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Overview of Animal Manure Management for Beef, Pig, and Poultry Farms in France

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Livestock manure management is the central issue for many environmental policies relating to water and air quality. However, there is little published data on the methods used in those countries affected by pollution from the livestock sector. This paper brings together the available data relating to manure management in France, specifically for pig, cattle and poultry production. An overview of livestock production and legislation is presented using data from the 2010 Agricultural Census, livestock farm surveys carried out in 2008 and other supporting documents relating to manure treatment (professional surveys, expert reports and technical publications). Cattle, pig, and poultry livestock produce around 120 million tons of manure per year not including those on pasture. This figure is made up from 60.6% solid manure, 38.8% livestock slurry (effluent) and a relatively small amount of poultry droppings. Solid manure is mainly stored in temporary field heaps. In the case of manure storage on the farm, the capacity varies from 45 days to 7.5 months depending on farm size and type of animals, time spent outside the buildings and the geographical location. Covered storage (whether rigid or natural crust) accounts for 17% of stored pig slurry, 45% of cattle slurry, and 39% of poultry slurry. Covered storage of solid manure is rarely used on pig or cattle farms whereas 27% of the solid poultry manure (including poultry droppings) is held in covered storage areas. Treatment applies to 13.6 million tons of the manure produced, mainly by methods based on composting or aerobic treatment. Nitrogen applied as slurry is mostly spread on the soil surface using splash plate tankers (83% in the case of cattle slurry, 63% for pig slurry, and 66% for poultry slurry). Incorporation within 24 h of the nitrogen spread on the soil concerns 28% of cattle, 44% of pig, and 56% of poultry manure. The most common method of manure management is storage (in building and pit) and spreading. The treatment of manure and the use of specific techniques to reduce gaseous emissions (such as frequent manure removal from buildings, storage covers, or injection) are not widely reported.

Keywords: overview, manure management, livestock, poultry, cattle, pig, France

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INTRODUCTION

Livestock activities have an environmental impact when manure is improperly handled due to the pollution from various nutrients and organic compounds (nitrogen, phosphorous, organic matter…), from the emission of ammonia (to water soil and air) and greenhouse gas emission (GG). The gases emitted (NH_3, CH_4, N_2O) result from the breakdown of animal manure containing carbon and nitrogen and are released in the buildings, during subsequent storage and during land spreading (Chadwick et al., 2011; Webb et al., 2012). Water pollution by nitrates (NO_3^-) or by phosphorous (P) in certain intensive livestock production areas arise from spreading manure rich in N and P beyond the capacity of the land. The surplus nitrogen and phosphorous is not used by the crop or soil and is washed out by surface run-off or seepage leading to eutrophication of water sources (Velthof et al., 2014; van Dijk et al., 2016). As a result, the livestock sector is considered as one of the principal sources of pollution leading to global warming (in the case of GG emission) water and soil contamination and the loss of biodiversity (Steinfeld et al., 2006). The scale of these impacts are thus closely linked to (amongst other factors) the management and composition of animal manure (Menzi et al., 2010; Chadwick et al., 2011; Petersen et al., 2013).

As a consequence, the management of livestock manure is a central issue in a series of international protocols, of European directives and national regulations. Effectively, the practical aspects of the methods chosen by farmers can influence the scale of diffuse emissions and the possibility to reduce these losses (Chadwick et al., 2011; Velthof et al., 2014). The European directive on emission ceilings (EC, 2001) resulting in the Gothenburg Protocol (The United Nations Convention on Long-range Transboundary Air Pollution or CLRTP) (UNECE, 1999) targets the control of ammonia emissions. Those emissions of CH_4 and N_2O are regulated by the Kyoto Protocol arising from the UN Framework Convention on climatic change (UN, 1997). Water pollution by nitrates and phosphorous is the subject of the EU Nitrates Directive (EEC, 1991) and the European Water Framework Directive (EC, 2000). The signatory countries of international conventions or those targeted by European Directives must measure the existing level of water pollution and make an inventory of current emissions of the listed gases. These measurements and inventories are thus the reference base for reduction objectives that imply the enactment of action programs.

Various published works relating to gas emission inventories or the movement of N and P, underline the need for detailed data due to the large variability of management methods in livestock production. In general terms, inventories and environmental analysis of livestock farms need data on animals, the operation of the farm, the level of manure production, the methods of handling of the manure (whether solid manure—FYM or slurry) and their composition (concentration of nitrogen, phosphorous, and organic matter). It is the acquisition of such data that is often considered the most demanding step in carrying out an inventory or an analysis of the farm. Furthermore, the quality of such data is central as this can improve the accuracy of the material balance and provide a reliable basis for subsequent actions (Milne et al., 2014; Velthof et al., 2015). Finally, the availability of data reflecting different manure management practices and its application in different countries remains limited or somewhat artificial or inconsistent thus rendering comparisons difficult between methods used in different countries affected by air and water pollution (Menzi et al., 2015b; Velthof et al., 2015).

France is one of the major livestock nations in Europe and the farming systems vary widely. In fact, the country makes the biggest contribution to the 1,400 million tons of animal manure estimated for the European Union (Foged et al., 2011). Thus, the purpose of this paper is to bring together, as far as possible, available data on the management of animal manure in France, especially information used in the different inventory tools or in the evaluation of technologies used for the reduction of water and air pollutants. This paper is not set out to provide new data but to assemble, standardize, and complete existing data sets.

ASSESSMENT OF POLICY, GUIDELINES OPTIONS, AND IMPLICATIONS

Framework of French Regulations of Livestock

All livestock farms in France fall under French and European regulations that seek to protect both the environment and local inhabitants. Farmers are, depending on the size of the farm, subject either to the RSD or "Règlement Sanitaire Départemental" (Departmental health regulations), that is the "Code de la Santé Publique" (Public Health Code) or subject to legislation for those farms coming under the ICPE or "Installations Classées pour la Protection de l'Environnement" (Livestock farms listed for environmental protection: Environmental Code). Basic nationally prescribed measures set out in specific decrees (MEDDE, 2013a,b,c) that relate to the installation (and management) of farm buildings, effluent storage, and land spreading may be reinforced by local rules depending on the local climate and the vulnerability of the local environment. European rules, reworked into French texts are also applied to those livestock farms targeted by the specific directive relating to the integrated prevention and reduction of pollution (that is the IED Directive, previously known as IPPC) or regionally applied as in the case of the Nitrates Directive and/or the Water Framework Directive (MEDDTL, 2011; MEEM, 2017b). These obligatory reglementations can affect the management of farm manure both directly and indirectly.

The Legal Status of Livestock Manure

Livestock manure (raw or treated) come under several legal categories (waste, by-product, product) depending on their use and each with different land spreading constraints (Houot et al., 2014). Raw livestock manure managed on the farm are considered as by-products from animal production and must respect the environmental rules set out by the RSD, ICPE, and IED with respect to collection, storage, and land spreading. The outputs from treatment (composting, anaerobic digestion, separation, drying,…) that are carried out on the farm or at an external site (composting center, joint AD facilities, and others), are still considered as farm manure and must be applied to the field following an approved scheme of land spreading. However, these same outputs (composts, digestates, solids from separators, dried material, etc.) may be considered as "organic fertilizers" (for free use of as a commercialized product) if they are standardized, homologated or in agreement with a specification approved by regulation. These fertilizer products are thus used according to the recommendations of the supplier without the need of a land spreading plan. Composts from the solids removed by separation and dried materials are generally put on the market (or made available) under the name "organic fertilizer" by simply following set standards (French Standard "Amendement organique) or "Organic soil improvers," NFU 44-051 or the (French Standard "Engrais organiques" or organic fertilizers, NFU 42-001). Digestates from AD must be approved (a long and costly procedure limiting approvals to just 3 products in 2014) or more recently, they can be used by following a set of procedures detailed under a decree published in 2017 (MAA, 2017). A farmer is allowed to give away, sell, or exchange (for straw) raw or treated effluents (that are neither standardized nor authorized) under a specific contract where the recipient undertakes to spread these effluents on land in full compliance with the rules in place. In the case of exported composts and AD digestate, a sanitary certificate is required.

Principal Regulations That Govern the Management of Livestock Manure

Minimal Distances for Buildings, Storage Tanks, and Land Spreading Operations

Livestock buildings, storage tanks and the spreading of effluent must observe minimal distances from residences or aquatic resources which vary depending on the effluent being spread (compost, raw manure, digestates from AD units...), on the specific regulation (RSD, ICPE, water protection…) and the specific region (rules governing vulnerable areas). The minimal distance is set at 100 m for buildings and storage facilities for all effluents. On the other hand, the minimal distances for land spreading depend on the effluent type (slurry, FYM, treated effluent) and the method of land spreading: thus 10 m for composts, 15 m for injected livestock slurry or that incorporated immediately, but up to 100 m for other products. In vulnerable areas, the spreading of slurry and solid manures is forbidden closer than 35 m from the banks of rivers and streams unless there is a permanent vegetative zone (where the minimal distance is reduced to 10 m).

Storage of Farm Manure

Livestock farmers must have available adequate storage capacity (measured in cubic meters for slurries or square meters for FYM), sufficient to enable compliance with the minimal storage periods before land spreading. The minimal storage capacity is for 45 days (RSD), 4 months (ICPE) or varies from 4 to 7.5 months in vulnerable zones depending on the animal type, the length of time at pasture and the geographical location. Two software tools (called Pré-Dexel and DeXeL) are recognized by the state for sizing and checking storage capacity for livestock farm manure (MEEM and MAAF, 2016). Legal exceptions are possible if the existing capacity is enough to enable the good agronomic use of applied manure. Field storage is allowed in the case of stable FYM (i.e., without drainage) and poultry manure with over 65% dry matter for periods not exceeding 10 months (ICPE) or 9 months (in vulnerable zones) with the stipulation that there is no reuse of the same site for storage for at least 3 years. Within vulnerable zones, field storage is forbidden from the 15 November to the 15 January except for grasslands or if the heap is placed on a bed of absorbent material (around 10 cm thick and with C/N ratio of less than 25) or if the heap is covered.

Land Spreading of Manure

Land spreading is forbidden during certain periods or on certain land that would otherwise lead to environmental impact via run off or by leaching of the applied nitrogen and phosphorous (e.g., bare soil, sloping ground, saturated land, frozen ground, etc.). In vulnerable areas, spreading periods are determined with respect to the effluent type in terms of the level of mineralization of the organic nitrogen content, local climatic conditions, and technical limitations (soil firmness, access to the field, etc.). The implementation of a maximum 170 kg N/ha in vulnerable zones is a restriction that can lead the farmer to treat livestock manure to allow legal application on fields. Under the ICPE rules, incorporation after land spreading on bare soil is obligatory within 24 h for cattle FYM and solid pig manure (raw or treated) previous held for at least 2 months in storage (for stabilizing with respect to drainage liquids) and 12 h for all other effluents from the farm, whether raw or treated.

Manure Treatment

Livestock manure treatment is obligatory in France under the Nitrate Directive for those farms located in high risk zones (known as ZAR or "zones d'actions renforcées") where the maximum applied nitrogen dose in the spread effluent, which can vary between departments and defined vulnerable zones, can be even more severe than the usual 170 kg N/ha. Effluent treatment is also obligatory under the Water Framework Directive in the Loire-Brittany catchment area with the purpose of ensuring an agronomic phosphorous balance. Treatment also becomes obligatory when using effluents or digestates in the case of AD as a soil improver or organic fertilizer defined by French standards (AFNOR, 2016).

Description of Livestock Production and Manure Management

Livestock Description

France is one of the main producers of meat in Europe being the largest in the case of cattle production, second for poultry and fourth for pig production (Eurostat, 2016). In 2010, the national agricultural census counted 490 000 farms of which 291 000 (59%) included a livestock activity (Agreste, 2011; Idele, 2013b). Cattle rearing covered 193 000 farm units and numbered in total 19.4 million animals; pig rearing covered 22 300 farms and numbered 13.8 million animals whereas poultry production was represented by 95 300 production farms with a total of 292 million birds. More recent data from 2013 indicates that livestock numbers are unchanged but spread across fewer farms (Agreste, 2013a): 176 500, 17 400, and 67 200 farms in the case of cattle, pig, and poultry respectively.

Geographic Distribution of Livestock Farms

Livestock numbers are not evenly spread across the country. More than half (55.3%) of cattle, pig, and poultry is found in two regions in the west of France (Brittany and the Pays de la Loire). These two regions contain around 70% of pigs and 60% of poultry numbers. Cattle is more evenly spread accross the French countryside but with nonetheless different regional concentrations of dairy cows (found predominantly in the north of the country) and beef animals (found mostly in the center of the country).

Utilized Agricultural Area (UAA) Associated With Livestock Farms

Agricultural land dedicated to the three livestock sectors, pig, cattle, and poultry, amounts to 15.2, 0.9, and 1.2 million hectares, respectively (Agreste, 2008a,b,c). For pig production, barely 10% of farms (representing 15% of pig numbers) have no adjoining farmland and a mean size much above the average (1,800 pigs or 310 sows) (Agreste, 2013b). Other farms have more than 50 ha of farmland (averaging 83 ha) of which 55% is in cereal production and oilseed/protein crops. In the case of poultry production, the mean area of farmland was in 2010: 63 ha per broiler farms, 56 ha for egg laying farms and 46 ha for pullets (Itavi, 2013a). Those poultry farms lacking any farmland account for 10% of broiler farms and 13% of egg laying farms (Itavi, 2013a). The average area of farmland of dairy farms was (in 2010) 91 ha of which 36% was given over to forage production, 37% was permanent pasture and 50% was used for cereal production and oilseed/protein crops (Agreste Centre, 2013a). In the case of beef farms, the average farmland area was slightly less at 83 ha of which 26% was used for cereal production and oilseed/protein crops and 71% was as permanent pasture (Agreste Centre, 2013b). More generally, these averages hide large regional differences. For example, in the Brittany region, many poultry farms have little agricultural land (over 30% of farms have less than 10 ha) whereas the 51 % of poultry farms in the Champagne region have more than 100 ha of farmland available.

Livestock Production and Farm Size

Livestock farms fall under either "standard" production or "quality" production the latter being such as "Plein air" (free range), "Lable Rouge" (Red label), "Biologique" (Organic), or "Appellation d'Origine Contrôlée" (AOC). Those "quality" farms have to follow certain official conditions laid out by the Ministry of Agriculture which includes rearing times, food regime, and so on. The conditions have an impact on the quantity and composition of the animal manure produced. 63% of broiler farms, 14% of turkey farms, and 67% of guinea fowl is currently subject to special regulations governing quality (Itavi, 2010). The organic production concerns mostly broiler and egg production, representing 1.0 and 7.6% of numbers respectively in 2014 (Agence Bio, 2016). In 2014, the pig sector covered by the regulations of Red Label code accounted for less than 3.3% of the total French pig production (Badouard, 2016) and sows managed under organic rules accounted for just 0.9% (Agence Bio, 2016). In the cattle sector, around 3% of beef animals fall under special quality regulations whereas the organic codes cover 4.2% of all french dairy cows (FranceAgrimer, 2016). The number of livestock farms covered by one or other quality codes is projected to increase for all types and especially for dairy and beef cattle farms (FranceAgrimer, 2016).

Cattle farm size

On average, the typical cattle farm had 101 animals in 2010 rising to 110 in 2015 (Agreste, 2016b), but the variation of the mean size from region to region was much greater ranging from 58 to 144 animals in 2010 (Agreste, 2014b). Considering the different herds of cattle, the average size is 45 heads of dairy cows, 34 heads of suckler cows while other animals (divided into <1 year, 1–2 years, and >2 years) are rearing in farms with less than 19 heads (Agreste, 2013a). In the case of milk production, 60% of farms keep only dairy animals whereas 40% have beef animals as well and/or veal calf production (Idele, 2013a). Dairy farms with more than 20 cows are predominantly for breeding (73.2% of farms) or for breeding and fattening including young beef and veal calf (20.8% of farms).

Pig farm size

In 2010, 48% of pig farms had fewer than 20 sows (or fewer than 100 pigs where the pig numbers were less than 1% of all farm animals) and the mean for this sector with very small herds was just 9 pigs (Agreste, 2013b). The bulk of pig numbers are thus held in livestock farms with more than 100 pigs (or 20 sows) and the mean size for this sector is 1,200 pigs, but with large regional differences ranging from a mean of 1,860 pigs per farm in Champagne-Ardenne, down to 150 pigs per farm in Corsica. Depending on their principal activity, pig farms can be divided between breeder/fattening (50% of the total), fattening farms (43% and generally without weaners), and pig breeding farms (6% including those with or without weaning).

Poultry farm size

The size of farms varies widely depending on the type of production and the methods used (whether standard practice or following specific codes relating to quality). In the case of both standard broiler production and egg laying systems (in cages), the farms are especially large scale (Agreste, 2013c). More than 60% of meat and egg poultry production is carried out in farms larger than 20 000 and 50 000 birds respectively. Those poultry farms governed by specific codes relating to quality are generally smaller (Itavi, 2010). As an example, the average size of a poultry house following standard practice is 870 m^2 whereas the average for a farm applying a quality code is 220 m^2.

Manure Management

Manure storage

Livestock farms for cattle, pig, and poultry had together in 2008 (Agreste, 2008a,b,c) around 155 000 slurry stores (mostly away from the animal house in the case of cattle and pig farms) and with a combined storage volume of 47 million m^3 (**Table 1**). Seventeen percentage of the storage pits were covered (in 2008)

TABLE 1 | Storage capacities of French livestock according to the 2008 survey (Agreste, 2008a,b,c).

Animal type	Solid manure		Slurry	
	Number of stores	Million m^2	Number of stores	Million m^3
Cattle	120 000	22 (28% covered)	120 000	35 (10% covered+ 35% crusted)
Pig	3,500	0.5 (24% covered)	16 200	9.6 (17% covered)
Poultry	6,800	2.3 (27% covered)	19 600 of which 20% are external	2.2 (39% covered)

in the case of pig farms and 10% on cattle farms. Thirty-nine percentage of poultry farms had covers on their *external* stores. It should be noted in this last case, that for 80% of poultry houses, manure storage is within the building which may be considered as covered. The storage of solid manure was in 2008 carried out at 130 000 stores representing a combined area of 25 million m^2 (2500 ha). Covers for such stores were in place for 21% of cattle FYM stores, 16% of solid pig manure stores but only 21.5% of those stores for poultry manure. A large part of the solid manure (55 million tons), mostly from the cattle sector (52 million tons), was stored in field heaps.

Manure Treatment

In 2008, 12% of pig farms, 11% of poultry farms, and 7.5% of cattle farms used some sort of treatment for their manure. Manure treatment for the three main farm animal types accounted for 13.6 million tons (Loyon, 2017), that is, 11.3% of the 120 million tons of manure produced annually. The main processes, predominantly used at the farm, were composting (8.5 million tons), aerobic treatment (2.9 million tons of pig slurry), and anaerobic digestion or AD (1 million tons). Other treatments of solid manure including physical-chemical methods, were less common (0.4 million tons). In addition, a large part of poultry droppings is dried in or out of the rearing house.

Land Spreading of Livestock Manure

The application of livestock manure (whether raw or treated) is mainly done on farmer's land or other land generally close to the farm (Quideau, 2010). Fields available for taking the applications of manure are linked to the crop rotation in practice at the farm (Ramonet et al., 2014). Based on the data given in **Table 2**, of the total nitrogen in the manure from livestock farms destined for land spreading [estimated as around 540 kt N: (Citepa, 2017), and personal communication] 36.5% is spread on grassland, 39.6% on maize ground, and 12.9% on cereal land. Nitrogen from cattle manure is more often spread on grassland than that from piggery manure because of differences in the crop cycle between the farm types whereas nitrogen from poultry manure is mostly spread on cereal land. In certain regions (Brittany, Pays de la Loire, Limousin), livestock manure make up the main source of nitrogen and are spread essentially on maize ground, of which the area included in crop rotation is greater than elsewhere (Agreste, 2014a).

According to the crop survey 2011 (Agreste, 2014a), nitrogen in the form of solid manure is more than 90% surface land spread but up to 67% is not incorporated within 24 h (**Table 3**). Nitrogen applied as slurry is mostly spread on the soil surface using splash plate tankers (83% of the nitrogen tonnage in the case of cattle slurry, 63% for pig slurry, and 66% for poultry slurry) (**Table 4**). Incorporation of the nitrogen content in the following 24 h occurs to 88% of the nitrogen tonnage of applied poultry slurry and to 45% of pig slurry whereas 73% of cattle slurry seems not incorporated. Incorporation within 24 h of nitrogen from solid manure concerns 31% of the nitrogen tonnage for cattle, 33% for pig and 56% for poultry manure. This difference between the animal types is explained by the large proportion of the slurry form produced by pig farms and the related obligation to reduce the odor nuisance (with respect to nearby people) by using the method of incorporation. The applied dose of organic nitrogen varies from 87 kg/ha on rapeseed crops to 154 kg/ha on forage maize.

Estimation of the Amount of Manure Produced

Manure type (slurry, FYM, or dropping) and the quantities produced at a farm depend on the housing type (slatted floor or bedding) and the stage of animal rearing. Manure management in the building (drying belt, scrapping, flushing, storage pit, etc.) also affect the quantities of manure to be handled. Generally, solid manure (FYM) is stored in field heaps or in manure stores and slurries stored in pits.

Cattle production

Eleven building types have been defined (MAPE and MAP, 2001) in order to estimate the storage capacity according to foor type (bedding or slatted floor), housing method (tied or free, "straw flow"—sloping floor with bedding, straw bedding, cubicle), possible inclusion of a yard for animal exercise—covered or exposed, and the amount of straw bedding in the different area accessible by the cattle. The most common system for all animal types is an open house design with FYM production (from deep litter, straw bedding areas or from cubicles) covering 80% of all animals (**Table 5**). Deep litter barns without an exercise yard is predominant in the case of cows with followers and other cattle but less so for dairy cows where straw bedding or cubicles are also common. Slurry-based systems are rarely used except for veal calf production and for dairy cows kept in cubicles with slatted floors. These different housing types produce slurry and/or solid manure more or less of high concentration in terms of the dry matter content (DM) (Degueurce et al., 2016). Only high solid FYM (defined as those with a dry matter between 18 and 25%) and very high solid FYM (over 25% dry matter) may be kept in field heaps. Wet FYM (below 18% dry matter) must be kept in FYM bunkers for at least 2 months before possible storage in the field. (MAPE and MAP, 2001; Idele, 2005).

Poultry production

Slurry is produced principally from farms rearing duck for the table or those force fed (for "foie gras"): otherwise, the slurry

TABLE 2 | Types of crop that receive the nitrogen contained in land-spread cattle, pig, and poultry manure (given as % of N applied) (Agreste, 2014a).

		Cereals*	Oilseed/protein crops**	Forage maize	Maize (sweet corn)	Temporary grassland	Permanent grassland	Others***	Total
Cattle	Slurry	4.7	1.7	12.4	3.0	47.7	29.8	0.8	100
	FYM	11.9	7.3	36.0	8.2	11.4	22.3	3.0	100
Pig	Solid manure	13.6	20.1	8.5	54.1	2.3	0.1	1.4	100
	Slurry	24.6	6.3	9.3	22.9	26.9	7.0	3.1	100
Poultry	Solid manure	15.4	13.8	24.5	33.3	2.2	6.8	4.0	100
	Droppings	23.1	41.7	13.9	11.3	1.2	0.0	8.8	100
	Slurry	1.6	13.5	4.9	55.6	0.0	24.4	0.0	100
	Total	12.9	7.9	28.3	11.3	16.8	19.7	2.9	100

(*) Soft wheat, hard wheat, barley, triticale.
(**) Rape seed, Sunflower seed, fat peas.
(***) Sugar beet, potatoes.

TABLE 3 | Time for incorporation of applied nitrogen (as a % of total nitrogen applied) (Agreste, 2014a).

		<4 h	4–12 h	12–24 h	>24 h and longer	No data	Total
Cattle	Slurry	4	4	6	14	72	100
	FYM	4	6	21	38	32	100
Pig	Solid manure	9	7	17	63	4	100
	Slurry	28	7	10	6	50	100
Poultry	Solid manure	9	20	27	27	18	100
	Droppings	9	9	36	31	15	100
	Slurry	63	14	11	12	0	100

TABLE 4 | Application method of nitrogen as livestock slurry (as % of total slurry nitrogen applied) (Agreste, 2014a).

	Broadcast	Trailing hose	Incorporation
Cattle slurry	82.7	10.5	2.1
Pig slurry	62.8	17.0	19.9
Poultry slurry	65.5	34.0	–

system is now virtually inexistent for egg producing hens (Itavi, 2013a). Solid manure arises from broiler production on litter, from pullets and from birds retained for future chick production (Itavi, 2010). Poultry houses operating alternative (non-cage based systems) for egg production (30% of layers) also produce solid manure (Itavi, 2013b). Laying birds that are kept in cages produce droppings that are collected and removed relatively frequently by conveyor belt (with or without drying) directing the manure to storage barns or a drying tunnel or drying building. Otherwise, the system is a building with a basement to collect and store the droppings produced being emptied at the end of a production cycle (one year) or removed more frequently using a scraping system.

Pig production

Buildings are mostly fitted with slatted floors (complete or partial) for all animal types, this system accounting for 91.5% of pig places (Ifip, 2010). Straw-based systems represent less than 8% of animal production. Slurry is held in pit located under the floor of the building for the whole production cycle or emptied more frequently to an external slurry pit. An alternative to this standard approach is the frequent removal of manure (gravity emptying every 15 days, automatic scraping several times each day…) but this remains unusual (estimated as representing less than 1% animal numbers in each case (Martin and Mathias, 2013). In the case of bedding systems, the solid manure is managed by accumulation (during a cycle) or removed by scraping 1 or 2 times a week.

The specific quantity of livestock manure produced (per animal) depends on many factors linked to the animal (feed regime, stage of process, type of production system, and so on) and the housing method used. Default values have been proposed by specialist and these are used by the administration to allow the farmers to estimate the storage capacity required by the regulations (**Table 6**). Based on numbers of animals (different from the number of places) in 2010 given as 19.5 million cattle, 13.9 million pigs, and 221.6 million birds, and applying standard data on amounts of manure per animal, recent estimates (Ifip, 2010; Itavi, 2013b; Degueurce et al., 2016) place the total quantity of manure produced annually as around 120 million tons (**Table 7**) of which 60.6% is as solid manure, 38.8% as slurry, and the remaining 0.6% as poultry droppings. This value is less than the 263 million tons estimated by Foged et al. (2011) due to different quantity of manure produced by animal or place and the distribution of place between slurry and solid manure. Linked to the regional distribution of livestock farms, the largest amount of slurry and solid manure is produced in the "Grand Ouest" of France (Brittany, Pays de la Loire and Lower Normandy, **Figure 1**).

ENVIRONMENTAL IMPACT

In France, total ammonia emissions amounting for 679 kt in 2015 (Citepa, 2017) arise principally from the handling of livestock manure (64%). The contribution from manure to emissions of methane and nitrous oxide in 2017 amounted to 2300 and 137 kt

TABLE 5 | Distribution of cattle numbers on the basis of housing type in 2010 (Agreste, 2010).

Housing type		Dairy cows*	Beef cows or followers*	Other cattle		
				<1 year	1–2 years	2 years
Tied stall	FYM and urine system	326 000	749 000	347 500	213 500	162 000
	Slurry system	52 000	108 500	59 000	29 000	21 500
Free stall	Deep bedding	779 500	2 521 000	3 284 500	2 199 000	1 747 000
	Straw bedding (lying area) FYM scrapping	822 000	430 000	760 500	514 000	422 500
	Straw bedding (lying area) Slurry scrapping	403 000	53 500	140 000	92 000	69 000
	Cubicles - FYM	866 500	212 500	270 000	166 000	129 500
	Cubicles - slurry	466 500	25 000	83 000	49 000	35 500
	≪ Baby box ≫	–	–	128 000	–	–
	Box with integrated slatted floor	–	–	517 500	80 500	71 500

(*) including old animals taken out of production.

TABLE 6 | Reference values of the specific quantities of livestock manure produced by the main animal types.

Cattle	FYM[(a)]	Wet (6,5 ≤ DM < 18 %): 16 t/ LU per year[(1).] Concentrated (18 ≤ MS < 25 %): 13.5 t/ LU per year[(1).] Very concentrated (MS ≥ 25 %): 15 t/ LU per year[(1).]
	Slurry[(b)]	Dairy cow: 1.8 m^3 /month; Breeding cow and follower: 1.3 m^3 /month; Cattle 0-1 year: 0.45 m^3 / month; Cattle 1-2 years: 0.9 m^3/ month; Cattle over 2 years: 1.1 m^3 /month
Pig	Solid[(a)]	1764 kg/sow place - 36 kg/piglet place - 243 kg/fattening pig place
	Slurry[(a)]	6.2 m^3/ sow place - 0.1 m^3/ piglet, 0.5 m^3/ fattening pig
Poultry	Solid manure[(c)]	Egg laying hen (1.1 kg/place) – Pullet [(2)] (2.9 kg/place) Broiler[(2)] (1.1 to 2.05 kg/place) Turkey[(2)] (7.to15 kg/place) – Guinea fowl[(2)] (1.5 to 2.3 kg/place)
	Slurry[(b)]	Duck for roasting: 27 liters/place – Ducks force-fed 45 liters/place
	Droppings[(c)]	17 kg/place[(3)]

References: (a) (Ifip, 2014) (b) (MAPE and MAP, 2001) (c) (Itavi, 2013b)
(1) Livestock unit Dairy cow – 1.1 LU; Breeding cow – 0.85 LU; Cattle under 1 year – 0.3 LU; Cattle 1-2 years – 0.6 LU;
Cattle over 2 years – 0.8 LU.
(2) Following the standard production methods or those specified by special qualities (Free range, Red Label, organic, AOC),
(3) Droppings of laying hens at 65% dry matter.

respectively which represent 11 and 4.5% of the national emission of each gas (Citepa, 2017). Manure production from intensive livestock farming in certain areas lead to a surplus of nitrogen (both organic and mineral) estimated nationally in 2013 as 902 kt (MEDDE, 2013d) which equates to an average of 32 kg N/ha of farmland. There is a large variation around this mean between areas of extensive farming (around 15 kg N/ha) and intensive regions (e.g., 69 kg N/ha in Brittany). In 2014 the surplus of phosphorous on average was 1 kg P/ha but 20 kg P/ha in Brittany (Agreste, 2016a).

TABLE 7 | Estimation of the total manure quantities (as raw manure) and corresponding nitrogen and P amounts produced by cattle, pig, and poultry farms (given as tons of raw manure and excluding manure deposited in pasture).

Animal type	Manure volumes produced	Nitrogen (tons)*	Phosphorous (tons)
Cattle[1]	FYM: 68,7 million tons Slurry: 18,2 million tons	530 000 excreted 374 000 applied	97 000**
Pig[2]	Slurry: 25,4 million m^3 Solid manure: 828 000 tons	130 000 excreted 89 000 applied	58 000[4]
Poultry [3]	5,6 million tons (around 8,5 million m^3): Solid manure: 2,5 million tons Droppings: 0,6 million tons Slurry: 2,5 million tons	140 000 excreted 79 000 applied	35 000[3]

(*) Citepa (personal communication) (**) estimation made by the author.
(1) Degueurce et al. (2016) (2) (Ifip, 2010) (3) (Itavi, 2013b) (4) (Ifip, 2010).

ACTIONABLE RECOMMENDATIONS AND CONCLUSIONS

The management of livestock manure (120 million tons per year nationally) depends greatly on the animal type, the region and the form of the manure (solid or slurry). The largest source of animal manure is from cattle farms that produce either solid manure (69 million tons per year) or slurry (18.2 million tons per year) across the country. Pig farms mostly produce slurry (25.4 million tons per year) which is principally concentrated in two regions of France (Brittany and the Pays de la Loire). Poultry production concentrated in the west of the country produces manure as solid manure, slurry, or droppings. In the case of cattle farms, 75% of the FYM produced is stored in the field (Loyon, 2015).

Slurry is most often stored in pits before land spreading on farmland. Poultry droppings are often dried and transported to other regions. The management of livestock manure is typically without the intentional use of methods to reduce ammonia emissions. In reality, the use of covers for external stores is

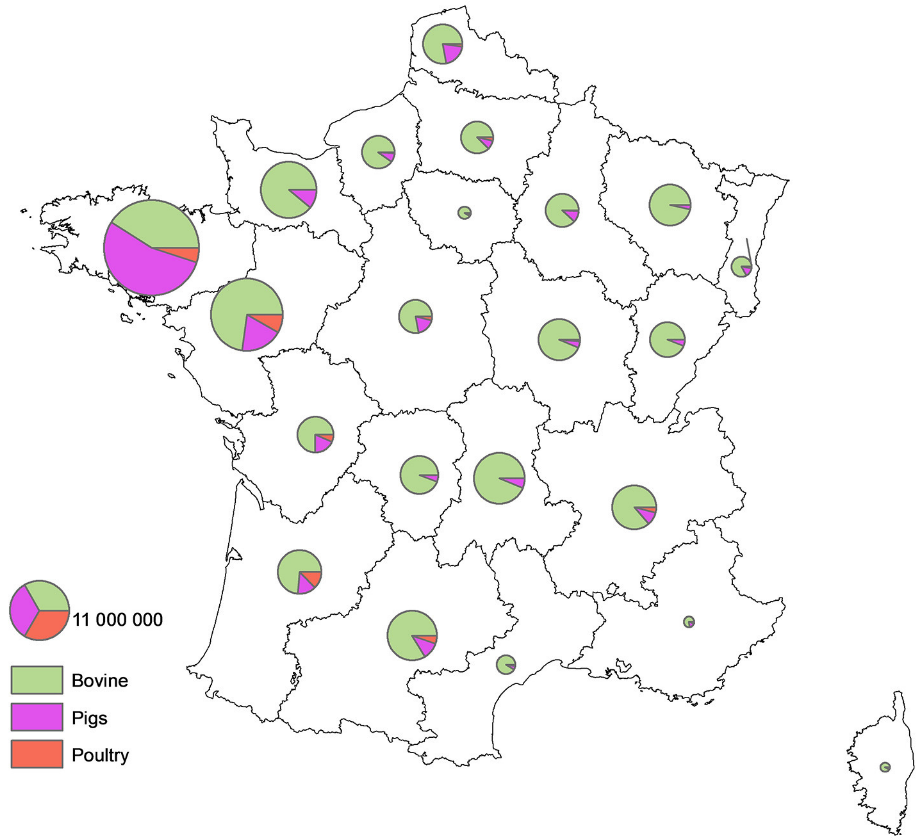

FIGURE 1 | Regional distribution of manure produced by cattle, pig, and poultry livestock in France (in tons).

not widespread and likewise the use of advanced spreading equipment (trailing hose, injection). The treatment of manure is above all used as a means to reduce the nitrogen surplus in those regions with a high livestock density, motivated by the demands of regulations linked to the Nitrates Directive. Treatment by composting is often used to enable a reduction in the obligatory minimal distances during landspreading. The use of methanisation (anaerobic digestion) to treat manure is restricted mostly due to financial reasons but also because of legal constraints. Until recently, the agricultural use of digestate required the registration or product standardization to reclassify it as a soil improver or organic fertilizer (Loyon, 2017). However, this constraint was due to be relaxed with the emergence in 2017 of a set of procedures enabling the marketing and use of agricultural digestates as fertilizing products (MAA, 2017). The movement of raw (untreated) animal manure between farms and the application of joint land-spreading plans is rare in France. This approach runs up against logistical issues about collection and a negative reaction from local people (Paillat et al., 2009). However, analysis of the best means of gaining value from livestock manure underline the importance to reformulate the manure as standard product to enable both the transport and satisfactory use on other farms bringing in (if possible) a commercial return as well (MEDDE and MAAF, 2013; Ademe, 2014). Nevertheless, for this strategy to succeed requires modified techniques that are economically viable for all livestock farms, and not just large farms are required (Quideau, 2010). This survey arising from 2010 is leading to the development of the release of new national action plans supported with financial packages that seek the reduction of ammonia emission (MEEM, 2017a) and of factors leading to climate change (MTES, 2017). The new BREF document for livestock farming (EC, 2017) arising from the Industrial Emissions Directive (EC, 2010) seeks to impose on around 3,300 pig and poultry farms in France practices determined as Best Available Technology (BAT) between the present time and 2021. New surveys of 2016 will enable an updating of the situation with manure management at livestock farms in France.

The current state of livestock manure management in France reveals that manure handling varies depending on the farm and the region. The main strategy is storage then local land spreading. In regions with a high animal density, policies of restoring water quality and the reduction of manure nuisance (especially with respect to offensive odor) have limited the agronomic use of animal manure. Newly emerging factors (depletion of mineral sources, energy costs, and economic guidelines) should increase the use of treatment technologies as well as new strategies for joint management of livestock manure.

Failing more recent data (2015 survey being in press), the compilation presented here is an important starting point to understand the French livestock production and the remaining efforts to be made to reduce its environmental impact. However, this paper is based on the analysis of a large number of official and non-official documents. One of the difficulties has been to cross-check the data most often formulated in different formats and based on unreported assumptions. As pointed out in recent publications (Kupper et al., 2015; Menzi et al., 2015a; Velthof et al., 2015; Smith and Williams, 2016; European Commission, 2017) the methodologies and data used by EU member states are often not well described. Thus, and whatever the environmental issue, there is a need for a common and harmonized methodology and procedure for collecting the data from reliable sources for the estimation of manure production and the nutrient balance.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and approved it for publication.

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