CALCULATION METHODOLOGY FOR CATTLE MANURE MANAGEMENT SYSTEMS BASED ON THE 2006 IPCC GUIDELINES

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Abstract. *The paper explains a methodology developed at Latvia University of Agriculture for calculating a percentage distribution for cattle manure management systems based on the 2006 IPCC recommendations. Calculations are based on the following input data: legal information on the output of manure and the dry content of manure, the length of grazing period, the size of herd at which transition from farmyard manure to liquid manure takes place as well as statistical data on the number of cattle and the amount of manure used for biogas production.*
Computer programs developed earlier may be conveniently employed for performing calculations.

Key words*: cattle, manure management system, percentage distribution of manure.*

INTRODUCTION

Since 1990, annual data on potential greenhouse gas (GHG) emissions from various economic activities, including manure management, has been collected in Latvia [1]. Previous GHG inventory data included seven groups of agricultural animals: cows, cattle, pigs, poultry, sheep, goats and horses. All kinds of manure management systems are divided into four groups: liquid manure, farmyard manure, pastures and manure for biogas production.
Yet, at present, a new GHG emission calculation methodology is introduced in Latvia in accordance with the 2006 IPCC Guidelines [2]. For this reason, a much more detailed percentage distribution of the kinds of manure management systems than the ones available in previous research studies and statistical summaries is necessary.
One of the most important groups of agricultural animals is cattle. According to the information available in the database of the Central Statistical Bureau of the Republic of Latvia [3],[4], 406 500 cattle, including 165 000 milk cows were registered in the country in 2013. However, according to national forecasts, the number of cattle might considerably increase.
At the same time, the percentage distribution of this group of agricultural animals has changed. Before 10-20 years, mostly milk cows were kept in Latvia, whereas at present a great focus is being placed on raising meat cattle. The reason is because hilly agricultural areas overgrown with shrubs that are not suitable for growing agricultural crops are exploited for grazing such cattle. And there are a lot of such agricultural areas, which are unsuitable for crops, in Latvia.
The manure management systems used in practice have changed. Earlier, milk cows were mainly stanchioned, producing farmyard manure, whereas now there is a gradual transition to keeping cattle unstanchioned and producing liquid manure.
Another novelty being observed in Latvia since 2007 is the production of biogas by partially using the manure of agricultural animals for this purpose, and at present approximately 40 biogas facilities are in operation in the country [5]. This factor additionally affects changes in GHG emissions and has to be taken into consideration in GHG emission calculations.
Accordingly, the aim of the present paper is to present a new methodology developed at Latvia University of Agriculture for calculating a percentage distribution for cattle manure management systems based on the 2006 IPCC Guidelines. Yet, in a similar way, a percentage distribution of manure may be calculated for other groups of agricultural animals.

MATERIALS AND METHODS

Based on the recommendations given in the 2006 IPCC Guidelines [2] and on the authors' considerations, cattle have to be classified into four separate subgroups that involve four kinds of manure management systems (Table 1).

Table 1

Cattle classification and the kinds of manure management systems

Cattle group	Manure management systems				Notes
	Pastures	Farmyard manure	Liquid manure, slurry	Anaerobic fermentation	
Milk cows	x	x	x	x*	Farmyard manure is produced on small farms and cows are put out to graze. Large farms produce liquid manure and do not exploit their pastures.
Calves of milk cows and young cattle less than 2 years of age	x	x		x*	Farmyard manure is produced; small farms put their young cattle out to graze from 6 months of age
Suckling cows and breeding bulls	x	x			Livestock are put out to graze in summer, while in winter the livestock are kept in sheds with bedding
Calves of suckling cows and young cattle less than 2 years of age	x	x			

* manure only from milk cow sheds where cows are kept unstanchioned in stalls are used for anaerobic fermentation

Further, the research is based on the following considerations:

– for calculations on manure management systems, first, the distribution of farmyard manure, liquid manure and manure left on pastures has to be identified, and only then the share of manure to be used for biogas production is calculated;
– solutions to keeping animals and producing manure are different for each cattle group; therefore the distribution of manure for each group has to be calculated by different formulas, given the specifics of keeping the animals of corresponding group.

For the milk cow group, a percentage distribution of manure management systems may be calculated as follows:

$$\lambda_{g.gan} = \frac{M_{g.gan}}{\sum M_g} \cdot 100,\ \lambda_{g.pak} = \frac{M_{g.pak}}{\sum M_g} \cdot 100,\ \lambda_{g.sk} = \frac{M_{g.sk}}{\sum M_g} \cdot 100, \quad (1, 2, 3)$$

where: $\lambda_{g.gan}$, $\lambda_{g.pak}$, $\lambda_{g.sk}$ – percentage distribution of cow manure: the shares of manure left on pastures, of farmyard manure and liquid manure, %;
$M_{g.gan}$, $M_{g.pak}$, $M_{g.sk}$ – amounts of manure left on pastures and of farmyard and liquid manure from cow sheds, t/year;
$\sum M_g$ – total amount of manure from milk cows, t/year.

A total amount of manure from milk cows is calculated by the following formula:

$$\sum M_g = M_{g.gan} + M_{g.pak} + M_{g.sk}, \quad (4)$$

An amount of manure left on pastures, given the fact that only the cows being kept stanchioned in a shed, producing farmyard manure, are put out to graze, is calculated as follows:

$$M_{g.gan} = k_{g.gan} \cdot Z_g \cdot \frac{\chi_{g.pak}}{100} \cdot q_{g.pak} \cdot \frac{S_{g.sv}}{S_{g.pak}}, \quad (5)$$

where: $k_{g.gan}$ – pasture utilisation rate;

Z_g – total number of cows, according to statistical data [3],[4];
$\chi_{g.pak}$ – proportion of cows producing farmyard manure, %;
$q_{g.pak}$ – output of farmyard manure at the average national milk yield, t/year;
$S_{g.sv}$, $S_{g.pak}$ – average dry matter of fresh manure (the mix of faeces and urine) as well as of farmyard manure, %.

A pasture utilisation rate is calculated as follows:

$$k_{g.gan} = \frac{t_{g.gan}}{24 \cdot 365} , \tag{6}$$

where: t_{gan} – average length of grazing period for cows, h/year.

A proportion of cows producing farmyard manure is obtained as follows:

$$\chi_{g\ pak} = \frac{Z_{g.pak}}{Z_g} \cdot 100 , \tag{7}$$

where: $Z_{g.pak}$ – number of cows producing farmyard manure in the country.

However, $\chi_{g.pak}$ may be calculated based on statistical data if knowing the size of herd at which transition from keeping cattle unstanchioned to keeping them stanchioned, i.e. transition from farmyard manure to liquid manure, takes place. The following formula may be used for this purpose:

$$\chi_{g.pak} = \chi_{g.pak.1} + \chi_{g.pak.2} + ... + \chi_{g.pak.n} , \tag{8}$$

where: $\chi_{g.pak1}$; $\chi_{g.pak2}$; $\chi_{g.pak.n}$ – percentages of cows in the herd's first group, second group and n-th group that produce farmyard manure (based on the distribution of cows by herd size available in statistics) [3],[4].

An amount of farmyard manure from milk cows is calculated as follows:

$$M_{g.pak} = (1 - k_{g.gan}) \cdot \frac{\chi_{g.pak}}{100} \cdot Z_g \cdot q_{g.pak} , \tag{9}$$

An amount of liquid manure from milk cows is obtained as follows:

$$M_{g.sk} = (1 - \frac{\chi_{g.pak}}{100}) \cdot Z_g \cdot q_{g.sk} , \tag{10}$$

where: $q_{g.sk}$ – output of liquid manure per cow, t/year.

Based on the formulas (4, 5, 9 and 10), one can obtain the following equation:

$$\sum M_g = \frac{k_{g.gan} \cdot \chi_{g.pak} \cdot Z_g \cdot q_{g.pak} \cdot S_{g.sv}}{100 \cdot S_{g.pak}} + \frac{(1 - k_{g.gan}) \cdot \chi_{g.pak} \cdot Z_g \cdot q_{g.pak}}{100} + (1 - \frac{\chi_{g.pak}}{100}) \cdot Z_g \cdot q_{g.sk} , \tag{11}$$

a share of manure left on pastures, %:

$$\lambda_{g.gan} = \frac{100 \cdot k_{g.gan} \cdot \chi_{g.pak} \cdot q_{g.pak} \cdot S_{g.sv}}{k_{g.gan} \cdot \chi_{g.pak} \cdot q_{g.pak} \cdot S_{g.sv} + S_{g.pak}[(1 - k_{g.gan}) \cdot \chi_{g.pak} \cdot q_{g.pak} + (100 - \chi_{g.pak}) \cdot q_{g.sk}]} , \tag{12}$$

a share of farmyard manure, %:

$$\lambda_{g.pak} = \frac{100 \cdot (1 - k_{g.gan}) \cdot \chi_{g.pak} \cdot q_{g.pak} \cdot S_{g.pak}}{k_{g.gan} \cdot \chi_{g.pak} \cdot q_{g.pak} \cdot S_{g.sv} + S_{g.pak}[(1 - k_{g.gan}) \cdot \chi_{g.pak} \cdot q_{g.pak} + (100 - \chi_{g.pak}) \cdot q_{g.sk}]}, \quad (13)$$

and a share of liquid manure, %:

$$\lambda_{g.sk} = \frac{100 \cdot (100 - \chi_{g.pak}) \cdot q_{g.sk} \cdot S_{g.pak}}{k_{g.gan} \cdot \chi_{g.pak} \cdot q_{g.pak} \cdot S_{g.sv} + S_{g.pak}[(1 - k_{g.gan}) \cdot \chi_{g.pak} \cdot q_{g.pak} + (100 - \chi_{g.pak}) \cdot q_{g.sk}]}. \quad (14)$$

The group of calves of milk cows and young cattle produces farmyard manure, but a part of the manure is left on pastures. Therefore, a total amount of manure is obtained as follows:

$$\sum M_{g.t} = M_{g.t.gan} + M_{g.t.pak}, \quad (15)$$

where: $M_{g.t..gan}$, $M_{g.t.pak}$ – amount of manure left on pastures and, accordingly, an amount of farmyard manure from calves of milk cows and young cattle less than 2 years of age, t/year.

An amount of manure left on pastures, given the fact only the calves of milk cows being kept stanchioned in a shed and young cattle are put out to graze:

$$M_{g.t.gan} = k_{g.t.gan} \cdot \frac{\chi_{g.pak}}{100} \cdot Z_{g.t} \cdot q_{g.t.pak} \cdot \frac{S_{g.t.sv}}{S_{g.t.pak}} \quad (16)$$

where: $k_{g.t.gan}$ – pasture utilisation rate for calves of milk cows and young cattle (calculated by Formula 7);
$Z_{g.t}$ – total number of calves and young cattle, based on statistical data;
$q_{g.t.pak}$ – average weighted output of farmyard manure from calves and young cattle of corresponding group, t/year;
$S_{t.j.sv}$, $S_{t.j.pak}$ – average dry matter of fresh manure (the mix of faeces and urine) as well as of farmyard manure for calves of milk cows and young cattle, %.

An amount of farmyard manure is derived as follows:

$$M_{g.t.pak} = (1 - k_{g.t.gan}) \cdot \frac{\chi_{g.pak}}{100} \cdot Z_{g.t} \cdot q_{g.t.pak} \cdot \frac{S_{g.t.sv}}{S_{g.pak}} + (1 - \frac{\chi_{g.pak}}{100}) \cdot Z_{g.t} \cdot q_{g.t.pak}, \quad (17)$$

Based on the formulas (15, 16 and 17), one can calculate a share of manure left on pastures, %:

$$\lambda_{g.t..gan} = \frac{100 \cdot k_{g.t.gan} \cdot \chi_{g.pak} \cdot S_{g.t.sv}}{\chi_{g.pak} \cdot S_{g.t.sv} + (100 - \chi_{g.pak}) \cdot S_{g.t.pak}}. \quad (18)$$

and a share of farmyard manure, %:

$$\lambda_{g.t.pak} = 100 - \lambda_{g.t.gan}. \quad (19)$$

Suckling cows and breeding bulls graze in pastures and stay in pasture sheds. Therefore they produce both farmyard manure and pasture manure, and in this case the distribution of manure is mainly determined by the pasture utilisation rate.
A total amount of manure:

$$\sum M_{l} = M_{l.gan} + M_{l.pak}, \quad (20)$$

where: $M_{l.gan}$, $M_{l.pak}$ – amounts of pasture manure and farmyard manure from suckling cows and breeding bulls, t/year.

An amount of manure left on pastures, t/year:

$$M_{l.gan} = k_{l.gan} \cdot Z_l \cdot q_{l.pak} \cdot \frac{S_{l.sv}}{S_{l.pak}} \tag{21}$$

where: $k_{l.gan}$ – pasture utilisation rate;
Z_l – total number of cattle of corresponding age group, based on statistical data;
$q_{l.pak}$ – average weighted output of farmyard manure from cattle of corresponding group, t/year;
$S_{l.sv}$, $S_{l.pak}$ – average dry matter of fresh manure (the mix of faeces and urine) as well as of farmyard manure for calves of milk cows and young cattle, %.

An amount of farmyard manure, t/year:

$$M_{l.pak} = (1 - k_{l.gan}) \cdot Z_l \cdot q_{l.pak}, \tag{22}$$

Based on the formulas (20, 21 and 22), one can obtain the following equation:

$$\sum M_l = \frac{Z_l[k_{l.gan} \cdot q_{l.pak} \cdot S_{l.sv} + (1 - k_{l.gan}) \cdot q_{l.pak} \cdot S_{l.pak}]}{S_{l.pak}} \tag{23}$$

Therefore, a share of manure left on pastures, %, is derived as follows:

$$\lambda_{l.gan} = \frac{100 \cdot k_{l.gan} \cdot S_{l.sv}}{k_{l.gan} \cdot S_{l.sv} + (1 - k_{l.gan}) \cdot S_{l.pak}}, \tag{24}$$

and a share of farmyard manure, %:

$$\lambda_{l.pak} = \frac{100 \cdot (1 - k_{l.gan}) \cdot S_{l.pak}}{k_{l.gan} \cdot S_{l.sv} + (1 - k_{l.gan}) \cdot S_{l.pak}} \tag{25}$$

Calves of suckling cows and young cattle, just like suckling cows and breeding bulls, graze in pastures and stay in pasture sheds. Therefore they also produce both farmyard manure and pasture manure, and the distribution of their manure may be calculated by similar formulas as in the previous case.

Calculation of the share of manure for biogas production. Liquid manure from milk cows as well as farmyard manure from calves and young cattle available in cattle sheds is used for biogas production. Manure from small milk cow sheds where livestock are kept stanchioned and therefore only farmyard manure is produced is not used for this purpose. Also, manure from meat cattle is not used for biogas production, as the largest share of this manure is left on pastures.

To calculate the share of manure used for biogas production for each cattle group included in Table 1, the amount of manure used for biogas production and the amount of manure obtained from each cattle group to be used for biogas production have to be known.

According to data provided by the Rural Support Service (RSS) [5], the total amount of cattle manure used for biogas production was estimated at 395150 t in 2013. Assuming that the amount of manure used for biogas production is proportional to the amount of manure from each cattle group, one can derive the following equation.

$$\psi_g = \psi_{g.t} = \frac{M_{b.l}}{M_{g.sk} + (100 - \chi_{g.pak}) \cdot M_{g.t.pak}}, \tag{26}$$

where: ψ_g, $\psi_{g.t}$ – ratios specifying the share of manure from milk cows as well as calves and young cattle that is used for biogas production;
$M_{b.l}$ – amount of cattle manure used for biogas production, based on RSS data, t/year;
$M_{g.sk}$ – amount of liquid manure from milk cows, i.e. cows kept in stalls, t/year;
$M_{g.t.pak}$ – amount of farmyard manure from calves of milk cows and young cattle, t/year.

Therefore, a share of liquid manure from milk cows used for biogas production, %, is derived as follows:

$$\lambda_{b.g.sk} = \psi_g \cdot \lambda_{g.sk}, \quad (27)$$

but a share of farmyard manure from calves of milk cows and young cattle, %:

$$\lambda_{b.g.t.pak} = \psi_{g.t} \cdot (1 - \frac{\chi_{g.pak}}{100}) \cdot \lambda_{g.t.pak}. \quad (28)$$

RESEARCH RESULTS

Data on the number of cattle and their distribution by herd size for 2013 provided by the Central Statistical Bureau [3],[4], information on the amount of manure used for biogas production provided by the Rural Support Service [5], information on the length of grazing period for cattle available in literatures [6],[7] as well as data on the output of manure and the content of dry matter for various species of agricultural animals given in Cabinet Regulation No 829 [8] were used to test the developed methodology.
The calculations on the share of cattle manure used for biogas production are summarised in Table 2.

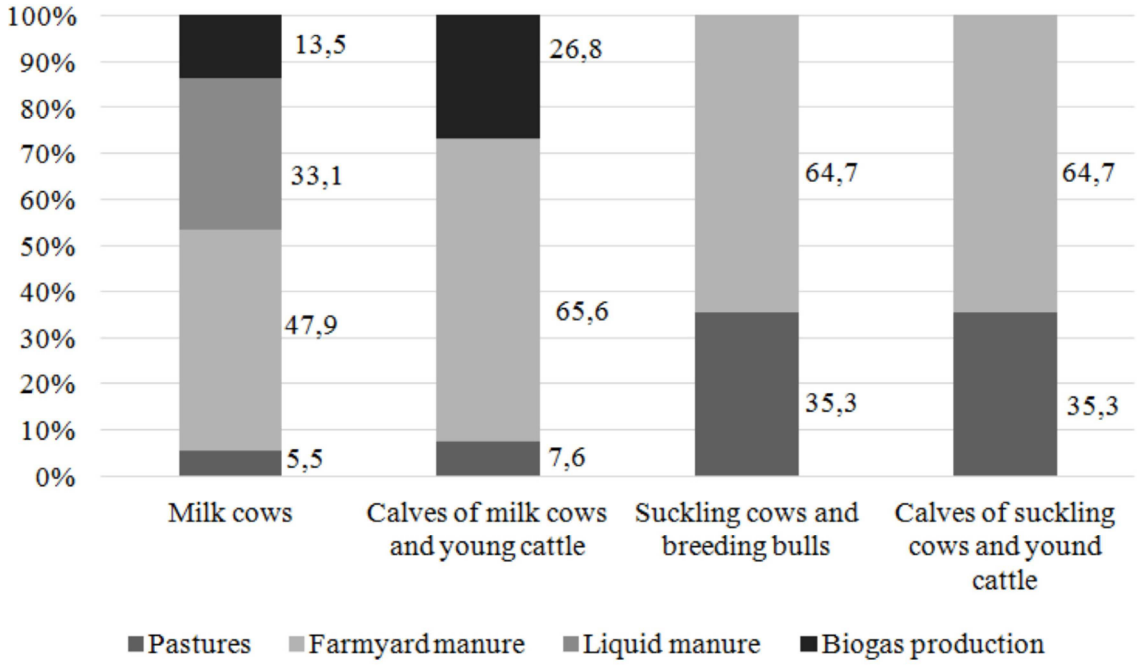
Table 2

Share of manure for biogas production and the amounts of manure produced (based on 2013 data)

Agricultural animal group	Number of animals whose manure may be used for biogas production, thou	Average output of manure		Share of manure used for biogas production, ratio ψ
		per animal, t/year	total, thou t	
Milk cows*	49.52	19.0	940.9	0.29
Young cattle (1-2 years of age)**	19.80	9.0	178.2	
Calves (less than 1 year of age)**	38.00	7.0	266.0	

* cows producing liquid manure, ** only the calves of milk cows and young cattle producing liquid manure

The distribution of manure calculated by the authors is presented in Figure 1.



Note: in the calculations the pasture utilisation rate was assumed to be 0.16 for milk cows and 0.50 for meat cattle (these data will be made more precise in further research studies by the authors); transition from farmyard manure to liquid manure, according to unpublished research studies by the authors, takes place at the herd size of 65 cows

Figure 1. **Percentage distribution of the cattle manure management systems (2013)**

As shown in Figure 1, farmyard manure accounted for the highest share among all the groups of cattle in 2013. More than 30% of the manure from meat cattle was left on pastures, while for milk cows as well as calves and young cattle it was 5.5% and 7.6%, respectively. The production of biogas consumed 13.5% of the liquid manure from milk cows and 26.8% of the farmyard manure from calves of milk cows and young cattle.

CONCLUSIONS

1. A methodology was developed for calculating a percentage distribution for cattle manure management systems based on data on the output of manure and the dry content of manure, the length of grazing period, the size of herd at which transition from farmyard manure to liquid manure takes place as well as the amount of manure used for biogas production. Part of the data may be obtained from legal documents and annual statistical reports, while the length of grazing period and the marginal size of herd at which transition from farmyard manure to liquid manure takes place can be identified through research studies.

2. The developed calculation methodology can serve as a basis for designing computer programs that can significantly facilitate the necessary calculations.

3. The calculations revealed that in 2013, approximately a half, or even more, of the manure from each group of cattle represented farmyard manure. Approximately 35% of the manure from meat cattle was left on pastures, while the production of biogas consumed 13.5% of the liquid manure from milk cows and 26.8% of the farmyard manure from calves of milk cows and young cattle.

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