GHG EMISSIONS FROM VARIOUS SYSTEMS OF DAIRY CATTLE HOUSING

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The ongoing global climate changes, characterised by the rising average temperature of Earth's surface, referred to as the greenhouse effect, are anthropogenic in origin. They include reactions taking place in the stratosphere and causing the disappearance of the ozone layer, which protects living organisms from ultraviolet radiation and highly energetic cosmic rays. This situation is blamed on the manufacturing and power industry. Carbon dioxide, water vapour and methane molecules can adsorb long-wave radiation in the infrared range, originating from the lithosphere and the lower troposphere. It was only in the 1980s that research results pointed to farming as an equally dangerous source of this effect. Cattle production contributes to this phenomenon. According to IPCC figures, over 50% of methane, one of the gases responsible for the global greenhouse effect, comes from the intestinal fermentation of cattle (Casey and Holden, 2005). The global carbon dioxide concentration grows by 2 ppm/year on the average. In cattle production. this gas is a product of respiration processes, both of the animals and the microflora contained in the rumen and that processing manure or liquid manure. In the EU, according to latest data, 10.2 million tons/year of methane is emitted (Moss et al., 2000). Greenhouse gas emissions are estimated using formulas and the appropriate ratios. These figures are a far cry from real measurements because they do not take into account the housing conditions and the microclimate (Dustan, 2002). Consequently, ny calculation on such a basis contains errors.

Animal production treated jointly with the fodder base contributes 18% of the global greenhouse effect. It is responsible for 9% of carbon dioxide, 37% of methane and 65% of nitrogen oxide emissions globally. It is therefore no surprise that a lot of attention is paid to the matters of animal farming in combating the greenhouse effect. However, what seems to be of key importance for this subject is to balance methane and nitrogen oxide emissions at every production stage, from the fodder base to manure management. Frequently reduction methods that would be effective at the feeding stage turn out, in an extended calculation that includes field production, to be counterproductive overall. With regard to carbon dioxide formed in respiratory processes, it is assumed to follow a short circulation with quick sequestration by photosynthesising plants. For this reason it does not concentrate in the atmosphere, and so is excluded from activities related to GHG mitigation and adaptation. Still different is the approach to the share of tje nitrogen cycle in the formation of GHG. Although the role of nitrogen compounds at the stage of animal feeding, housing and manure storage has an undeniable environmental significance, these matters have mainly been excluded to other panels, which in the EU are the Nitrates or IPPC Directives. In the context discussed here, nitrogen compounds are considered to be the precursors of nitrogen oxides emitted during the storage of farm animal manure.

As a consequence of the above assumptions, various forums concentrate mainly on the carbon cycle. The majority of animal consumption of this element is excreted into the environment through respiration. Only a small proportion is retained in animal tissues and milk. Between 20% and 40% of the carbon contained in the feed ration is not digested and is returned in the form of faeces. Depending on the species, it is estimated that per one unit of product, there are 17.4 kg of CO2 equivalent for sheep and goats, 13.0 kg for meat cattle, 6.35 kg for pigs, 4.57 kg for poultry and 1.32 kg for milk. Taking into account the productivity of the species listed, it becomes obvious why the greatest attention is paid to dairy cattle which naturally excretes methane while digesting.

Comparing GHG emissions between farming systems (intensive vs. extensive, e.g. organic), housing systems (bedding or beddingless), feeding systems (pasturage vs. complete feedingstuff) or ever individual countries from the same climate zone (differences in the genetic value of animals, digestibility of fodder, productivity etc.) yields rather ambiguous results. This is why it is best to use the aforementioned level of the CO_2 equivalent and not of individual gases, and within one topical field, e.g. liquid manure storage.

The problems of combating GHG emissions fall within three areas: mitigation, sequestration and adaptation. Mitigation covers the issues of estimating the amount of gasses released and reducing the phenomena. Statistics kept by the National Emissions Estimation Centre are based on general methods which do not account for the specific nature of Polish farming. The National Research Institute of Animal Production is successfully supporting this work to make the emissions so far reported for animal production more realistic. Great hopes can be attached to the possibility of moving to the so-called second type of the estimation formula, for which an individual national methodology approved by the IPCC must be developed. Sequestration refers to the storage of carbon compounds, particularly as part of cultivation and soil management. Adaptation deals with adapting human activities to the climate changes taking place.

With regard to animal production, GHG emissions can be reduced by feeding, breeding and technological means. Feeding methods that would have a large reduction potential have overwhelmingly not been developed in detail and are among expensive solutions exposed to the risk of production cost increase. Breeding methods turn out to be the cheapest, as they are in a sense implemented by the constant breeding improvement oriented towards raising production effectiveness. However, the potential of these methods is relatively limited. Technological solutions mainly concern animal faeces storage. Issues of building fitout are usually connected with another area, namely preventing the dispersal of nitrogen compounds and the release of odours.

The majority of farm GHG generation is due to producing fodder and its digestibility. The level of faeces production is also strictly connected with the quantity of fodder used. In meat production, emissions are tied to carcass quality - the more fat there is, the more emissions. Also the composition of the feed ration has a strong impact on the emission level. In monograstric animals this impact is relatively small, as only up to 50% of the total emissions are released in the intestines. In ruminants the emission level drops along with an increase in the feeding level and fodder digestibility. Methane production falls as feed ration concentration goes up. This also reduces nitrogen content of faeces, thus pushing down the emission of nitrogen oxides during natural fertiliser storage. By reducing the protein level of fodder for monogastric animals while at the same time improving its digestibility (adding enzymes, supplementing with synthetic aminoacids, multi-phase feeding), the quantity of excreted nitrogen – the precursor of nitrogen oxide – is reduced. However, compared to various types of pig feeding based on legume plants, on soybean or synthetic amino acids, the greatest reduction was achieved with a ration based on peas, and the lowest for soybean feeding. In the case of cattle such measures are not easy. Moving from feeding cattle with complete feedingstuff to pasturage feeding causes the methanogenesis occurring in the rumen to accelerate, so the emission goes up. However, if you account for the fact that these cattle defecate mainly directly onto the soil and there is no need to store and apply natural fertilisers, and in addition, no cereals are cultivated, the overall CO_2 emission is 20% lower. This is why, per unit of product, New Zealand emits only 800 kg eq CO_2/ton of milk, while the Netherlands as much as 1,200 kg eq CO_2/ton of milk. In the first country the pasturage system is still generally used, while in the EU feeding is based on cereals and no pasturing. The metabolic activity of rumen microflora causes hydrogen to be released and synthesised with the involvement of methane. Feeding strategies for reducing methane emissions from cattle housing are therefore aimed are reducing the quantity of hydrogen in the rumen, changing its final product, or replacing it with another one. If ruminants are fed with easier to digest feed, the quantity of gross energy used for life processes drops and the proportion used for production increases, so the GHG emissions are brought down.

Generally, the following should be included among feeding methods:

- Raising the concentration of ruminants' feed ration – up to 50% reduction in meat cattle, up to 9.5% reduction in dairy ones;
- Replacing cereal (corn) silage with grass silage - greater share of propionic fermentation - 10% reduction;
- Using natural feed supplements - saponins, tannins, rhubarb and garlic extracts reduce methane emissions by up to 20%;
- Changing the feeding scheme, improving pasture quality – introducing fresh grass with legumes reduces emissions by 10% due to the presence of active chemical compounds;
- Extending the pasturage period – 12% reduction;
- Adding fat or oil (linen, sunflower, other oil) - toxic to methane-producing microorganisms and protozoa, also stops fibre decomposition, but negatively impact animals themselves - up to 50% reduction;
- Ionophores - chemical compounds like monensin, antibacterial in action, improve digestibility by 6% and thus reduce the intake of dry mass, shift the balance of the rumen towards volatile fatty acids. Emission reduction up to 5%. Banned by the EU;
- Removing fauna from the rumen – protozoa elimination reduces methane emissions by over 50%.

Relatively little emphasis is placed on breeding-based reduction methods. The standard selection of animals for productivity and fodder utilisation also brings about improvements in gross energy utilisation and reduces GHG emissions. This method makes it possible to achieve up to 3% of reduction a year. In the context of milk quotas, more productive animals additionally reduce the headage. Analyses of the Institute of Animal Science to this effect were used by Poland to report the greatest emission reductions for 1990-1999. Improving the genetic potential of animals within breeds cuts the duration of their fattening, and so mitigates GHGs. Special animal selection for low GHG emissions is possible, but very expensive and therefore not used yet. Some research points to differences between specific genotypes of dairy cattle amounting to 10% of the methane emission level. However, there is no data on the heritability of this trait. Improvement of the animals' health condition and welfare also yields mitigation of up to 3%. The effectiveness of breeding procedures reduces the proportion of culls, and thus extends animals' longevity. This reduces their number and shortens non-productive periods which, with regard to emissions, are included in the cost of a production unit. Between 10% and 15% of GHG reduction is possible by these means.

The longer liquid manure is kept in anaerobic conditions and the higher the temperature, the greater the methane emissions. The production of nitrogen oxide requires aerobic conditions, so in the case of faeces or manure, its emission is greater than from natural liquid fertilisers. However, even the emission from the latter can be significant, particularly when they are applied to the soil. In some publications it is claimed that GHG emissions increase when pigs are housed on straw or sawdust. The presence of aeration (aerobic conditions) and the consequent reduction of methane emissions is more than offset in this case by the increase in released oxides. Still, a lot depends here on the procedures used and these results cannot be considered as confirmed, or even less as applicable in Poland. Research conducted by the Institute of Animal Science points to lower GHG emissions precisely from domestic bedding systems, coupled with a negligible level of nitrogen oxides, frequently even below the detection threshold. In the case of cattle. such great variability is not demonstrated and it is believed that aerobic conditions are similar, so emissions are also at a similar level. According to the Institute of Animal Science, domestic shallow bedding systems are 15% better than beddingless systems due to wastes being removed more frequently. Unlike feeding aspects analysed in past decades with a view to production efficiency, technological solutions to limit GHG release have not been developed yet. This is because the subject is relatively novel. At present, equipment used so far to reduce nitrogen dispersal and odour release is applied. The potential existing in this field should be assessed as significant and easier to roll out than feeding methods.

Technological solutions used to reduce GHGs should be considered to include:

The shallow bedding system in cattle housing – up to 15% of reduction, assuming frequent removal;

Self-cleaning floor system in pig housing – up to 25% reduction;

pH-modifying bedding additives – up to 10% reduction;

Microbiological additives to bedding – up to 20% reduction;

Covering liquid manure tanks – up to 40% reduction;

Burning off methane from liquid manure tanks – up to 70% reduction;

Manure firing – up to 80% reduction;

Filtering air from livestock buildings: 25% - 30% reduction depending on the method used, relative to ozone or ionizing treatment. Bio-filtration based on filter types developed so far does not influence this potential.

Biogas production – 100% reduction compared to manure storage.

Using renewable energy sources in animal production – no direct influence on reducing GHGs from farms, but indirectly, in the balance of the global warning cost of power generation, this can yield a 35% reduction equivalent. This applies to both building heating or ventilation and fodder production.

Taking into account the state of the matter described, the purpose of the research conducted was to determine the actual quantities of methane emitted from the most commonplace Polish housing systems of individual technological groups of cattle. So far, there has been no research in Poland dealing with this matter. Calculated emission magnitudes apply only to ammonia and methane (Pilarczyk, 1997; Sapek, 1995) and are in no way relevant.

Material and method

The research material consisted of black and white cattle (some 70% proportion of hf blood) from various technological groups, namely: milk cows, heifers and calves. Altogether 168 head of cattle were involved in the experiment (including 60 cows). The trials were conducted in three repetitions. Animals from particular technological groups were housed over 2 months (milk cows at the peak of lactation, heifers from 90 days old, calves from birth). They were housed in 6 climatic respiration chambers, each of which was fitted out with a different housing system. For the experiment, the solutions most widespread in Poland were adopted:

- bedding stall – an expanded clay (LECA) concrete floor covered with barley straw, solid manure removed once a day;
- a deep bedding stall – a LECA concrete floor covered with softwood sawdust, solid manure removed once a day;
- bedding stall – an expanded clay concrete floor covered with softwood sawdust, solid manure removed once a day;
- a deep bedding stall – bedding of softwood saw dust, bedding accumulating throughout the housing period, solid manure removed after the housing period;
- beddingless stall – expanded clay concrete floor, stall cleaned once a day with a shovel and water – only for heifers and calves;
- beddingless slated floor stall – cast iron slats over 2/3 of the box area, 1/3 of the area with LECA concrete, liquid manure flows off to a collecting gutter, cleaning with water once a day – for heifers.
- beddingless slated stall in the form of a raised cage for calves.

Climatic respiration chambers for individual categories had the same area per head. For every animal category, the amount of air exchanged per hour and head in accordance with standards was assumed (milk cows and dry cows: 375 m^3/h/head, heifers 250 m^3/h/head; calfs 100 m^3/h/head). Each chamber housed two stalls. All animals were fed in accordance with the scheme generally adopted at farms (according to INRA standards). The climatic chambers were located in a single building equipped with heating and cooling systems. Every chamber was supplied from a separate ventilation duct whose inlet was located outside the building, beyond the discharge zone of worn-out air. The temperature in the building and chambers was maintained within the thermal neutrality range depending on the technological group examined: (milk cows 16^{o}C; heifers 16^{o}C; calves 20^{o}C). Relative humidity was maintained within the 65% - 75% range. During individual repetitions gas concentrations were measured continuously using electrochemical and infrared probes by Dräger and a gas chromatograph. Microclimatic measurements were taken using automatic monitoring apparatuses on a continuous basis.

Results

Table 1 shows the results of microclimate parameter monitoring. These are in the upper zone of the optimum conditions for particular cattle categories. This situation was intended. What is important, courses of parameters not statistically different were maintained for individual groups, which rules out the role of the microclimate in the variability of emission levels.

Table 1.

Average values of microclimatic parameters inside chambers.

Parameter/ technological group	Housing system					
	Straw bedding	**Sawdust bedding**	**Deep straw bedding**	**Deep sawdust bedding**	**Beddingless**	**Slated stall**
Temperature (^oC)						
- **calves**	**-**	**-**	**19,2±2,1**	**18,9±2,9**	**-**	**19,0±2,4**
- **heifers**	**16,3±2,9**	**16,1±2,4**	**16,8±1,8**	**16,9±2,9**	**16,8±2,3**	**16,2±1,9**
- **cows**	**17,4±2,6**	**17,5±2,3**	**17,8±1,6**	**17,1±2,3**	**17,0±2,1**	**-**
Relative humidity (%)						
- **calves**	**-**	**-**	**72,1±5,2**	**73,4±4,6**	**-**	**73,2±4,1**
- **heifers**	**65,6±4,1**	**64,2±4,3**	**67,5±3,4**	**68,6±3,5**	**69,8±4,1**	**71,5±3,8**
- **cows**	**74,2±3,1**	**73,3±2,1**	**75,2±2,3**	**76,3±3,8**	**77,3±4,3**	**-**
Air flow rate (m/s)						
- **calves**						
- **heifers**	**-**	**-**	**0,19±0,05**	**0,19±0,04**	**-**	**0,18±0,03**
- **cows**	**0,15±0,04**	**0,14±0,05**	**0,15±0,04**	**0,16±0,04**	**0,16±0,05**	**0,21±0,02**
	0,22±0,04	**0,21±0,04**	**0,22±0,04**	**0,23±0,04**	**0,23±0,05**	**-**

For cows, the lowest methane emissions were detected in the case of shallow bedding of straw (108 kg/year/head) and sawdust (112.9 kg/year/head). The first one emitted statistically significantly less gases than a tying stall with sawdust bedding and than the remaining ones. A similar difference was confirmed in the case of deep bedding of the above materials. However, these were the systems that emitted the most methane (sawdust – 126.32 kg/year/head, straw – 123.53 kg/year/head). The emission from cows in a beddingless system (119.2 kg/year/head) was average and statistically different both from shallow bedding and deep bedding systems.

The described relationship between the lack and the presence of bedding material and its type was confirmed for the remaining technological groups of cattle. Heifers housed on shallow straw bedding were again characterised by the lowest emission in the group (56.3 kg/year/head), while the greatest came from animals on deep sawdust bedding (84.27 kg/year/head). Once again, these differences were statistically significant. For calves, methane emissions were statistically the lowest in the beddingless system (19.68 kg/year/head) as these animals were not analysed for housing in a shallow bedding system.

Table 2.

Level of gas emissions from basic housing systems of various technological cattle groups (kg/year/head).

Gaseous compounds	**Housing system**					
	Straw bedding	**Saw dust bedding**	**Deep straw bedding -**	**Deep sawdust bedding**	**Beddingless**	**Slated stall**
Milk cows						
- carbon dioxide	2664.8 aBCD	2545.3aEFg	2989.4 BEhi	2844.1 CFhij	2764.8 DGij	X
- methane	108.4abcd	112.91aefg	123.53behi	126.32cfhi	119.2dgij	X
- nitrogen oxides	0.032aBCD	0.045aeFG	0.062BehI	0.073CFhJ	0.416DGIJ	X
Heifers						
- carbon dioxide	1944.6abd	1823.8aefgH	2078.3beijk	1924.5fil	1998.2gj	2129.7dHkl
- methane	56.3BCde	57.4FGhi	79.32BFjkl	84.27CGjMN	66.73dhkMo	67.58eilNo
- nitrogen oxides	0.015a	0.016fghi	0.019bfjkl	0.021cgjm	0.022dhkn	0.024eilmn
Calves						
- carbon dioxide	X	X	1108.23ab	1046.3ac	X	987.8bc
- methane	X	X	21.21ab	24.47ac	X	19.68bc
- nitrogen oxides	X	X	0.006aB	0.004aC	X	0.003BC

aa – statistically significant differences; AA, BB – statistically highly significant differences

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With regard to carbon dioxide emissions, they obviously come from the respiratory process of cattle and the microflora contained in liquid manure and it mixture with the bedding. Although the official emission balances disregard respiratory process, it is worth noting their share determined by measurements. For milk cows, the statistically greatest emission was determined in the case of deep straw bedding (2,989.4 kg/head/year) and the lowest in the system using shallow sawdust bedding (2,545.3 kg/head/year). A similar relationship was found for housing heifers, whereas the greatest emissions were recorded from the slated floor system (2,129.7 kg/head/year). Due to the restricted possibilities for housing calves, carbon dioxide emissions were dominated by the deep straw bedding system followed by the sawdust and slated floor systems.

Nitrogen oxides were emitted in the greatest quantities in the beddingless system of milk cow housing (0.416 kg/head/year). The least of this gas was released from the shallow straw bedding system (0.032 kg/head/year). Identical statistical relationships were also recorded for the heifer group. For calves, the lowest emission was found in housing on grates.

Discussion of results

Microclimate monitoring results from the chambers have confirmed their autonomy assured by automatic air conditioning and exchange systems. The main purpose was independence from external weather conditions, stabilising the temperature within the optimum and thus obtaining reliable emission data (Yuwono et al., 1999). This is because in the case of cattle, temperature impacts the quantity of methane released (Misselbrook et al., 2005). Consequently, in the newest emission estimating methodologies, both IPPC and IPCC take account of the climatic differences between regions and set separate values of the B_o ratio (Dustan, 2002; Moss et al., 2000). The structure of the sub-floor part and the so-called manure drawer made it possible to collect and then analyse faeces, urine and manure or liquid manure. These elements generated additional emissions due to the housing conditions, apart from those of strictly animal origin caused by intestinal fermentation. The fact that these amounts are quite significant is proven by the data obtained. It is also confirmed by literature sources (Hao et al., 2001; Zhu et al., 2000; Powers et al., 1999). Every system differed in the level of methane emitted. The factor responsible for this is the high availability of organic carbon for methane bacteria and other anaerobes, which leads to the high intensity of methanogenesis (Mathison et al., 1998). The reason for differences between the straw and sawdust is due to the absorbability of both materials stemming from the arrangement of cellulose chains and the presence of tannins. The difference in emissions between shallow and deep bedding is due to the variability of oxygen conditions. A relatively shallow layer of straw or sawdust is much better aerated than a substrate of around half a meter. This is because the microflora active in methanogenesis is anaerobic (Hinz and Linke, 1998). In the case of the beddingless system, the anaerobic conditions prevailing in the manure channel are quite sufficient for these transformations to take place, but there is a shortage of carbon as a substrate. Similar conclusions were also reached by Brewer and Costello (1999) about poultry hosing or by Aneja (2000) for liquid pig manure or Jeppson (1999) for cattle. The difference in the emission level between groups is very easy to understand and is due to physiological factors – the development of the rumen, the stage of body growth and the type of feeding (Jeppsson, 1999).

Summarising the above data it should be noted that the figures here are much lower than those given in literature sources. Hence the different nature of Polish solutions and technological conditions makes it necessary to adjust the estimation algorithms of the emission level of methane as a greenhouse gas taken from other countries. This is because European and global production is based on beddingless systems and much higher productivity of animals.

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SUMMARY

The purpose of the research conducted was to estimate the level of methane emissions from housing different technological cattle groups. The experimental material consisted in 135 heads of black and white cattle: cows, heifers and calves. The animals were housed in 6 climatic respiration chambers, each of which was fitted out with a different housing system: bedding – deep and shallow bedding of sawdust or straw, and beddingless – with a full concrete floor or a grate. The results obtained unanimously indicate deep sawdust bedding systems (126.32 kg/head/year) as the source of the largest methane emissions. In the case of dairy cows, the lowest emission of this gas came from the shallow bedding system (108.4 kg/head/year). Similar relationships were recorded for the remaining technological groups of cattle. With regard to carbon dioxide emissions, their source is obviously the respiratory process of cattle and the microflora contained in liquid manure and it mixture with the litter. Although the official emission balances disregard respiratory process, it is worth noting their share determined by measurements. For milk cows, the statistically greatest emission was determined in the case of deep straw bedding (2,989.4 kg/head/year) and the lowest in the *system using shallow sawdust bedding (2,545.3 kg/head/year). A similar relationship was found for housing heifers, whereas the greatest emissions were recorded for the slated floor system (2,129.7 kg/head/year). Due to the restricted possibilities for housing calves, carbon dioxide emissions were dominated by the deep straw bedding system followed by sawdust and slated floor systems. Nitrogen oxides were emitted in the greatest quantities in the beddingless system of milk cow housing (0.416 kg/head/year). The least of this gas was released from the shallow straw bedding system (0.032 kg/head/year). Identical statistical relationships were also recorded for the heifer group. For calves, the lowest emission was recorded when housed on grates.*

Key words: cattle, GHG emission, housing systems