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EFFECT OF HUSBANDRY SYSTEMS ON THE ENVIRONMENTAL IMPACT OF PIG PRODUCTION

Jean-Yves DOURMAD [1, 2], François CASABIANCA [3]

ABSTRACT

Pig production is pointed out as a major contributor to main environmental issues, either at a global (global warming, energy used) or a local level (eutrophication, acidification…). Many studies have been conducted in recent years in order to quantify the effects of farming practices on the environmental impact of pig production. Amount and composition of pig manure are highly dependent on feed composition, animals housing and manure management, which also affect gaseous emissions. More recently, methodologies, such as life cycle assessment, have been developed for the environmental evaluation of contrasted pig farming systems. This allows a multi-criteria evaluation of systems including climate change, eutrophication, acidification, energy use, land use… The aim of the present paper is to review the different methodologies and data available for the environmental evaluation of pig production with a special attention to the specificities of traditional systems.

Key words: pigs / environment / system / manure

1 INTRODUCTION

Societal concerns about livestock production have been increasing for a number of years in many countries. World livestock production has major impacts on the environment, because of its emissions which affect air, water and soil quality, and the use of limited or non-renewable resources (Steinfeld *et al.*, 2006). Livestock production, particularly pig production, is pointed out as a major contributor to the environmental issues, either at a global (greenhouse effect) or a local level (eutrophication, acidification…) (Basset-Mens and Van der Werf, 2005). Direct impacts are associated to water pollution by nitrates, phosphorus, organic matter, micro-organisms or trace elements, air pollution by ammonia (acidification and aerosols), N_2O and CH_4 emissions (global warming effect), and soil pollution by excessive accumulation of phosphorus or trace elements (Cu, Zn). These releases to the environment may be an important threat to biodiversity, ecosystem stability (and their use by human activities such as fishery or tourism), or human or animal health. Their reduction would therefore significantly contribute both to sustainable development and to the own sustainability of pig production chain, as economic efficiency or improvement of meat quality. Indeed, the environmental impact affects the perception of pork production by citizens, and to some extent of pork meat by consumers, thus participating to the overall product quality (Kanis *et al.*, 2003). Moreover, ecosystem degradation might reduce the agricultural production potential in the medium term.

In this context, the EU pork production systems are facing major challenges. There is an increasing public concern regarding the currently prevailing intensive production systems (Petit and Van der Werf, 2003), mainly because of environmental and animal welfare issues. Moreover, due to economic constraints and globalisation, pig production systems tend to homogenise all

1 Corresponding author, e-mail: jean-yves.dourmad@rennes.inra.fr
2 INRA Agrocampus Ouest, UMR1348 PEGASE, 35590 Saint-Gilles, France
3 INRA LRDE Corte France

around the world, the same conventional intensive system prevailing in most countries. Concomitantly, there is a loss of systems adapted to local conditions and to the diversity of demands from society and consumers (Petit and Van der Werf, 2003; Kanis *et al.*, 2003; Bonneau *et al.*, 2011). Although, non conventional production systems, are often believed to be more sustainable (Degré *et al.*, 2007), their real benefits for the environment, animal welfare and product quality may be controversial (Basset-Mens and van der Werf, 2005).

The aim of the present paper is to review the different methodologies and data available for the environmental evaluation of pig production with a special attention to the evaluation of traditional systems.

2 EVALUATION OF NUTRIENT FLOW AT THE ANIMAL LEVEL

2.1 NUTRIENT BALANCE

Nutrient excretion, especially of N, P, K and trace elements, is generally calculated as the difference between nutrient intake and nutrient retention. Calculation of nutrient intake requires information on feed intake and feed composition. Feed nutrient contents can be obtained from feed analysis, be provided by the feed company, or calculated from feed ingredients using feed composition tables (INRA-AFZ, 2004). In indoor pig production systems feed intake is generally rather easy to obtain. This is often more difficult in traditional production systems especially with outdoor raising. Moreover, pigs may have access to grass or others ingredients, such as chestnut or acorn in amounts that are difficult to assess (Secondi *et al.*, 1992). Not considering this fraction in the calculation of excretion will result at the animal level in an underestimation of excretion and related gaseous emissions. The extent of the error will thus depend on the relative contribution of complete feed and grazing to nutrient supply. Nevertheless, at field level the effect should remain rather limited, because the grazed nutrients are coming from the same area as where their undigested fraction is excreted.

For growing animals, retention is calculated as the difference between body content at the beginning and at the end of a given period. For reproductive sows, the amounts retained in uterine contents during gestation and in the body of suckling piglets during lactation are also accounted for. Equations have been proposed by Rigolot *et al.* (2008a), from a literature review, to predict these retentions of N, P, K and trace elements.

These equations were used in table 1 to calculate N and P balance of fattening pigs from different European production systems. The data used for this calculation were obtained from a study conducted within the EU Q-Pork-Chains program. Fifteen production systems from five countries were categorized according to a typology defined by Bonneau *et al.* (2011) among conventional, adapted conventional, and differentiated, including organic and traditional (Dourmad *et al.*, 2013). Compared to conventional, adapted conventional systems were little differentiated with only some changes in order to improve meat quality, animal welfare or environmental impact, depending on system. The difference was much more marked for the traditional systems with the use of fat, slow-growing traditional breeds and generally outdoor raising of the fattening pigs. Two of these traditional systems were Mediterranean production systems. Average pig slaughter weight was 113 kg in conventional systems, rather close to organic systems (109 kg). It was higher in adapted conventional and traditional systems, by 11 and 27 kg, respectively. Feed conversion ratio during fattening period was the lowest in conventional systems (2.74 kg/kg) and the highest in traditional systems (5.29 kg/kg) (Table 1).

The difference in feed efficiency and to some extent in body composition resulted in rather marked differences in N and P balance (Table 1). Compared to conventional systems, N and P excretion per kg BW gain are increased in traditional systems, by 130 and 170%, respectively. Excretion is also higher in adapted conventional and organic systems, but to a much lesser extent. This resulted in lower efficiency of retention of N and P in traditional, compared to conventional systems. This is partly related to differences in retention potential between genotypes of pigs. However, excessive nutritional supplies might also be involved, suggesting that there is some possible improvement of the feeding strategy, especially in terms of protein supply. Indeed, in the recent years many nutritional studies have been undertaken in order to reduce N, P and trace elements in pig manure (Dourmad and Jondreville, 2007). These approaches are mainly based on a better agreement between supply and requirement, and the improvement the biological availability of the nutrients. Substantial reduction in N excreted by pigs can be achieved by phase feeding combined with a better adjustment of dietary amino acid balance. Phase feeding is also effective in reducing P excretion, but for P the most efficient is the use of phytase in order to improve digestibility of phytate-P. Less information on nutritional requirements of pigs is generally available in traditional systems. This could explain the excessive supply of some nutrients due to the use of large safety margins. Moreover, for practical reasons related to the long duration of fattening, the outdoor raising of pigs and

Table 1: *Estimation of N and P balance of fattening pigs in different European production systems* [1]

Production system	Conventional	Adapted conventional	Organic	Traditional
Initial weight, kg	28.1	27.8	29.7	25.4
Final weight, kg	113.2	123.9	109.2	140.4
Feed conversion ratio, kg/kg	2.74	3.18	3.03	5.29
Feed composition				
Crude protein, g/kg	157	153	174	145
Phosphorus, g/kg	4.65	4.50	5.10	4.81
N Balance, kg/pig				
Intake	5.86	7.48	6.71	14.11
Retention	2.22	2.51	2.07	2.74
Excretion	3.64	4.97	4.63	11.37
N retention/Nintake, %	38%	34%	31%	19%
N excretion/BW gain, g/kg	42.8	51.8	58.3	98.9
P balance, kg/pig				
Intake	1.08	1.38	1.23	2.93
Retention	0.45	0.51	0.42	0.61
Excretion	0.63	0.87	0.81	2.32
P retention/P intake, %	42%	37%	34%	21%
P excretion/BW gain, g/kg	7.4	9.0	10.2	20.1
Enteric CH_4 emissions				
per pig, g	281	407	289	765
per kg BW gain, g/kg	3.3	4.2	3.6	6.7

[1] Performance data obtained from 15 European production systems (Dourmad *et al.*, 2013) grouped according to Bonneau *et al.* (2011).

the farm size, phase feeding is generally more difficult to achieve in these systems.

2.2 ENTERIC EMISSIONS

Enteric methane production varies according to the physiological status of the animal and the amount of digested fibre (Rigolot *et al.*, 2008a). It can be calculated according to feed composition and feed intake, considering also the type of pig. Sows have higher emissions than growing pigs, due to their increased capacity to digest fibre. Methane production increases with feed intake and dietary fibre content. This means that per kg of live weight gain the emission will be higher in pigs with higher feed conversion ratio (FCR). Moreover, it can be expected that outdoor pigs, because they graze ingredients with high fibre content, might have a higher methane production. However, to our knowledge, this has not been measured yet. In the same way as for N and P balance, enteric methane production of growing pigs were estimated for the different systems reported in table 1.

2.3 GAZEOUS EMISSIONS FROM MANURE

After excretion, many biophysical processes occur in the excreta inducing gaseous emissions: NH_3 which is involved in acidification and eutrophication, and N_2O and CH_4 which are involved in global warming. These processes are dependent on the composition of the excreta and their management. In conventional production systems, pigs are generally raised on totally or partially slatted floor with the production of liquid slurry that is stored for a certain time in a pit under the floor, and then transferred to an outdoor storage. In traditional production systems the use of deep litter straw bedding is more frequent, resulting in the production of solid manure. Pigs may also be raised outdoor, the excreta being directly spread on the field without any storage. Gaseous emissions are generally calculated using emissions factors (EF), which depends on manure management.

In slurry, because of the anaerobic conditions, most of the nitrogen is present as ammonia, mainly issued from urea conversion. This explains why most of the gaseous emission of N-compounds is NH_3. Many factors are known to affect NH_3 emissions, including slurry ammo-

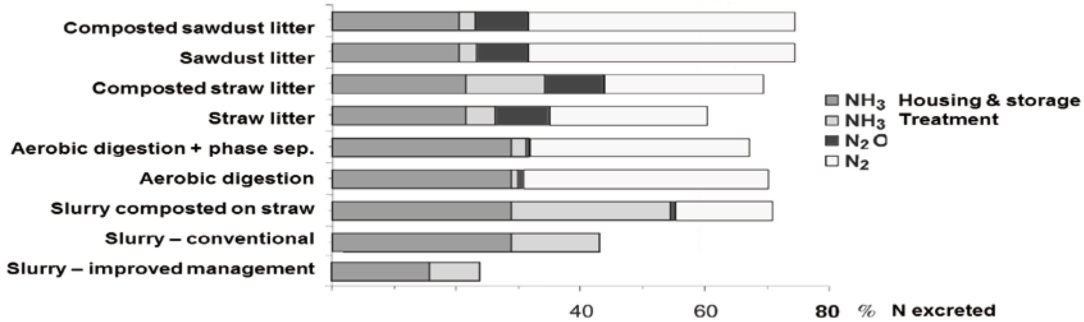

Figure 1: *Effect of different manure management strategies on gaseous N emissions (Bonneau et al., 2008a)*

nia concentration and pH, size of the emitting surface, temperature of the slurry and surface air speed, and duration of storage. For systems with full slatted floor and slurry storage under the floor, Rigolot *et al.* (2008b) estimated from a literature review, an EF of N-NH_3 of 0.24, indicating that on average 24% of N excreted was lost as NH_3 in the building. He also proposed different modulation of the EF according to the frequency of slurry removal (daily EF = 0.15; weekly EF = 0.20), type of slats, water dilution … The emission of NH_3 during outdoor storage depends on the duration and the type of storage. It is reduced when the slurry tank is covered. According to Corpen (2003) N-NH_3 emission factor during storage vary between less than 5% for short storage duration and/or storage cover to more than 10% for long storage without storage cover. The emission of N_2O from slurry is limited because of the anaerobic conditions. IPCC (2006) indicates an EF factor of 0.2% for N-N_2O.

In deep litter, both aerobic and anaerobic conditions are found allowing nitrification-denitrification processes to occur. This results in increased emissions of N_2 and N_2O compared to the slurry system. Only limited data are available in the literature for these systems. They were reviewed by Rigolot *et al.* (2008b) who proposed EF for N-NH_3 (20%), N-N_2O (6%) and total N (64%). Most of the difference between total N and (N-NH_3 + N-N_2O) emissions is N_2 which is produced by denitrification. Although litter management has only limited effects on total N emission it may affect its partition among N_2, N-NH_3 and N-N_2O emissions. The main factors affecting these emissions are litter type (straw or saw dust), animal density, quality of litter management and amount of substrate. For instance with straw bedding, a low animal density and appropriate management with sufficient amount of straw, EF for N-NH_3 and N-N_2O are reduced to about 8% and 2.5%, respectively. Conversely with inappropriate litter management, resulting in a dirty and wet litter, EF for N-NH_3 may exceed 53% (Rigolot *et al.*, 2008b).

In practice, the different manure management strategies results in a large variability in gaseous N emissions and consequently the amount of N that can be recycled as fertilizer. Bonneau *et al.* (2008) compared different strategies existing in France for pig manure collection, storage and treatment (solid phase separation, composting or aerobic management) (Fig. 1). Depending on the strategy used, total gaseous N emissions varied between less than 20% to almost 80%. This was associated with large differences in NH_3 and N_2O emissions, two gases with adverse effects on the environment, and also in the amount of N that could be recycled as fertilizer, resulting in an increased N deficit at system level.

Using the EF listed above, N flow was calculated for a 100-sow farrow-to-finish farm with two types of housing and manure management, either slatted floor with slurry or straw bedding (Table 2). Ammonia emission was reduced with straw bedding, whereas N_2O emission was increased. Total N emissions were higher with straw bedding, mainly because of N_2 emissions, resulting in less N in solid manure at spreading. According to the EU

Table 2: *Estimation of N flow (kg /year) in a farrow-to-finish farm with 100 sows, according to the management of manure (slurry or deep litter)*

	N excreted	N-NH_3	N-N_2O	N gaz	N at speading
Slurry system	11980	3160	24	3303	8677
% of N excreted	100	26.4	0.2	27.6	72.4
Straw deep litter system	11980	2435	565	6555	5425
% of N excreted	100	20.3	4.7	54.7	45.3

regulation on N spreading (170 kg/ha) the area required for manure spreading would be 51 and 32 ha, for slurry and deep-litter systems, respectively.

CH_4 emission from slurry can be estimated from standard values proposed by IPCC (2006) per pig or according to *Tier 2* methodology, also proposed by IPCC (2006). In this calculation CH_4 production depends on the amount of volatile solid (VS) excreted (ie undigested organic matter), the maximum methane producing capacity (m3/kg VS, about 0.4 m^3 CH_4 / kg VS) and conversion factor (MCF) for the management system considered (slurry of litter). The MCF depends on ambient temperature and is much higher for slurry (eg 18% at 10 °C), because of the anaerobic conditions that are favourable to methanogens bacteria, than in solid manure (eg 2.5% at 10 °C).

There are only very limited data on the emissions from effluents in outdoor production systems. It is generally assumed that there is no methane emission in these systems. Conversely, according to IPPC (2006), N_2O emission is increased compared to slurry systems, with an emission factor of 1% for N-N_2O, compared to 0.2% in slurry systems. Ammonia emission also occurs in outdoors system, with a 20% emission factor proposed by IPPC (2006). After excretion part of the N is lixiviated as NO_3. The extent of these losses is highly variable depending on the presence of a vegetal cover and the season. Basset Mens and van de Werf (2005) assumed that on average 35% of urinary N was lixiviated in case of a grass cover.

3 EVALUATION OF ENVIRONMENTAL IMPACT OF PIG FARMING SYSTEMS

Within the EU Q-PorkChains project (Bonneau *et al.*, 2011) an inventory of different tools available for assessing environmental sustainability of pig farms in various conventional and traditional production systems has been performed (Dourmad *et al.*, 2008). Among the different tools, the life cycle assessment (LCA) framework appeared the most appropriate, in agreement with van der Werf and Petit (2002) and Halberg *et al.* (2005). LCA-based methods are the only ones which consider the whole production chain and not only the farm itself. Moreover, LCA analysis allows taking into account local and global impacts, and indicators are values that can be expressed either per ha or per kg. This is important in the case of pig farms which are often highly dependent on imported feed, produced locally or abroad, and may export large amounts of manure to neighbour farms or at longer distance.

In LCA, the system considered is the whole production chain, as illustrated in Fig. 2, and not only the pig farm (Dourmad *et al.*, 2013). The main sub-system is the pig unit which includes the production of piglets and their raising until slaughter weight. This unit interacts with land use through the import of feed and the deposition/use of manure produced by the animals. The land used in case of outdoor pig raising is also considered within the system, but not its possible role in carbon storage. An inventory of resource use and emissions to the environment is performed over the whole system, and used for the calculation of different environmental impacts. Many environmental impacts can be calculated, the most common being climate change (CC), eutrophication potential (EP), acidification potential (AP), cumulative energy demand (CED), and land occupation (LO). The impacts are expressed according to a functional unit which is generally 1 kg of live weight pig leaving the pig unit or 1 ha of land occupied for the production of feed and the raising of animals.

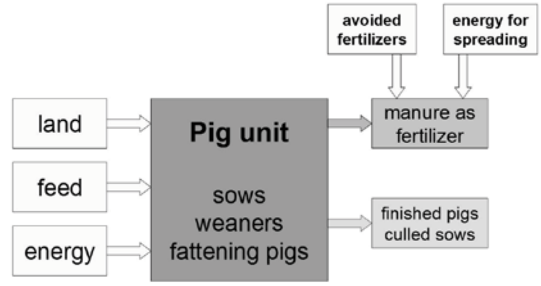

Figure 2: *Simplified description and boundaries of the pig production system*

This approach was used in the EU Q-PorkChains program to evaluate a large variety of European pig production systems already reported in table 1 for the calculation of N and P balance (Dourmad *et al.*, 2013). The environmental impacts of the different systems are presented per kg of pig produced and per ha of land occupied during a year (Table 3).

There were large differences between systems for all impact categories expressed per kg pig produced. On average, CC, EP, AP, CED and LO amounted 2.6 ($\pm$27%) kg eq CO_2, 0.022 ($\pm$41%) kg eq PO_4, 0.047 ($\pm$23%) kg eq SO_2, 18.2 ($\pm$26%) MJ, and 6.6 ($\pm$56%) m^2 per kg pig, respectively. There were substantial differences between extreme values for all impacts (× 2.1 to × 4.0). Excepted for some indicators, the values obtained in this study are within the range of values reported by de Vries and de Boer (2010).

On average in this study, CC per kg pig was the lowest for conventional systems and the highest for traditional systems (+54%), adapted-conventional and organic systems being intermediate. For conventional sys-

Table 3: Potential environmental impact in different European production systems [1], expressed per kg pig produced or per ha of land used

	Conventional	Adapted conventional	Organic	Traditional
Impact per kg live weight				
Climate change, kg eq CO_2	2.251	2.549	2.350	3.470
Eutrophication, kg eq PO_4	0.019	0.020	0.016	0.034
Acidification, kg eq SO_2	0.044	0.044	0.057	0.054
Energy demand, MJ	16.2	16.5	18.1	24.3
Land occupation, m^2	4.13	4.78	9.14	10.58
Impact per ha land use				
Climate change, kg eq CO_2	5467	5319	2606	3672
Eutrophication, kg eq PO_4	46.3	41.4	17.3	35.3
Acidification, kg eq SO_2	106.1	89.9	61.6	63.8
Energy demand, MJ (× 1000)	39.4	34.8	19.9	25.7
Pig produced, kg live weight	2429	2162	1114	1229

[1] Performance data obtained from 15 European production systems (Dourmad *et al.*, 2013) categorized according to Bonneau *et al.* (2011).

tems similar values were reported by Basset-Mens and van der Werf (2005) and Nguyen *et al.* (2011): 2.3 and 2.2 kg eq CO_2, respectively. For organic systems, Halberg *et al.* (2010) and Basset-Mens and van der Werf (2005) reported higher values mainly because of lower animal performance. Traditional systems have higher CC impact per kg pig. This is mainly due to the lower feed efficiency in these systems, in connection with the raising of traditional fat breeds.

EP per kg pig was similar for conventional and adapted-conventional systems; it was higher for traditional systems (+79%) and lower in organic systems (–16%). Among the evaluated systems, Organic systems had the lowest EP impact in connection with a much lower EP impact of feed in that system. For the same reason as for CC, Traditional systems had the highest EP impact.

AC per kg pig was similar for conventional and adapted conventional systems, whereas higher values were calculated for traditional and organic systems (+23 and +29%, respectively).

CED demand per kg pig was the lowest for conventional and adapted conventional systems and was higher for organic (+11%) and traditional (+50%) systems. The value for organic systems 18.1 MJ / kg pig is slightly lower than that published by Basset-Mens and van der Werf (2005; 22.2 MJ / kg pig). In relation with the use of larger amounts of feed, traditional systems have the highest CED impact per kg pig.

Marked differences were found for LO, between conventional and adapted conventional systems, on the one hand (4.1 and 4.8 m^2/kg pig, respectively), and traditional and organic systems, on the other hand (10.6 and 9.1 m^2/kg pig, respectively). These values for LO are partly outside the range of values (4.2 to 6.9 m^2 / kg live pig) reviewed by de Vries and de Boer (2010). This is mainly related to traditional and organic systems which obtained higher values for LO. For traditional systems the main reason is the outdoor raising of fattening pigs; if that area is not included in the calculation LO is reduced to 5.7 m^2/kg pig. In the case of Organic systems the larger LO is mainly related to the reduced yield of organic crops.

When expressed per ha of land occupied, there were also large differences between systems for all impact categories (× 2.6 to × 4.0 between extreme values, table 3). On average, CC per ha was the lowest for organic systems and the highest for conventional and adapted conventional, traditional systems being intermediate. EP per ha was substantially lower for organic systems; it was the highest for conventional systems (+170%) followed by adapted conventional and traditional. AP and CED per ha were lower for organic and traditional than for conventional and adapted conventional systems.

The relative contributions of feed production, animal housing, including indoor manure storage, and outdoor manure storage and spreading to CC, EP and AP are presented in Fig. 3. In all systems feed production has the major contribution to CC (65 to 75%), followed by animal housing and manure storage and spreading. The relative contributions of housing and manure tend to be lower in organic and traditional systems, compared to conventional and adapted conventional. Animal housing has the main contribution to AP (40 to 50%), the relative contribution of feed production to AP (25 to 30%) being much less than in the case of CC.

The use of plural functional unit is rather common in the application of LCA in agriculture, but still under debate. As suggested by different authors (Nemecek *et*

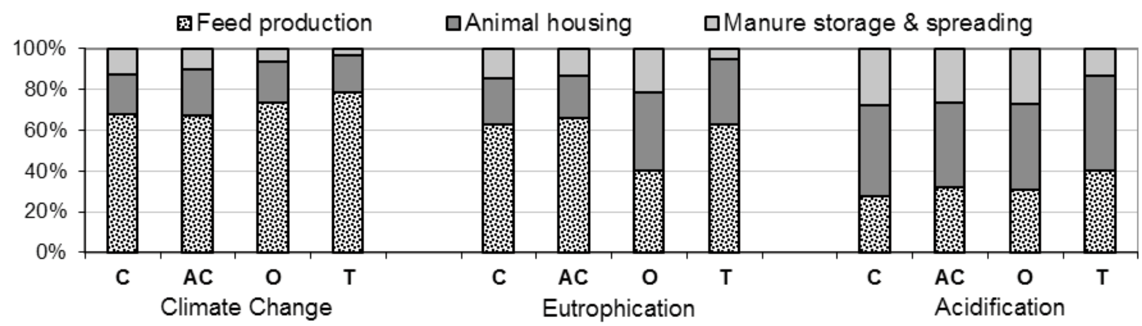

Figure 3: *Relative contribution of feed production, animal housing and manure management to climate change, eutrophication and acidification impacts, in conventional, adapted conventional, organic and traditional systems (from Dourmad et al., 2013)*

al., 2001; Payraudeau and van der Werf, 2005) this refers to two essential functions of agriculture: the production of food and land occupation. The results clearly indicate that the choice of the functional unit has a major effect on the ranking of systems in terms of environmental impact (Basset-Mens and van der Werf, 2005; Dourmad *et al.*, 2013). The degree of intensification inversely correlates with the environmental impact per kg pig, whereas the opposite is found when the impact is expressed per ha. This illustrates that neither intensive nor extensive farming systems are environmentally sustainable per se (Nemecek *et al.*, 2001).

4 CONCLUSION

Methods and data are available in the literature to quantify the nutrient flows at animal or pig unit level. However, most of these data are adapted for conventional production with indoor housing of pigs and the use of a complete feed. These different methods can also be used for traditional pig production systems but this requires some adaptations, especially concerning animal performance and emission factors. In case of outdoor raising of pigs specific emissions factors should be used and it may be expected that they may be highly dependent on the climate, the season and the composition of the vegetal cover, most often forest and pastureland. For instance, field studies show degradation of forest and pastureland by the pigs, in particular during the wet period (Casabianca, 2013). The impact of feed consumed as grass, chestnut or acorn on nutrient balance and gaseous emissions should also be better considered. Conversely, the use of grazed area may induce carbon storage in soils, reducing the global warming impact. These areas can also contribute to the improvement of natural biodiversity by providing a specific biotope. This means that specific data and complementary methodologies need to be developed for the environmental evaluation of these production systems.

In traditional systems the size and the composition of the outdoor area is generally described in the code of practices. However, the main objective is generally to improve or differentiate meat quality and not really to control the impact of pigs on their environment (Casabianca, 2013). As an indirect influence, it could be considered that natural resources are under control by the stocking rates, suggesting that this stocking rate could be used as a pressure indicator. This indicates we still need to improve our methodologies for assessing the environmental impact of pig production systems when based upon natural resources (Edwards and Casabianca, 1997).

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