62° CONGRESS OF EUROPEAN REGIONAL SCIENCE ASSOCIATION, Alicante, 28 August-1 September 2023

Urban Challenges and Sustainable Technological Revolution - Session 22: Spatial dimensions of climate change

Distribution of Italian livestock activity at local scale from 2020 Census and administrative data to support the estimation of main GHG emissions in agriculture

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1. INTRODUCTION

Efforts to reduce greenhouse gas emissions are fundamental in achieving global climate goals, and while quick progress has been made in recent years, there is still much to be done to ensure the sustainability of these practices in the long term. Each economic sector is called to contribute to these goals by finding and addressing key sources of climate-altering gas emissions.

Methane is one of the major greenhouse gases, with a climate impact 81 times that of CO_2 over 20 years (IPCC, 2023) and a lifespan of 10-15 years. The agricultural sector, particularly enteric fermentation in ruminants and the management of livestock manure, is the primary source of CH_4 emissions, contributing 45% to national emissions and 5% to greenhouse gas emissions overall, despite a continuous decrease in agricultural emissions in recent decades (ISPRA, 2022b).

Nitrous oxide has a much greater climate impact than methane, with a Global Warming Potential (GWP) of 273 over 20 years (IPCC, 2023) and a lifespan of over 100 years. Once again, the agricultural sector is responsible for the main emissions (66%), with a specific focus on the use of nitrogen-based fertilizers, both natural and synthetic. The management of livestock effluents plays a significant role for N_2O released, and like methane, there have been reductions in N_2O emissions in recent decades (ISPRA, 2022a).

Various international and national organizations are strongly committed to producing data and indicators to support policy decisions about climate change. In particular, ISPRA plays a crucial role in identifying and quantifying greenhouse-gas emission sources, while others have played a fundamental role in the livestock sector by creating georeferenced databases, such as the National Livestock Registry[3], or developing models to estimate the production and use of natural resources in the livestock sector on a global scale (GLEAM, FAO, 2022).

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[3] National Livestock Registry (BDN) established by the Ministry of Health at the CSN "G. Caporale" Institute of Teramo (ITALY). https://www.vetinfo.it/j6_statistiche/#/

On the other hand, data produced by ISTAT (Italian National Institute of Statistics) supply detailed and exhaustive information, especially through the Agricultural Census, which offers essential insights into material and energy flows within the livestock sector and covers informational gaps about the management practices of livestock effluents.

The economic nature of the Agricultural Census can indirectly be used in estimating environmental indicators through the territorialization of the recorded material and energy flows. More recently, GIS technologies have allowed the georeferencing of some livestock statistics, enabling the investigation of more specifically environmental effects arising from agriculture.

To this end, the aim of this study is to quantify and geolocate zootechnical activities, as recorded in the latest General Agricultural Census of 2020, concerning the livestock population (size and housing methods) and the management of livestock effluents (storage and use) by agricultural holdings.

2. METHODS

The use of administrative sources in support of the latest 2020 General Agricultural Census occurred both during the preparation of the census frame and in the data processing phase, with particular emphasis on the georeferencing of agricultural holdings centers (as requested by Eurostat) and livestock stabling sites by points, and of agricultural lands by polygonal objects. However, some statistical units that are not present in the administrative sources are still included. For this reason, the actual dissemination of census data will take place at the municipal level, following the prescribed guidelines.

The survey units of the census statistical source encompass all agricultural holdings within the target population[4]. The reference period includes the agricultural year 2019-2020 for crops and poultry, while for other species of animals, the data refer to December 1, 2020.

Duplicate questionnaires (N=100) have been eliminated from the census source. Additionally, holdings with agistment contracts were excluded if their manager declared to be only an owner and not also a stockbreeder (N=440), to avoid animal double counting.

Frequencies and quantities of Utilized Agricultural Area [UAA], number of heads, stabling methods derive from the statistical source and concern the animal heads belonging to: Cattle, Buffalo, Sheep, Goats, Swine (only pigs)[5], and subgroups based on age, sex, and/or productive orientation; Poultry (meat chickens, laying hens, turkeys, Guinea fowls, and geese). Other categories have not been included, as they are considered less relevant from the perspective of animal effluents production.

For stabling, census data provide the number of animals in each subgroup raised using specific methods, including fixed or free-range stabling, with or without bedding, with solid, partially slatted, or fully slatted flooring, etc. The MASAF Decree (2016) supplies the average annual live weight per

[4] Population target includes holdings carrying out economic activity in the agricultural and zootechnical sector with al least an UAA of 2000 m^2 (1000 m^2 if the UAA concerns vineyards, or greenhouses, or mushrooms), and/or at least 1 animal not for self-consumption among cattle, buffaloes, horses, sheep and goats, pigs, poultry, rabbits or at least 3 hives.

[5] Following were excluded from our analysis: bees, horses, wild boars, rabbits, ducks, other poultry, and ostriches.

head for each subgroup of animals and the conversion coefficients from annual live weight to quantities of livestock effluents divided into slurry, manure, and used straw.

The animal categories present in the Decree include one or more census classes, so the effluent production will be calculated for the following aggregate groups:

a. Dairy cows in production

b. other cattle (<1 year, males 1-2 years, females 1-2 years, males >2 years, heifers >2 years, other cows (non-dairy, replacement cows, nurse cows)

c. Sows

d. other swine (adult males, weaned pigs, growing and fattening pigs)

e. Laying hens.

Moreover, the following sub-categories have not been included because the census classes do not have an exact correspondence with one/more parameters present in the Annex of MASAF Decree: other bovines, other cows, other swine, sows with other stabling type, laying hens in raised cages, laying hens with other stabling methods, and animals always grazing.

Finally, for the storage and use of livestock effluents, agricultural holdings with or without animals have been included if they have storage facilities and/or UAA fertilized with animal effluents.

The geolocation of census data results from the integration of multiple administrative sources through deterministic record linkage using the livestock holding codes or, for crops, using the codes of the cadastral parcels.

The administrative sources used are:

a. The National Livestock Registry (at December 2020) provided the geographic coordinates of the stabling units to which one or more holdings with animals are affiliated. This database also yielded the percentage of animal heads from a single holding present in each stabling unit, enabling the distribution of animal consistencies from the census source. The same coordinates were used to refer to the stabling methods of livestock and the presence of storage facilities on the farms. Animals consistently grazing were not included in the geolocation.

b. The Land Registry[6] (2020) and the Farm Folders[7] (2020) were used to georeference agricultural lands and their related crops. This archive was prepared following an earlier project.

c. Administrative Units map[8] (January 2020) were used to update the PROCOM code of data from several sources.

The software used for processing was ARCGIS (©ESRI) and SAS (©SAS Institute Inc.).

[6] By Italian Revenue Agency (AdE)
[7] By Italian agricultural payments agency (AGEA)
[8] By ISTAT - Directorate for environmental and territorial statistics

3. RESULTS

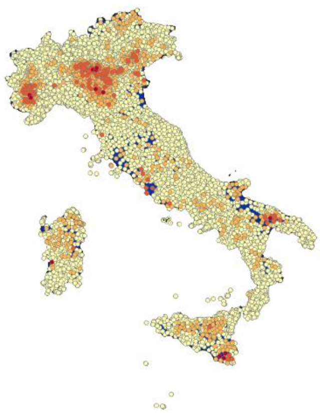
3.1. LIVESTOCK HEADS: CONSISTENCY AND LOCALIZATION

According to our elaboration of the 2020 Census data, there are 244,487 livestock farms with a total of 143,681,475 heads, including 5,374,955 (3.7%) from biological farming (Fig. 1).

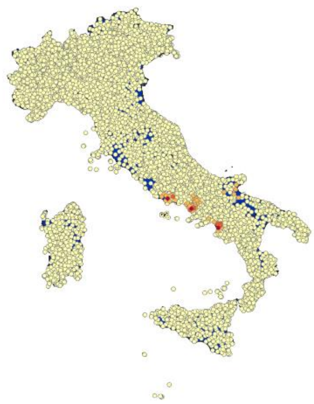
Fig. 1 - Number of heads reared on 1 December 2020 (for poultry, on the agricultural year 2019-2020). Livestock holdings = 244,487 (Authors' elaborations).

Out of the total heads, 63% are allocated to their geo-referenced breeding places using BDN administrative data, while 37% of them are geocoded through the Local Administrative Units (LAU-2 - NUTS5) codes. Therefore, the overall distributions of livestock statistics are georeferenced to the LAU-2 centroid and represented with cartograms (Fig. 2).

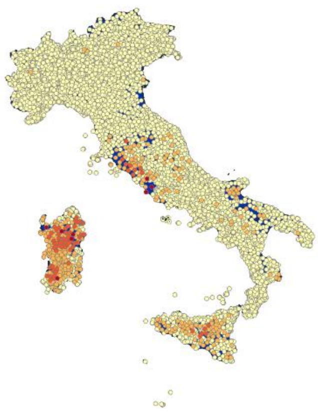
Figure 2 – LAU-2 (NUTS 5) distribution of livestock heads (Authors' elaborations)



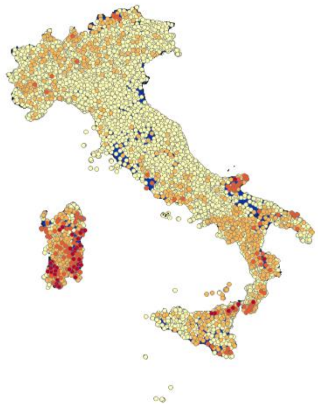
Cattle



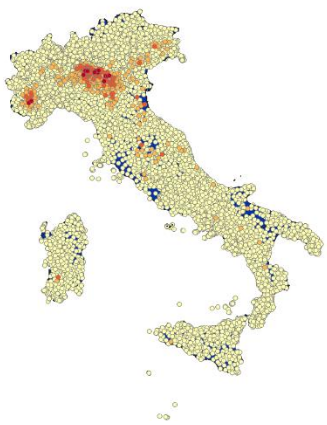
Buffaloes



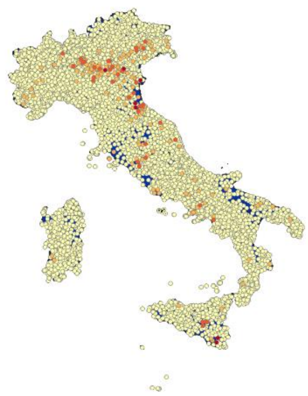
Sheep



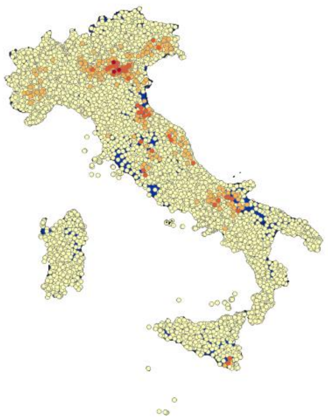
Goats



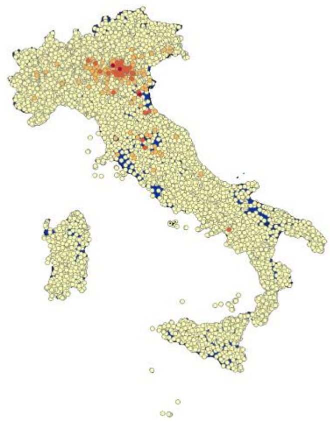
Swine



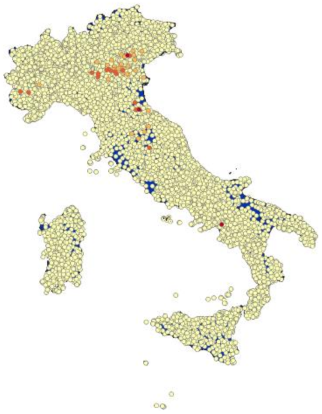
Laying hens



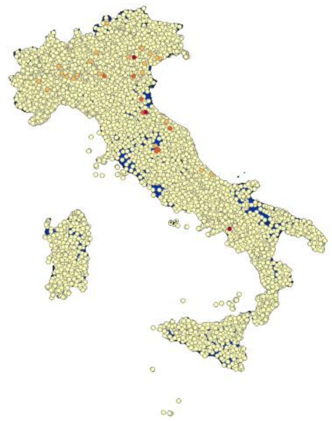
Chickens



Turkeys



Guinea fowls



Geese

Legend (classes with natural breaks (Jenks)
Heads frequencies

CATTLE	BUFFALOES	SHEEP	GOATS	SWINES	LAYING HENS	CHICKENS	TURKEYS	GUINEA FOWLS	GEESE
1 - 1700	1 - 1600	1 - 4000	1 - 300	1 - 5000	1 - 50000	1 - 70000	1 - 16000	1 - 3000	1 - 200
1700 - 6300	1600 - 6300	4000 - 16000	300 - 1000	5000 - 19000	50000 - 190000	70000 - 310000	16000 - 65000	3000 - 13000	200 - 1000
6300 - 18000	6300 - 21100	16000 - 50000	1000 - 2800	19000 - 47000	190000 - 670000	310000 - 970000	65000 - 162800	13000 - 40000	1000 - 15000
18000 - 36300	21100 - 29500	50000 - 98000	2800 - 6700	47000 - 78000	670000 - 1560000	970000 - 2250000	162800 - 278400	40000 - 140000	15000 - 120000

3.2. STABLING AND LIVESTOCK EFFLUENTS: QUANTITY AND LOCALIZATION

Regarding stabling, the total number of animals included in the estimate of the amount of livestock effluents is 43,676,193 about 85% of the total heads foreseen for the estimates. Different housing methods are considered in relation to the conversion coefficient between the live weight of the animals present for each category, and the quantity of manure produced. Results are presented in terms of the quantity of slurry and manure produced in millions of cubic meters/year (total in Fig.3 and by groups in Fig. 4), and for manure and straw in millions of tons/year (Fig. 3). Here we will not deal with the conversion of the quantities of zootechnical effluents in terms of climate-altering gases produced.

In 2020, the total amount of manure produced was approximately 32 million cubic meters. Out of this, 47% came from dairy cows, and 88% came from cattle in general. In terms of slurry, the total volume was 40 million cubic meters, with the majority originating from swine (74%) and a smaller portion from dairy cows (20%).

Figure 3 – Liquid and solid livestock effluents produced in 2020 (Authors' elaborations).

Figure 4 - Livestock effluents production by year. Other cattle include cattle < 1 year, male cattle 1-2 years, female cattle 1-2 years, male cattle > 2 years, heifers > 2 years, other (non-dairy) cows. Other pigs include piglets, pigs for fattening and adult males. (Authors' elaborations)

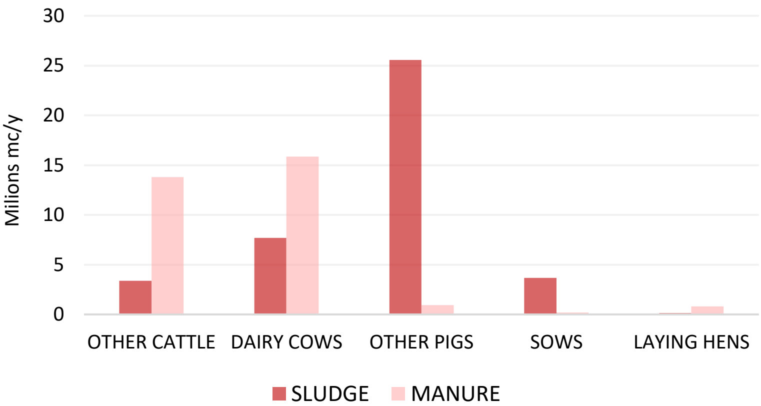
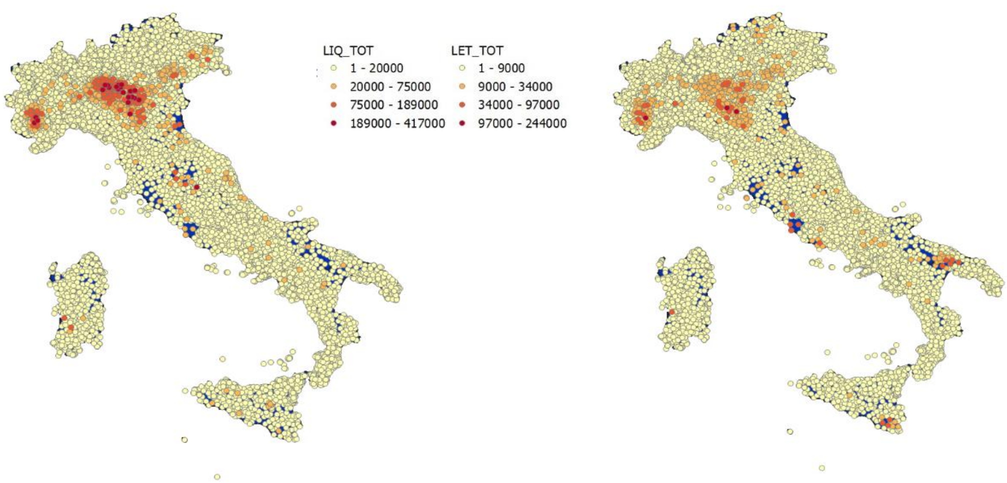


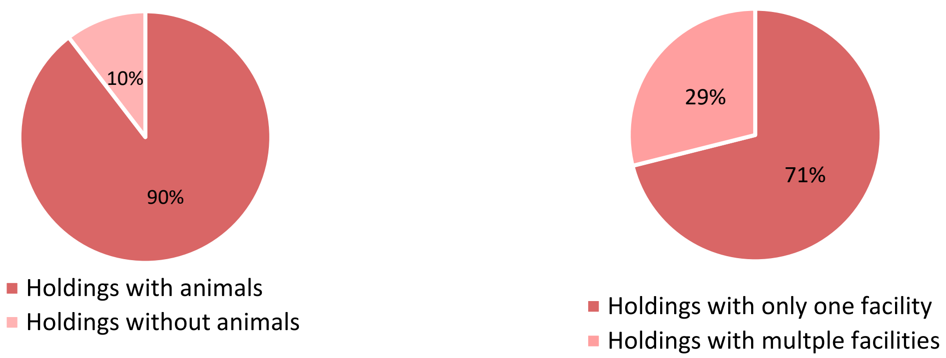
Figure 5 - LAU-2 distribution of slurry (A) and manure (B) production in mc/y (Authors' elaborations)



3.3. EFFLUENTS STORAGE: FACILITIES AND LOCALIZATION

Agricultural holdings with storage facilities are 37,015. There is a 10% of livestock holdings that have storage facilities even though they do not have animals (Fig. 6). This is because the storage facilities refer to the 2019-2020 agricultural year, while the presence of animals refers to 1 December 2020, except for poultry. It follows that these are livestock holdings that raised animals (except poultry) up to June-July 2020 (because 5-6 months is the median capacity of storage facilities) but no longer have them.

Figure 6 - Holdings with storage facilities. N=37,015 (Authors' elaborations)



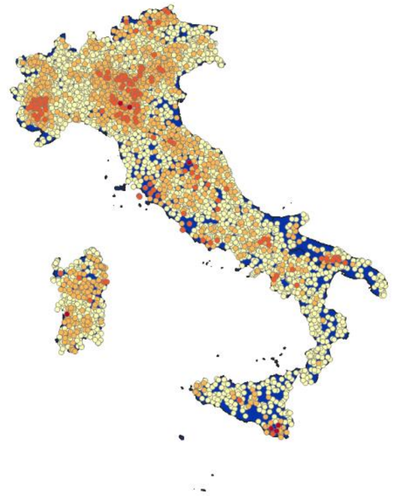
Most of livestock holdings have only one storage method (Fig. 6). Storage facilities are localized in 5,507 LAU-2, as represented with cartograms in Fig. 7.

3.4. UAA FERTILIZED WITH LIVESTOCK EFFLUENTS: METHODS AND LOCALIZATION

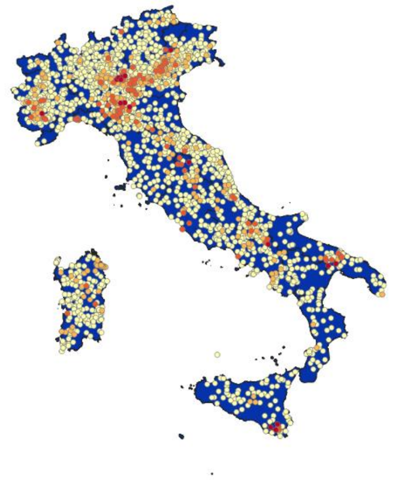
Agricultural holdings that use livestock effluents to fertilize their crops, only or with synthetic ones, are 141,542 (12.5%) of the total number of farms surveyed. 70% of them are livestock holdings, and 30% are holdings with only crops.

Application techniques of livestock effluents (Fig. 8), their residence time on the soil surface, have a strong impact on the amount of ammonia produced. Net of several environmental parameters, such as temperature and rainfall, volatilization, leaching and runoff of NH_3 are reduced with rapid burial of effluents. The most used application is across the field spreading methods, mainly with incorporation within 4 hours but also no incorporation is very frequent. All application methods are used to spread a median of 25% - 49% of effluents, except for band spreading with deflectors, which is used by companies for less than 24% of livestock effluents.
Altogether, fertilized UAA is 1,600,247 hectares and its distribution is represented in Fig. 9.

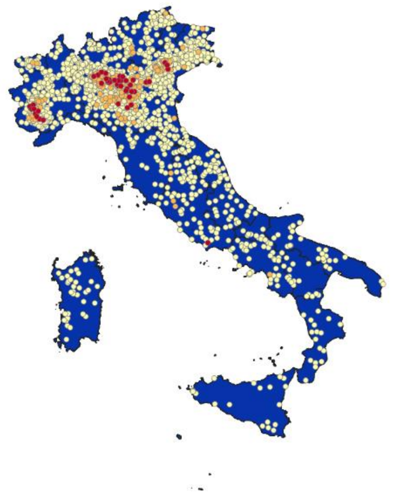
Figure 7 - LAU 2 (NUTS 5) distribution of livestock effluents storage methods (Authors' elaborations)



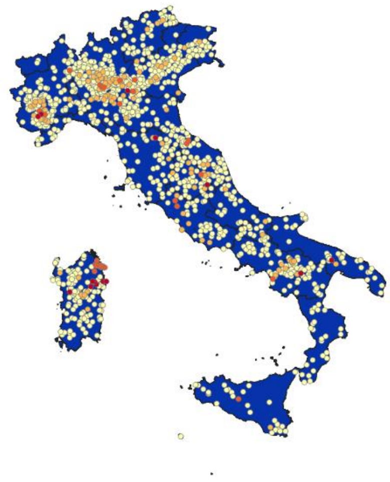
STOCC1– Heaps of manure
N=20,362. Median capacity in months=6



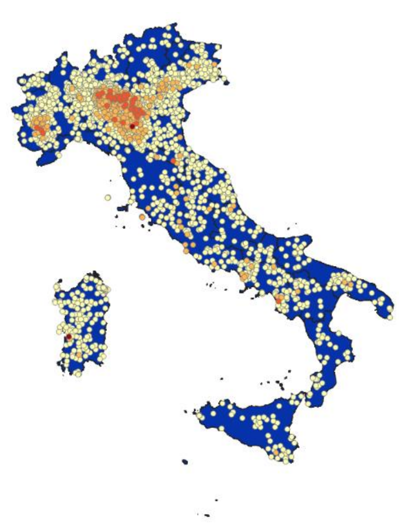
STOCC2– Composting in heaps of manure.
N=4,378. Median capacity in months=5



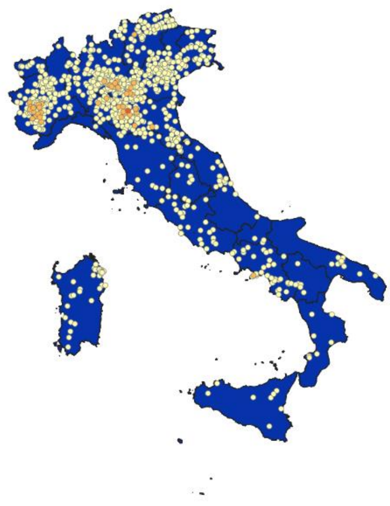
STOCC3– Effluent in pits under the shelter floor
N=3,873. Median capacity in months=5



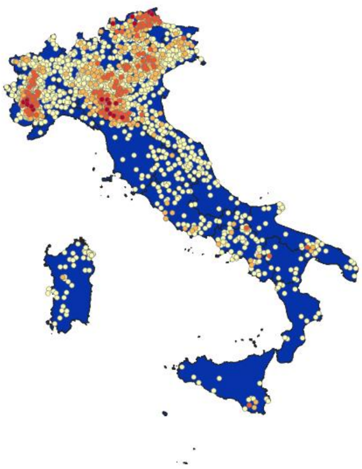
STOCC4– Manure in deep litter systems
N=2,035. Median capacity in months=6



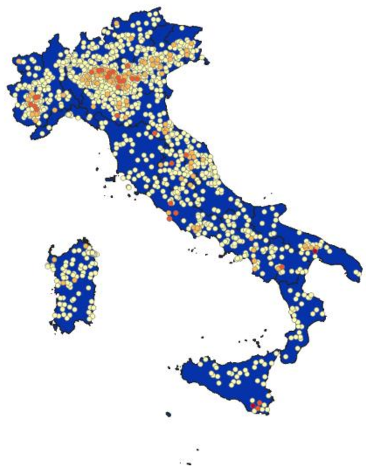
STOCC5– Uncovered slurry
N=6,406. Median capacity in months=6



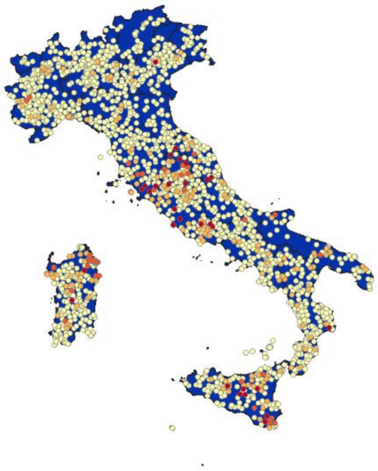
STOCC6– Slurry with permeable cover
N=1,395



STOCC7 – Slurry with waterproof cover
N=4,376



STOCC8 - Effluents in other facilities.
N=2,481



STOCC9 - Daily distribution of effluents
N= 5,654

Legend (classes with natural breaks (Jenks)
Storage facilities frequencies

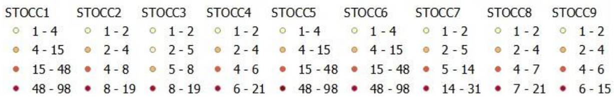


Figure 8 - Application methods of livestock effluents (Authors' elaborations)

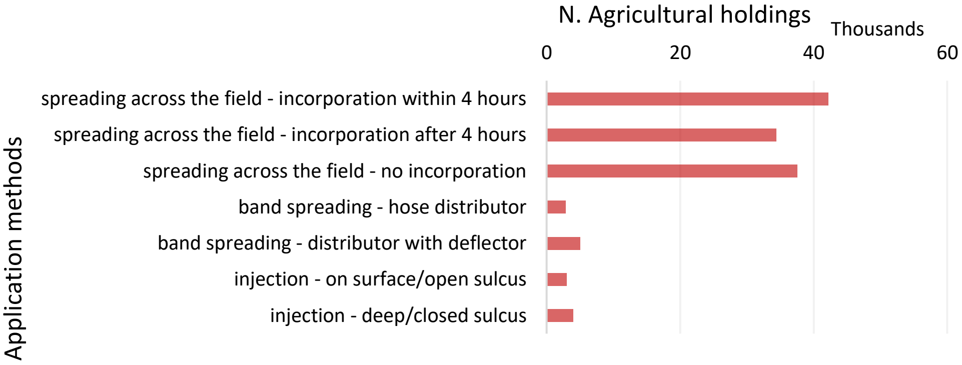
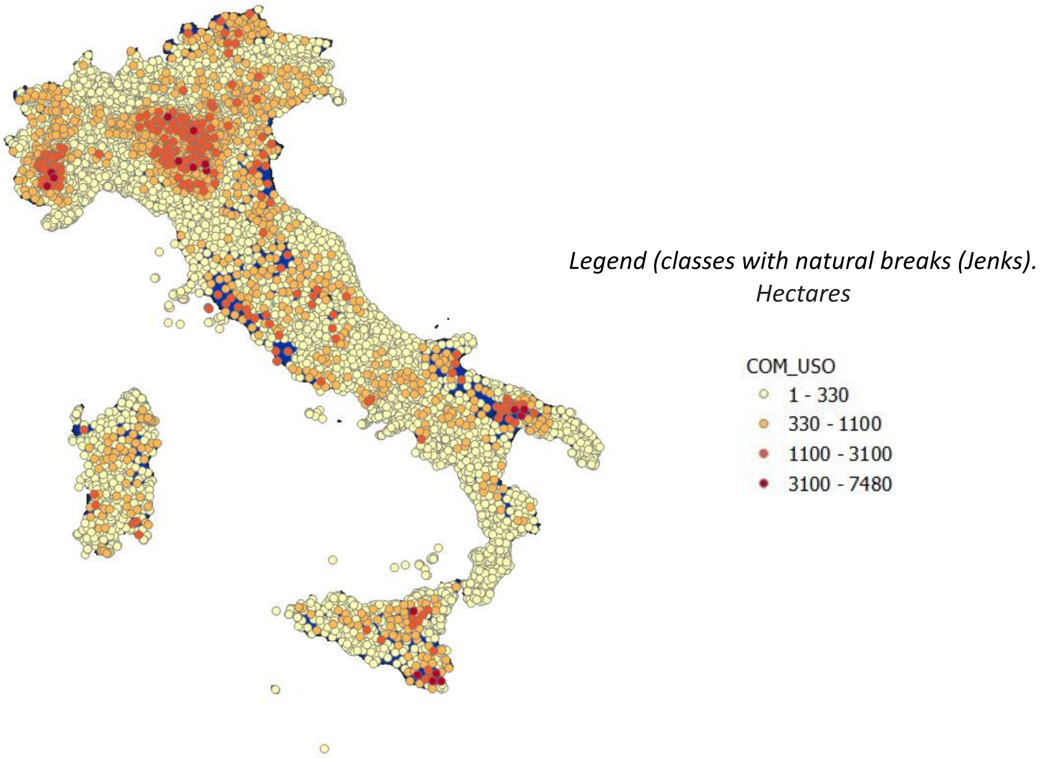


Figure 9 – LAU-2 (NUTS 5) distribution of fertilized UAA with livestock effluents (Authors' elaborations)



4. DISCUSSION

Reducing emissions of climate-altering gases from livestock effluents, particularly N_2O, involves implementing various techniques outlined in the Code of Good Agricultural Practice (UNECE, 2015). These techniques can be adapted for different types of farms and production approaches, covering all aspects of livestock farming from dietary composition to housing, storage, and crops application.

In this context we have provide census data related to the quantities of raised livestock, generated effluents, fertilized crops with them, and their distribution at the LAU-2 scale.

Using data extracted from General Agricultural Censuses spanning from 1982 to 2010 (ISTAT, 2013), along with the Author's analyses for the most recent decade, it becomes evident that the dairy cow population has undergone a significant decline of 38.6% since 1982. This decline occurred over successive decades, with variations of -1.2%, -31.6%, -9.7%, and a slight uptick of +0.6% in the most recent decade. Similarly, other ruminants (including *Bos taurus* other than dairy cattle, and buffaloes) have also witnessed a decline of 30.4% since 1982, characterized by variations of -14.8%, -13.7%, -2.4%, and -3% in the last 10 years. Conversely, the total number of swine has decreased around 17% since 1982, with variations every 10 years of -6.1%, +4.0%, +8.5%, -21.3% for last 10 years for total swine and -2% for sows .

The highest concentration of cattle at the LAU-2 level is observed in regions historically renowned for breeding both dairy and meat cattle, forming a cornerstone of the "Made in Italy" agri-food sector. The most substantial geographical concentration is witnessed in the Pianura Padano-Veneta, spanning Lombardia, Veneto, Piemonte, and Emilia-Romagna. Interestingly, significant LAU-2 cattle concentrations also occur in smaller areas, such as the Gravine and Bassa Murgia (covering the provinces of Taranto, Matera, and a portion of Bari province), Maremma (encompassing Grosseto and Viterbo), as well as the provinces of Ragusa and Oristano. Additionally, regions with higher buffalo numbers are primarily concentrated in the provinces of Salerno, Caserta, and Latina. The distribution of swine is widespread throughout Italy, though LAU-2 areas with the highest pig counts are situated exclusively in Lombardia (Brescia, Mantova, and Cremona provinces) and Piemonte (Cuneo province). Other regions such as Veneto, Toscana, Umbria, and Sardegna have high pig numbers in only a few select LAU-2 areas.

Estimates of the total amount of livestock effluents, is around 72 million of cubic meters in 2020, consider the weight and housing method of various classes of non-grazing, raised animals (according to species, sex, age, and production orientation). Amount and distribution of manure closely aligns with that of cattle, whereas slurry primarily corresponds to swine and secondarily to cattle. Poultry produce very useful effluents, but their quantity is very small.

Livestock farms using storage methods are 15% of the total and 10% of them (no poultry farms) have effluents but no animals remaining on the 1st of December.

Farms with only one method are 71% of the total. Most common storage method is manure heaps, with over 20,000 places and a median capacity of 6 months. Covered manure in deep litter systems is not common (around 2,000 with a median capacity of 6 months). Uncovered slurry facilities number is over 6,000 with a median capacity of 6 months. Covered slurry facilities are around 10,000, with waterproof or permeable covers, or in pits under the floor with a capacity floor of under 5 months. There are around 4,000 composting facilities for the aerobic degradation of digestate. Finally, around 5,000 farms distribute their livestock effluents on their crops daily. Loyon (2018) obtained very similar results using 2010 French census data regarding the percentages of storage methods used, although with different total quantities and composition between solids and liquids effluents.

Livestock effluents are used as soil fertilizer or improver, alone or together with synthetic ones, on flat, hilly, and mountainous areas, in North Italy (Pianura Padano-Veneta, Trentino Alto Adige), Central Italy (Maremma and central Apennine) and South Italy (parts of Puglia, Sicilia and Sardegna). Most of UAA is fertilized with field spreading methods, mainly with quick burial but also no burial at all is very common among farms. Finally, farms using slurry spreading on bands or injection methods are very few.

The aim of this project was to utilize agricultural census data to address critical environmental issues for sustainable development, in alignment with the directives of our ISTAT-Directorate for Environmental and Territorial Statistics. However, the lack of geographical coordinates for a portion, albeit small of crops and livestock prevented us from conducting spatial analyses, which cannot be replaced by the discrete subdivision of administrative units.

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