water for irrigation at low cost is another key factor which impinges on the production system intensification level.

From the beginning of *the green revolution* of early sixties up to the end of eighties, a process of sedentarization of sheep flocks and intensification of sheep production has been accomplished. During that period, thanks to urban market expansion, decrease of land renting fees, and favourable milk price trend, sheep farms have become increasingly able to base sheep flock nutrition on farm resources (cultivated pastures and conserved forages) with an increasing proportion of the farm land owned by the farmer and a decreasing use of rented land. Other factors in favour of sheep flock sedentarization were: the availability and the ease of transport and delivery at farm gate of concentrate and conserved hays produced elsewhere, sometimes in remote locations (Paoli, 1997).

At the end of this sedentarization and intensification process, a bipolar system emerged with big extensive to semi-extensive farms, with moderate to low stocking rate, concentrated in the areas characterised by low land capability (usually on hills and mountains) and small semi-intensive to intensive farms, with high stocking rates, prevailing in areas where most of land was arable and possibly irrigated. Interestingly, due to this bipolar trend and its consequence; the trade-off of land with labour and capital investments, the economic return of sheep farms belonging to these systems has tended to converge (Natale et al., 1999).

Nowadays the picture of sheep sector has become more complex due to the superimposed growing impact of EU legislation, which has supported in a biased way some of the systems while penalizing others.

Therefore, we can now grossly classify the production systems as follows (Porqueddu, 2008):

1. Sylvo-pastoral systems, which are typical of mountain areas. They are based on the combination of herbaceous and ligneous feed resources. These are very rarely implemented with sheep only but often are devoted to goats or used farms raising on common land sheep, goats cattle and pigs.
2. Agro-pastoral systems in the hilly areas with moderate slopes in which a small part of farm land (<30%) is cultivated to grow annual forages as buffer crops (‘erbai’);

3. Cereal-based dairy sheep systems in the lowlands with higher land capability. In these systems, usually located in the rainfed lowlands or in moderate sloping hills most of land farm is cultivated. Other crops can be also used to rotate cereals such as grain legumes or forage legumes for grazing and haymaking purposes.
4. Intensive irrigated systems where forage production includes irrigated legumes such as lucerne and summer C4 forage crops (Sorghum spp. and maize for grain or silage). In these systems the use of total or partial complete diet feeding technique is frequent.

Within these four classes, other strata can be identified using criteria such as: farm total area, arable land area, flock size; agricultural mechanization level; feed self-sufficiency; organic vs. conventional farming. Socio-cultural factors (for instance the age of farmer) can also play a role and are often superimposed to bio-physic factors, impinging on structure and performance of the farm within each system class.

Although this *conceptual* classification, based on historical and bio-physic survey data is well rooted, a *statistical-based* classification could be also envisaged. This can be implemented, for example, running a principal component analysis and a cluster analysis of a well-designed and consolidated database. For instance, this statistical procedure was successfully used by Usai et al., (2006) to cluster a representative sample of goat farms in Sardinia and identify the variates, which contributed more to cluster separation.

However, this approach has some shortcomings such as in many cases it gives raise to spurious classes, difficult to be explained on the basis of physical, biological or technical criteria because they just group *border-line* cases falling between two or more main clusters. Moreover, this approach can give biased classification response, if based on data gathered in a particular year in which management and performance are odd due for example to extraordinary meteorological events .

In contrast, a clustering based on land capability and climate (biophysic criteria) can be useful in order to assess the *relative carbon footprint* of a farm at system class scale. In fact, this relative index can be a useful criterion to identify within the same background conditions (i.e. within the same system class): i) the top and bottom carbon-friendly farms; ii) the best and worst practice within a limited range of possible practices (equal opportunity conditions).

Therefore the approach proposed hereunder is based on the preliminary characterization of sheep production systems featured by contrasting pedologic and climate conditions based on an *ex-post* analysis of available data on farm structure and farm input and output.

A similar procedure was used in the EU "LEGGRAZE" project in Sardinia in early twenties. This project was aimed at evaluating the role of legume forages in Sardinian dairy sheep farming. A survey was run on 40 sheep farms located in 5 zones with different average rainfall (high, North Sardinia; low South Sardinia) and soil parental rocks (granite/metamorphic, effusive (only with high rainfall) and alluvial) in 3 consecutive years (2002-2005). This study results overall suggested that:

- Sheep systems in different pedo-climatic zones have different land use, use different forages, differentiate well each other for the level of supplementation and sheep milk performance;
- some territories within the Island are particularly suitable to produce milk and hence cheese rich of nutracines, such as conjugated linoleic acid (CLA) and poly-unsaturated fatty acids FA (Addis et al., 2007).

5. Characterization of dairy sheep production system: B. Application

In this chapter the application of the procedure of characterization of sheep farms implemented in LEGGRAZE survey is run using an updated database regarding around 12,000 dairy sheep farms. Moreover, since nowadays GIS is the most potent available tool for mapping and analyzing geo-referenced data, the use of this tool has been introduced and applied to the National Database of farms.

The detailed process of characterization of sheep farms as implemented in this report is detailed in Figure 5. It is a step-by-step process.

In step 1, the database on the geo-located sheep farms of Sardinia was exported from the National Database of Farm Animals (2016) as a vectorial file, manageable by GIS. These data were then inserted on a Sardinian map and validated to screen out farms with no sheep and farms with clearly wrong GPS coordinates. The layer of geo-located farms was then overlapped by GIS to the soil map to assess the parental rock type for each farm. This information was integrated with data on altitude and basic climate features. At the end of step one, the data on geo-located 12,056 sheep farms were validated.

In step 2, three soil classes and two climatic regions (North and South) were discriminated as described in Chapter 3, then farms were assigned to these pools. Descriptive statistics were run to characterize each pool. In particular, the farm size was classified into five classes in terms of sheep heads (<100 heads; 100-300 heads; 300-500 heads; 500-700 heads; >700 heads).The pools were then characterized for farm distribution among these classes.

In step 3, a subsample of farms (sub-pools) was extracted from each pool, identifying on Sardinian GIS map areas featured by high concentration of sheep farms, presumably representing the most of sheep milk production within the pool area. These areas were: Nurra and Ozieri lowlands (SN), Campidano (SS) with sedimentary soils but featured by different climatic features (approximately 50-100 more annual rainfall in SN than SS); Marghine Belt (EC) featured by effusive soils in the Central western hilly area and Nuorese (IC), featured by crystalline soils in the Central eastern mountainous area (Gennargentu Massif). Descriptive statistics were then run to characterize each sub-pool as previously described for the pools.

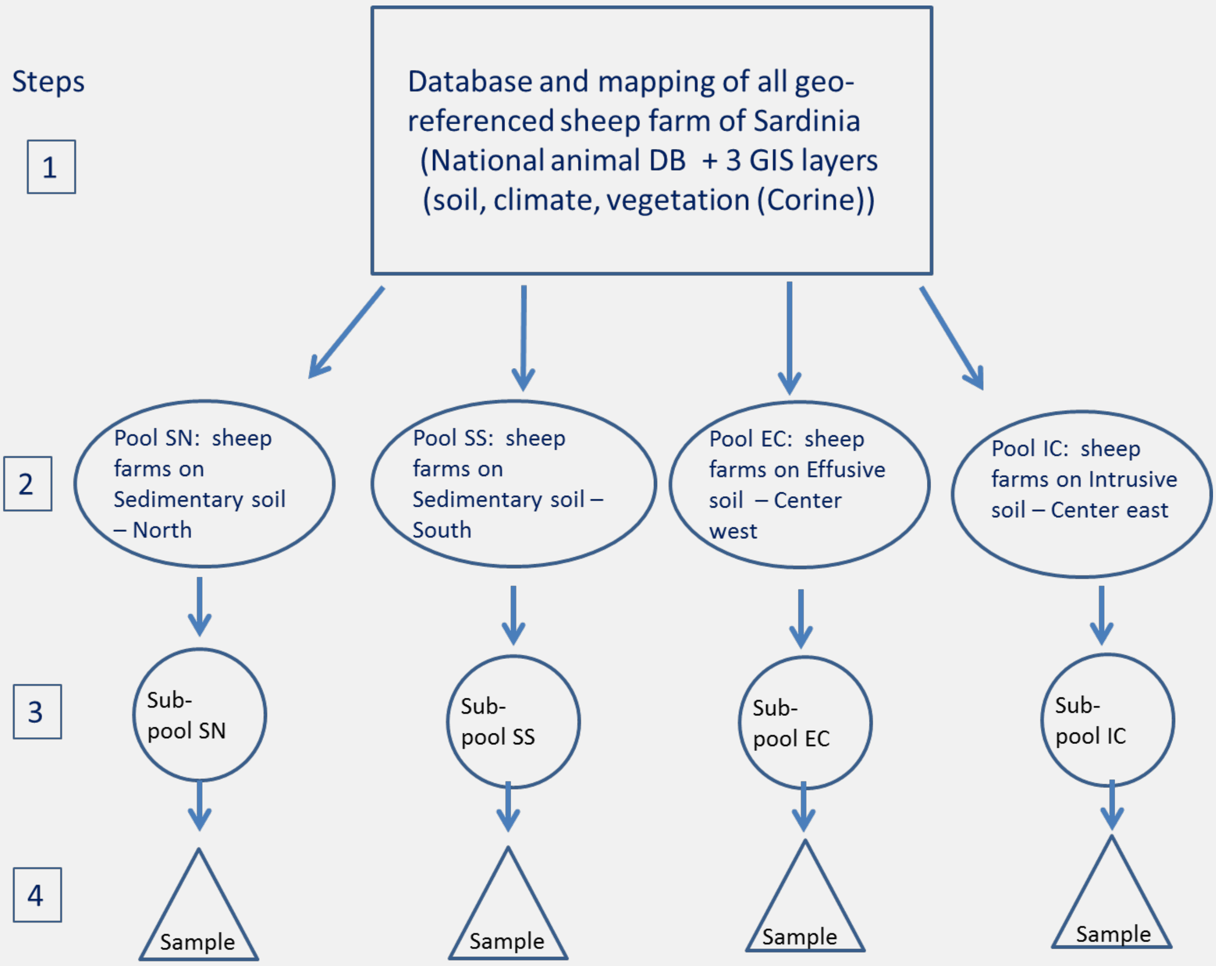

Figure 5. *The sheep farm step-by-step characterization and sampling process. (SN: Nurra and Ozieri lowlands; SS: Campidano; EC: Marghine belt; IC: Nuorese mountains).*

In step 4 (not done yet) a smaller sample of representative farms (final sample) will be extracted from each sub-pool. Although they will be featured by a similar biophysics background, they will be chosen in order to explore a range of farm indicators such as stocking rate, production level and feed self-sufficiency. This will help the detection of the hotspots and the tailoring of feasible mitigation-adaptation strategies. The farms to be surveyed for LCA analysis will be selected within this final sample,.

6. Characterization of dairy sheep production system: C. Results

Figure 6 shows the map of Sardinian soil classes with indication of sheep farms whose location was validated (step 1).

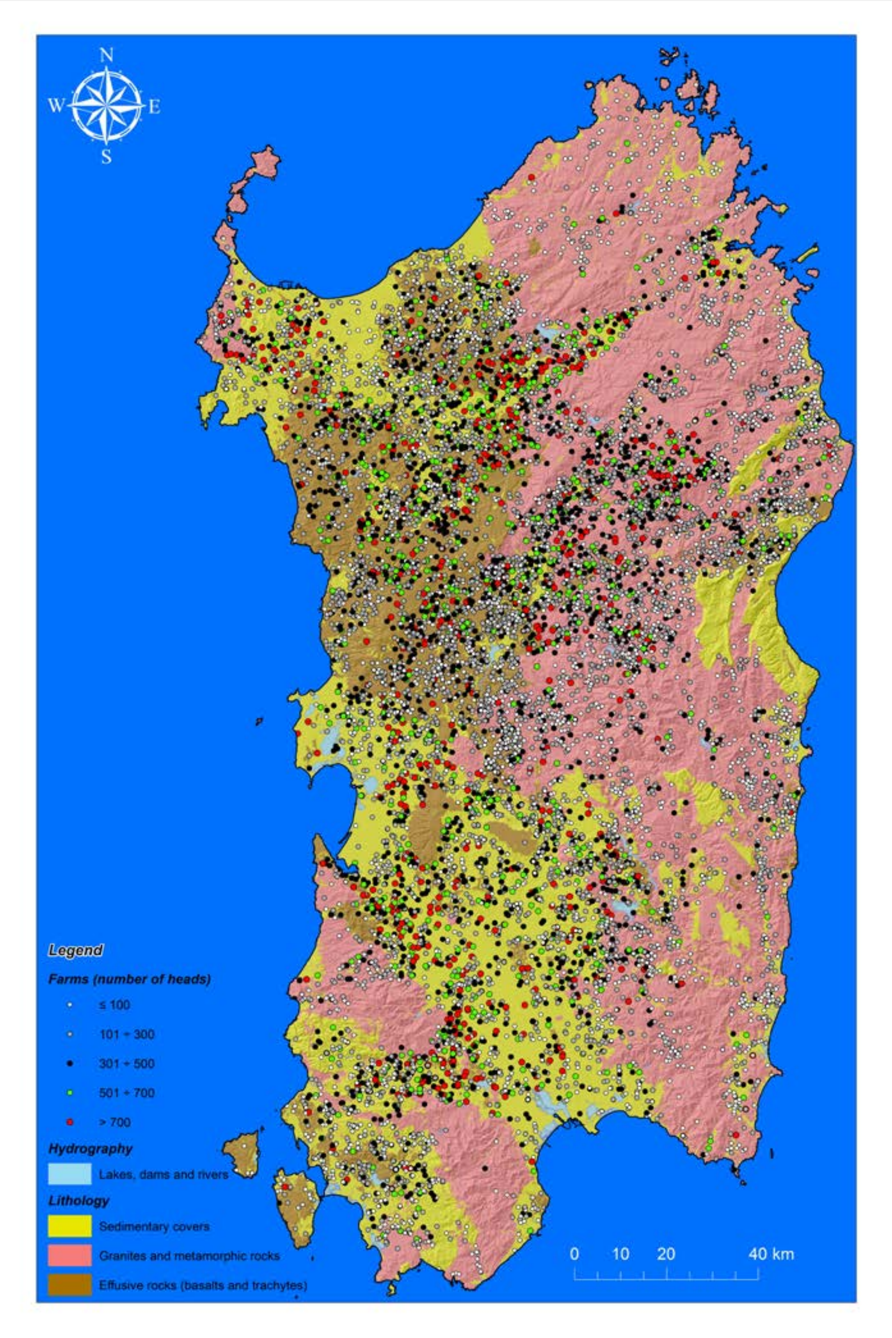

Figure 6. *Maps of Sardinian soils and sheep farms distribution classified on the basis of head number per farm (geographic map modified from RAS, 2016; http://www.sardegnageoportale.it).*

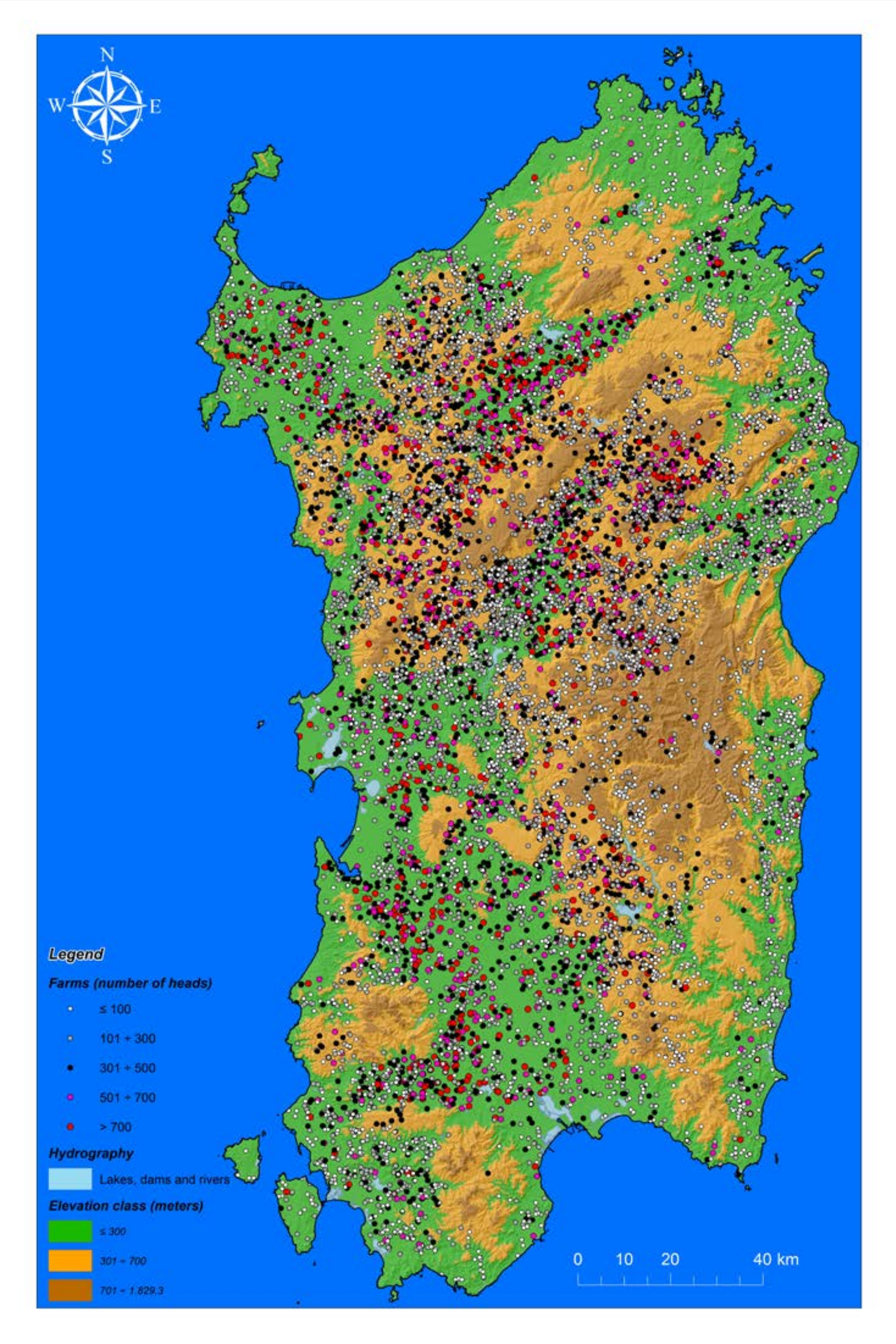

Figure 7. *Geographic map of Sardinia and sheep farms distribution classified on the basis of head number per farm (modified from RAS, 2017a; http://www.sardegnageoportale.it) (ISTAT, 2017).*

It is evident that sheep farms are spread over all the island, although with a lower apparent frequency on the granite-metamorphic soil area, where are located the highest mountains (Figure 7).

Results of the descriptive statistics of the four identified pools (step 2) are summarised in the following tables (5 to 8). Overall the four pools are constituted by about 82% of Sardinian geo-located sheep farms and about 83% of sheep stock.

Pools representing farms settled on sedimentary soils include 16% of farms with a stock bigger than 500 sheep (Tables 5 and 6). In these two pools, the overall share of sheep raised in these farms amount to 39% in Northern farms and 44% in Southern farms. Average number of sheep per farm, is also slightly higher in the Southern sedimentary pool. The size of the farm in terms of sheep stock tends to increase along with the decrease of the altitude, particularly in the South sedimentary pool. This can be explained with a higher frequency of these farms in the lowlands.

Table 5. *Inventory of dairy sheep farms in an area of North Sardinia characterized by a soil of sedimentary parent rocks.*

Farms with flock size of	N° Farms Total	%	N° Heads Total	%	Average farm heard size	Average elevation
< 100	339	26	13,632	4	40	222
100-300	529	41	106,097	31	201	258
300-500	238	19	91,290	26	384	259
500-700	101	8	59,332	17	587	236
> 700	75	6	76,034	22	1,014	177
Total	1,282		346,385		270	242

Table 6. *Inventory of dairy sheep farms in an area of South Sardinia characterized by a soil of sedimentary parent rocks.*

Farms with flock size of	N° Farms Total	%	N° Heads Total	%	Average farm heard size	Average elevation
< 100	464	26	19,902	4	43	214
100-300	679	38	130,345	26	192	208
300-500	361	20	137,463	27	381	171
500-700	135	8	79,111	16	586	161
> 700	134	8	140,664	28	1,050	141
Total	1,773		507,485		286	193

In the central part of the Island, where hills and mountain prevail, the proportion of farms with stock higher than 500 decreases, being only 10% (corresponding to 32% of sheep stock) of the farms settled on crystalline soil (Table 7) and 12% (32% of sheep stock) in those on a effusive soil (Table 8).

In these pools of farms, the main stock class is 100-300 with an average sheep number per farm of 229 and 267 on the granite-metamorphic and trachyte-basalt pools, respectively.

As expected, in general, altimetry is higher in these pools, with a numeric higher values in the farms settled on crystalline soils.

It is worth noting that in the granite-metamorphic pool there is an opposite trend to what seen in the lowland, with bigger farms on the highest altitude levels. This is not confirmed in the trachyte –basalt pool.

Table 7. *Inventory of dairy sheep farms in an area of Central Sardinia characterized by a soil of intrusive (granite) and metamorphic parent rocks.*

Farms with	N° Farms		N° Heads		Average farm	Average
flock size of	Total	%	Total	%	heard size	elevation
< 100	1,323	33.1	55,045	6.0	42	394
100-300	1,633	40.8	317,557	34.7	194	454
300-500	661	16.5	252,888	27.6	383	478
500-700	232	5.8	135,819	14.8	585	478
> 700	154	3.8	153,408	16.8	996	508
Total	4,003		914,717		229	442

Table 8. *Inventory of dairy sheep farms in an area of Central Sardinia characterized by a soil of effusive (mainly trachyte and basalt) parent rocks.*

Farms with	N° Farms		N° Heads		Average farm	Average
flock size of	Total	%	Total	%	flock size	elevation
< 100	631	22.3	30,005	4.0	48	320
100-300	1,255	44.3	248,651	32.8	198	343
300-500	611	21.6	234,241	30.9	383	360
500-700	194	6.8	113,317	14.9	584	368
> 700	144	5.1	132,107	17.4	917	353
Total	2,835		758,321		267	344

Results on step 3 refer to areas (sub-pools) sketched in Figure 8.

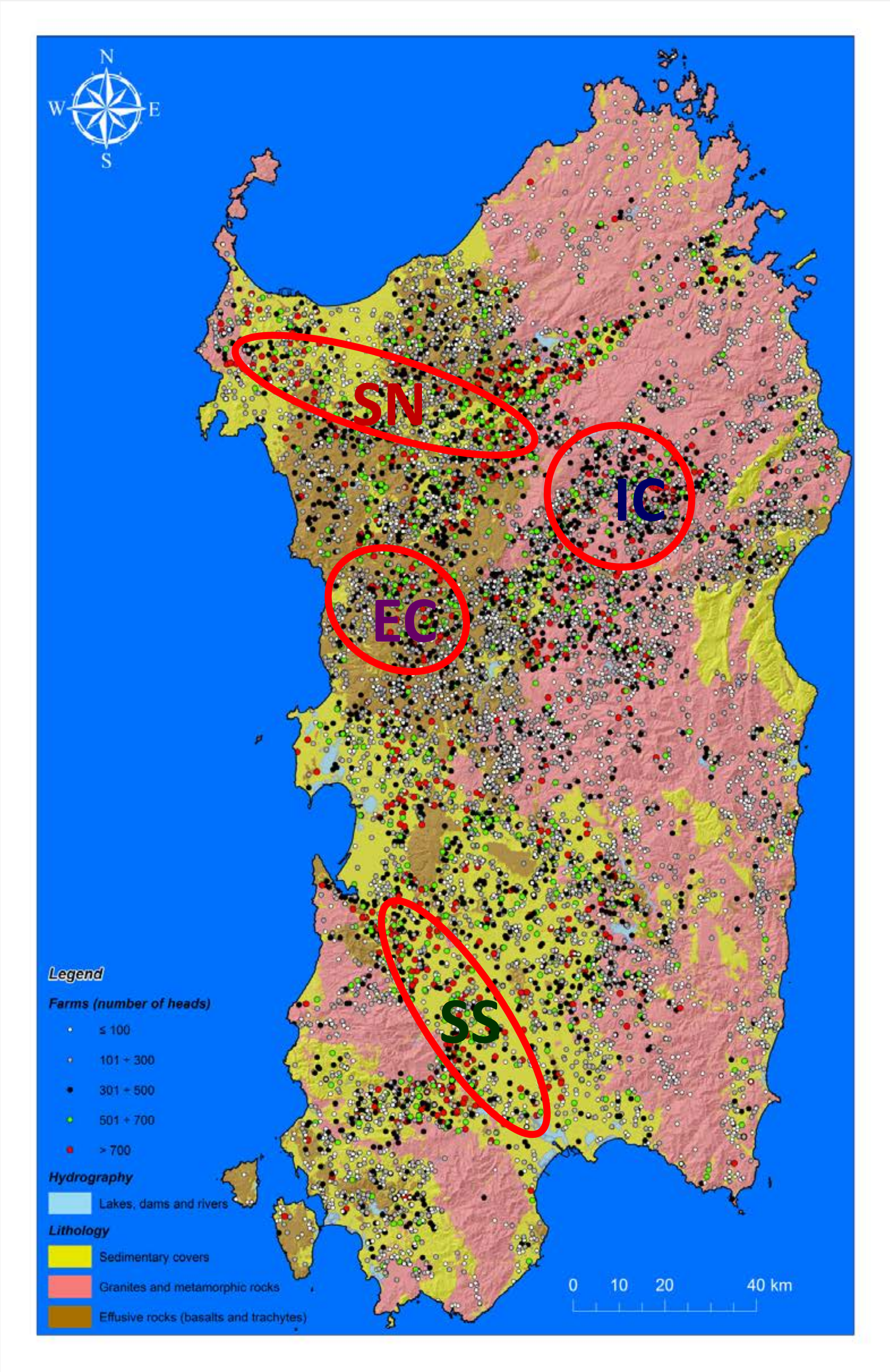

Figure 8. *The sub-pools of sheep farms with homogeneous soil classes. SN is the "Nurra and Ozieri plain" sub-pool based on sedimentary soils; EC is the "Marghine Belt" sub-pool based on effusive soils; IC is the "Nuorese" sub-pool based on crystalline soils and SS is the "Campidano" sub-pool based on sedimentary soils (geographic map modified from RAS, 2026; http://www.sardegnageoportale.it/).*

Descriptive analysis are summarized in tables 9 to 13.

The data in table 9 refer to the RAS (2017b) classification of soil use in the sub-pool areas above described hereunder briefly termed as Nurra (SN: Nurra and Ozieri lowland), Campidano (SS), Nuorese (IC) and Margine (EC). Overall, the sub-pool areas represent about 11% of Sardinia area.

The RAS (2017b) vegetation map layer shows that the sub-pool areas featured by the sedimentary soils, as expected, are characterised by a high share of crops in irrigated arable land, which is the main class in both Nurra (SN, 49%) and Campidano (SS, 75%). Including the non-irrigated crops, SN reaches 66% whereas SS 89% of total area.

Crop share decreases abruptly in the other two farm sub-pools being only 17% in the granite-metamorphic sub-soil area (IC) and reaching an intermediate value in the sub-pool based on trachyte-basalt subsoil area (EC). In these sub-pools the main classes are respectively the broad leaved forest (35.95%, mainly cork oak forests) in the IC sub-pool and natural grassland (20.60%) in EC. In both sub-pools, *maquis* and *garrigues* totalize c.a. 10% of the land share. Woodland based on cork and bushland are often grazed in the mountain areas in Sardinia as well as in other Mediterranean areas. In Sardinia the grassland scattered with cork trees is named “Pascolo arborato” or “Meriagos” (Puxeddu, Pintus and Pulina, 2008). This ecosystem is similar to the Spanish “Dehesa” or the Portuguese “Montado”.

Table 9. Land cover characterization of dairy sheep farms located in areas of Sardinia with different soil parent rocks (ha).

RAS code and description of land cover (2017b)	Nurra and Ozieri lowlands (SN)		Campidano (SS)		Nuorese (IC)		Marghine (EC)	
	(ha)	**%**	**(ha)**	**%**	**(ha)**	**%**	**(ha)**	**%**
2111 – Crops in non-irrigated arable land	8,364.65	9.51	7,012.34	11.35	3,767.60	6.13	5,750.13	11.17
2112 – Forage crops in non-irrigated arable land	6,552.96	7.45	1,914.99	3.10	3,975.32	6.46	6,859.44	13.33
2121 – Crops in irrigated arable land and open field vegetable gardens	43,070.95	48.95	46,103.66	74.65	2,769.48	4.50	5,072.53	9.86
231 – Permanent pastures							5,737.62	11.15
3111 - Broad-leaved forest	5,985.10	6.80	357.11	0.58	22,108.29	35.95	4,949.13	9.62
31121 – Eucaliptus, poplar, willow	154.32	0.18	1,220.56	1.98	0.04	0.00	4.30	0.01
31122 – Cork-oak forests	3,583.71	4.07	60.67	0.10	10,393.60	16.90	4,124.16	8.01
31124 – Other broad-leaved forest plants					10.92	0.02		
3121 - Coniferous forest	154.40	0.18	14.22	0.02	545.71	0.89	49.32	0.10
313 - Mixed forest	128.81	0.15			245.08	0.40	56.81	0.11
321 - Natural grassland	6,146.97	6.99	1,360.84	2.2	3,208.82	5.22	10,601.20	20.60
3221 – Heathlands and moorlands	357.29	0.41			184.81	0.30	53.10	0.10
3222 – Riparian shrubland	271.88	0.31	200.04	0.32	32.51	0.05	9.77	0.02
3231 - *Maquis*	9,603.25	10.91	1,776.33	2.88	4,614.28	7.50	3,118.50	6.06
3232 - *Garrigue*	1,870.53	2.13	1,384.25	2.24	5,887.25	9.57	2,200.31	4.28
3241 – Young stands after cutting (and/or clear cuts)	1,706.11	1.94	120.53	0.20	653.06	1.06	2,706.47	5.26
3242 – Natural young stands	36.39	0.04	231.96	0.38	3,107.81	5.05	168.56	0.33
Total	**87,987.31**		**61,757.4**		**61,504.5**		**51,461.3**	

In the following tables the distribution of farms and sheep by stock classes is shown with reference to Nurra (SN, Table 10) and Campidano (SS, Table 11). In these sub-pools the proportion of farms with a size bigger than 500 sheep and the corresponding head number tends to be higher than in the source pools. This is because sub-pools were selected in order to represent most of milk production in each pool area. In both these sub-pools almost 50% of sheep are raised in big farms (> 500 sheep per farm).

Table 10. *Inventory of a sample of dairy sheep farms in an area of North Sardinia (Nurra and Ozieri lowland) characterized by sedimentary soil (SN-sub-pool).*

Farms with flock	**N° Farms**		**N° Heads**		**Average farm**
size of	**Total**	**%**	**Total**	**%**	**heard size**
<100	106	25	3,892	3	37
100-300	157	379	30,977	23	197
300-500	87	20	33,789	26	388
500-700	34	8	20,302	15	597
>700	41	10	42,624	32	1040
Total	425		131,584		310

Table 11. *Inventory of a sample of dairy sheep farms in an area of South Sardinia (Campidano) characterized by sedimentary soil (SS sub-pool).*

Farms with flock	**N° Farms**		**N° Heads**		**Average farm**
size of	**Total**	**%**	**Total**	**%**	**heard size**
< 100	69	20	2,846	2	41
100-300	123	36	24,861	22	202
300-500	82	24	31,107	27	379
500-700	38	11	22,635	20	596
> 700	32	9	33,237	29	1,039
Total	344		114,686		333

Also the sub-pools located in the hilly areas include a higher share of big farms than the parental pools, although in this case the proportion of big farms was only 13% (29% of sheep) in the Nuorese (IC, Table 12) and 19% (41% of sheep) in the Marghine sub-pool (EC, Table 13).

Table 12. *Inventory of a sample of dairy sheep farms in an area of Central Eastern Sardinia (Nuorese) characterized by crystalline soils.*

Farms with flock size of	N° Farms Total	%	N° Heads Total	%	Average farm heard size
< 100	62	12.4	3,318	2.3	54
100-300	258	51.6	53,712	37.2	208
300-500	119	23.8	45,661	31.6	384
500-700	43	8.6	25,668	17.8	597
> 700	18	3.6	16,029	11.1	891
Total	500		144,388		289

Table 13. Inventory of a sample of dairy sheep farms in an area of Central Western Sardinia (Marghine) characterized by effusive soils (mainly trachyte and basalt).

Farms with flock size of	N° Farms Total	%	N° Heads Total	%	Average farm heard size
<100	52	12.8	2,698	2.0	52
100-300	164	40.5	35,519	25.7	217
300-500	111	27.4	43,009	31.2	387
500-700	48	11,9	27,887	20.2	581
>700	30	7.4	28,926	21.0	964
Total	405		138,039		341

Interestingly, sub-pool farms located on the effusive soils were characterised also by a numerical higher average sheep stock number per farm.

The last step (Step 4, Figure 5) of the selection process has been the identification of a sample of farms within each sub-pools to be surveyed for LCA. This step was implemented as follows:

- a wide database the Regional Breeder Association (ARAS) containing information on farm basic features, inclusive of farm and flock size, feed budget, and forage crops investments was screened in order to identify candidate dairy sheep farms falling in the sub-pool areas (Figure 9);
- candidate farms were selected on the basis of two criteria expected to impact on their carbon footprint: they were: flock size (number of sheep per flock) and stocking rate (number of sheep per hectare). This former (flock size) is a good proxy for fixed investments (costs) and corresponding impacts such as those related to buildings (shed, milking parlour) machinery stock and labour workload. The latter (stocking rate) is related to the intensity of the land and animal utilization: proportion of land devoted to cropping, level of supplementation and so on. So this parameter is mostly related to variable costs and corresponding impacts.

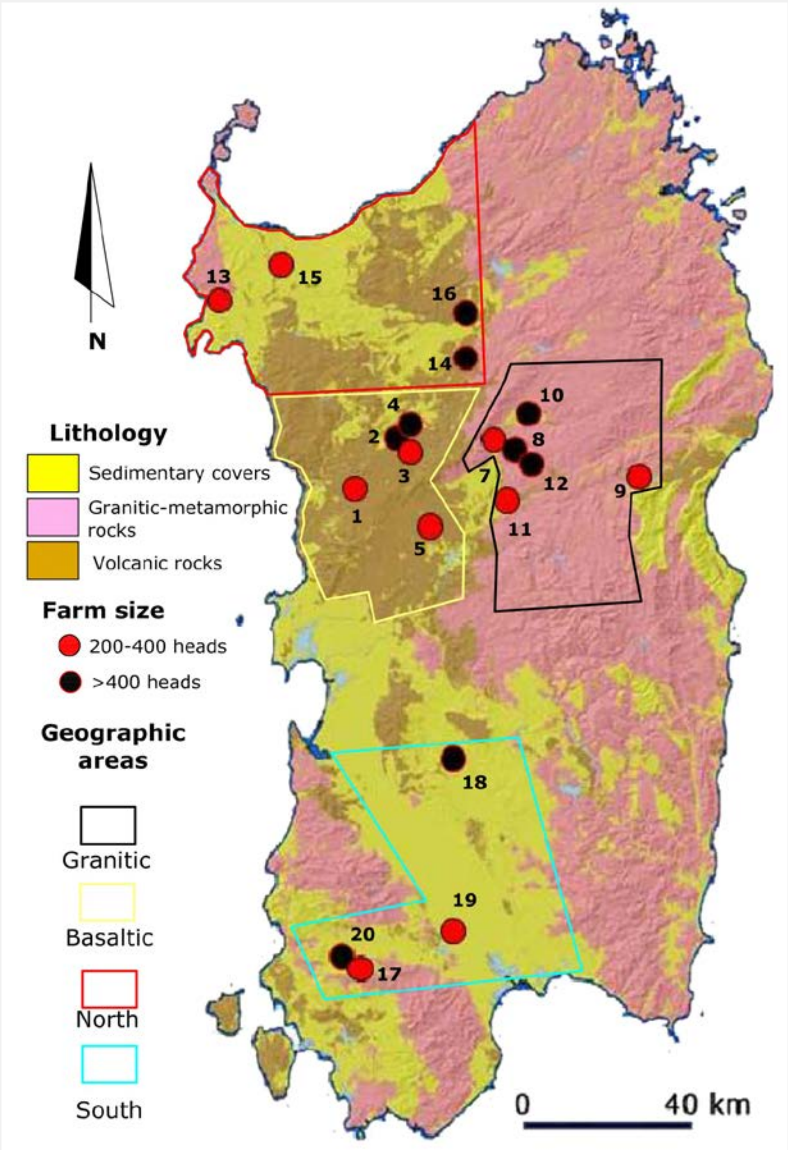

Figure 9. *Location of the 20 sheep farms representative of the whole Sardinian dairy sector*.

Finally, among the candidate farms, only those whose owners showed availability to collaborate were retained, being the final set composed as indicated in the following table.

Table 14. *Selected farms basic features.*

Central Western (BASALT)			Municipality	Farm name
Farm No.	Stocking rate	Flock size		
1	3-6 head/ha	200-400 heads	Sindia	Deriu
2	3-6 head/ha	> 400 heads	Bonorva	Flli. Mura
3	6-9 head/ha	200-400 heads	Bonorva	Sanna
4	6-9 head/ha	> 400 heads	Bonorva	F.lli Deriu.
5	> 9 head/ha	200-400 heads	Borore	Pinna

Central Eastern (GRANIT)			Municipality	Farm name
Farm No.	Stocking rate	Flock size		
6	3-6 capi/ha	200-400 capi	Bottida	Molozzu
7-8	3-6 capi/ha	> 400 capi	Bono	Fressura L. e N.*
9	6-9 capi/ha	200-400 capi	Oliena	Ticca
10	6-9 capi/ha	> 400 capi	Bultei	Orritos
11	> 9 capi/ha	200-400 capi	Orani	Ziranu
12	> 9 capi/ha	> 400 capi	Orotelli	Lunesu

North (SEDIMENTARY)			Municipality	Farm name
Farm No.	Stocking rate	Flock size		
13	3-6 capi/ha	200-400 capi	Sassari	F.lli. Riu.
14	3-6 capi/ha	> 400 capi	Ozieri	Manconi
15	> 9 capi/ha	200-400 capi	Sassari	Arca
16	> 9 capi/ha	> 400 capi	Ozieri	Solinas

South (SEDIMENTARY)			Municipality	Farm name
Farm No.	Stocking rate	Flock size		
17	3-6 capi/ha	200-400 capi	Villamassargia	Cugusi
18	3-6 capi/ha	> 400 capi	Turri	Diana
19	> 9 capi/ha	200-400 capi	Decimoputzu	Ena
20	> 9 capi/ha	> 400 capi	Iglesias - Domusnovas	Mulas

* Farm split into two, owned by brothers.

On these farms the LCA survey has been recently carried and preliminary results are reported elsewhere(LCI report).

7. Conclusions

The characterization process of dairy sheep farms in Sardinia has been completed.

It has been a challenging task due to: i) the high number of farms (c.a. 12,000) which makes Sardinia the most important region in Europe for sheep milk production, with approximately. 400 million of liters produced every year; ii) the wide spreading of these farms on the whole regional area (24,000 km^2); the diverse pedo-climatic background of these farms.

The step-by-sytep stratified sampling process used in this project, based on the use of different data layers sourced locally from trustworthy geo-referenced databases could be regarded as a model for the implementation of LCA approach to other rural areas across Europe. LCA is in fact, a complex and labour-intensive methodology and its implementation at Tier level higher than 1, is feasible only on a limited number of farm units, which should represent the population they are extracted from.

References

Addis, M. Cabiddu, A., Decandia, M., Fiori, M., Spada, S. Bulleddu, C. Cammelli, R. Caria, A., Lai, V. Lutzoni, G. Natale, A. Oppia, P. Pintus, C. Spiga, A. Piredda, G. Porqueddu, C. Molle, G. 2007. A survey on the milk fatty acid composition of forty dairy sheep flocks in Sardinia. Italian Journal of Animal Science, 6 (Suppl. 1), 532-534.

Aru, A., Baldaccini, P., Vacca, A., Delogu, G., Dessena, M.A., Madrau, S., Melis, R.T., Vacca, S. 1991. Nota illustrativa alla carta dei suoli della Sardegna. Dipartimento di Scienze della Terra, Università degli Studi di Cagliari, Assessorato regionale alla Programmazione Bilancio ed Assetto del Territorio, Cagliari, 83 pp.

Bodini, A., Cossu, Q.A., 2008. Analisi della piovosità in Ogliastra (Sardegna, Italia) nel periodo 1951-1999. IMATI MI/4, CNR, 56 pp.

Bodini, A., Cossu, Q.A., 2010. Vulnerability assessment of Central-East Sardinia (Italy) to extreme rainfall events. Nat. Hazards Earth Syst. Sci., 10, 61-72.

Caballero, R., Fernadez-Gonzalez, F., Molle, G., Roggero, P.P., Bagella, S., D'Ottavio, P., Papanastasis, V.P., Fotidias, G., Sidiropoulou, A., Ispikoudis, I. 2009. Grazing systems and biodiversity in Mediterranean areas: Spain, Italy and Greece. Pastos XXXIX, pp. 154.

Canu, S., Rosati, L., Fiori, M., Motroni, A., Filigheddu, R., Farris, E. 2015. Bioclimate map of Sardinia (Italy), Journal of Maps 11:5, 711-718.

Chessa P., Delitala, A., 1997. Il Clima della Sardegna. Servizio Agrometeorologico Regionale, Sassari, Italy, 200 pp.

CLAL, 2016, http://www.clal.it/index.php?section=formaggi_dop.

Costantini, E.A.C., L'Abate, G., Barbetti, R., Fantappié, M., Lorenzetti, R., Magini, S. 2012. Carta dei suoli d'Italia, scala 1:1.000.000 (Soil map of Italy, scale 1:1,000,000) – Consiglio per ricerca e la sperimentazione in agricoltura - S.EL.CA. Firenze, Italia.

Delitala, A.M., Cesari, D., Chessa, P.A., 2000. Precipitation over Sardinia (Italy) during the 1946-1993 rainy season and associated large-scale climatic variations. International Journal of Climatology 20, 519-542.

Delitala, A., 2003. Le variazioni delle precipitazioni in Sardegna nel XX secolo. Atti Workshop "CLIMAGRI – Cambiamenti Climatici e Agricoltura" Cagliari, 16-17 gennaio 2003, 47-54.

Furberg, M., Steyn, D.G., Baldi, M. 2002. The climatology of sea breezes on Sardinia. International Journal of Climatology 22, 917-932.

Furesi, R., Madau, F.A., Pulina, P., 2013. Technical efficiency in the sheep dairy industry: an application on the Sardinian (Italy) sector. Agricultural and Food Economics, 1:4. DOI: 10.1186/2193-7532-1-4.

EUROSTAT, 2012. http://ec.europa.eu/eurostat.

Idda, L., Furesi, R., Pulina, P., 2010. Economia dell'allevamento ovino da latte. Produzione, trasformazione, mercato. Franco Angeli, Milano (Italy) pp. 314.

INEA, 2010. Valutazione del rischio di salinizzazione dei suoli e di intrusione marina nelle aree costiere delle regioni Meridionali in relazione agli usi irrigui. R. Napoli (ed.). INEA, pp. 232.

INEA, 2013. L'agricoltura in Sardegna, caratteristiche strutturali e risultati aziendali. Report 2013. www.rica.inea.it/public/it/view_file.php?action=commenti_risultati_contab

ISMEA 2012. Italian institute for food and agricultural products. Database available at: http://www.ismea.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/4173.

ISTAT 2010. 6° Censimento agricoltura 2010. http://www.istat.it/it/censimento-agricoltura/agricoltura-2010.

ISTAT 2014. Annuario Statistico Italiano, Istituto nazionale di statistica, pp. 774. www.istat.it

ISTAT 2015. Annuario Statistico Italiano, Istituto nazionale di statistica, pp. 810. www.istat.it

ISTAT 2016. Annuario Statistico Italiano, Istituto nazionale di statistica, pp. 779. www.istat.it

ISTAT 2017. Zona altimetrica, Istat, http://www3.istat.it/cgi-bin/glossario/indice.pl

Natale, A., S.R. Sanna, P. Oppia, A. Carta and S. Ligios, 1999. Economic significance of some productive traits in Sarda sheep farming systems. Proceedings of the meeting of the Sub-Network on Genetic Resources of the FAO-CHIHEAM Inter-Regional Cooperative Research and Development Network on Sheep and Goats, jointly organized by CIHEAM and FAO-REU, with the support of FAO-AGA, Zaragoza (Spain), 18- 118 D. 20 November 1999, pp. 27-31.

National Database of Farms Animal 2016. https://www.vetinfo.sanita.it/

Paoli, J.C., 1997. Patrons and bergers sardes: origine et transformations d'un élevage ovin méditerranéen. PhD thesis, pp. 377.

Porqueddu C., 2008. Low-input farming systems in southern Europe: the role of grasslands for sustainable livestock production. In: Biala K., Terres J.M., Pointereau P. and Paracchini M.L. (eds.) Proceedings of the JRC Summer University on 'Low input farming systems: an opportunity to develop sustainable agriculture', Ronco (Italy) 2–5 July 2007, pp. 52–58.

PSR, Plan of Rural Development of Sardinia 2014-2020.
http://www.regione.sardegna.it/speciali/programmasvilupporurale/psr-20142020

Puddu, R., Fanni, S., Loddo, S., Manca, D., 2008. La salinizzazione dei suoli nelle piane agricole della Sardegna. Distribuzione, intensità e valutazione del rischio. Pubblicazione AGRIS, 80 pagg., aprile 2008, cod. ISBN 978-88-903404-1-3.

Puxeddu, M., Pintus, A., Pulina, G. 2008. I Meriagos: il confine tra prateria e foresta. http://www.sardegnaagricoltura.it/documenti/14_43_20081014112126.pdf

RAS - Regione Autonoma della Sardegna, 2016. SardegnaGeoportale, Carta Geologica di base della Sardegna in scala 1:25.000. http://www.sardegnageoportale.it/ (last access: november 2016).

RAS - Regione Autonoma della Sardegna, 2017a. SardegnaGeoportale, Modello Digitale di elevazione, passo 10 metri. Available at: http://www.sardegnageoportale.it/

RAS - Regione Autonoma della Sardegna, 2017b. SardegnaGeoportale, Carta dell'Uso del Suolo in scala 1:25.000. http://www.sardegnageoportale.it/ (last access: january 2017).

Savona, P., 1983, Il settore lattiero-caseario in Sardegna Aspetti e Prospettive, Franco Angeli, Milano (Italy), pp. 290 pp.

Secci, D., Patriche, C.V., Ursu, A., Sfîcă, L., 2010. Spatial interpolation of mean annual precipitations in Sardinia. A comparative analysis of several methods. Geographia Technica, 1, 67-75.

Usai, M.G., Casu, S., Molle, G., Decandia, M., Ligios, S., Carta, A. 2006. Using cluster analysis to characterize the goats farming system in Sardinia. Livestock Science 104, 63-76.

Vardabasso, 1972. Sguardo alle vicende geologiche della Sardegna, Fossataro, Cagliari (Italy), pp. 14.

sheep to ship LIFE