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EMISSION OF AMMONIA, NITROUS OXIDE AND METHANE FROM HEN HOUSE IN DEEP LITTER/SLATTED FLOOR SYSTEM

Summary

The objective of this paper was to report a characterization of NH_3, N_2O and CH_4 concentrations and emissions from a commercial poultry farm under Polish conditions. The research was conducted in the deep litter/slatted floor poultry house in Greater Poland Region, where breeding hens (line ROSS 308) were housed. During 18 months, for 13 selected days the temperature and the concentration of NH_3, CH_4, and N_2O were monitored inside and outside the building. To measure the concentrations of the gases the photo-acoustic spectrometer Multi Gas Monitor Innova 1312 was used. Mean gas concentrations in the studied poultry house were: 21.3 ± 11.6 $mg \cdot m^{-3}$ for NH_3, 2.50 ± 1.23 $mg \cdot m^{-3}$ for N_2O and 6.3 ± 3.4 $mg \cdot m^{-3}$ for CH_4. Gas concentrations in the studied poultry house were correlated with the ventilation rate. The correlation coefficients were: $r_{NH3} = -0.92$, $r_{N2O} = -0.66$ and $r_{CH4} = 0.86$. The gas emission factors were on average 2.01 ± 0.53 $g \cdot day^{-1} \cdot hen^{-1}$ (284 ± 88 $g \cdot day^{-1} \cdot LU^{-1}$) for NH_3, 0.118 ± 0.087 $g \cdot day^{-1} \cdot hen^{-1}$ (16.8 ± 13.9 $g \cdot day^{-1} \cdot LU^{-1}$) for N_2O and 0.90 ± 0.77 $g \cdot day^{-1} \cdot hen^{-1}$ (130 ± 114 $g \cdot day^{-1} \cdot LU^{-1}$) for CH_4.

***Key words**: ammonia, greenhouse gases, emission, deep litter/slatted floor system, poultry*

EMISJA AMONIAKU, PODTLENKU AZOTU I METANU Z KURNIKA ŚCIÓŁKOWO-RUSZTOWEGO DLA KUR REPRODUKCYJNYCH

Streszczenie

Celem pracy było wyznaczenie stężeń oraz emisji amoniaku i gazów cieplarnianych z budynku ściółkowo-rusztowego dla kur nieśnych w polskich warunkach klimatycznych. Badania prowadzono w obiekcie zlokalizowanym w województwie wielkopolskim, gdzie były utrzymywane kury reprodukcyjne linii ROSS 308. W ciągu 18 miesięcy, przez 13 wybranych dni monitorowano temperaturę i stężenia NH_3, N_2O oraz CH_4. Do pomiaru stężeń badanych gazów na zewnątrz i wewnątrz budynku używano spektrometru foto-akustycznego Multi Gas Monitor Innova 1312. Średnie stężenia gazów w badanym kurniku były równe: $21,3 \pm 11,6$ $mg \cdot m^{-3}$ dla NH_3, $2,50 \pm 1,23$ $mg \cdot m^{-3}$ dla N_2O oraz $6,3 \pm 3,4$ $mg \cdot m^{-3}$ dla CH_4. Wskaźniki emisji badanych zanieczyszczeń gazowych średnio wynosiły $2,01 \pm 0,53$ $g \cdot dzień^{-1} \cdot szt.^{-1}$ (284 ± 88 $g \cdot dzień^{-1} \cdot DJP^{-1}$) dla NH_3, $0,118 \pm 0,087$ $g \cdot dzień^{-1} \cdot szt.^{-1}$ ($16,8 \pm 13,9$ $g \cdot dzień^{-1} \cdot DJP^{-1}$) dla N_2O oraz $0,90 \pm 0,77$ $g \cdot dzień^{-1} \cdot szt.^{-1}$ (130 ± 114 $g \cdot dzień^{-1} \cdot DJP^{-1}$) dla CH_4.

***Słowa kluczowe**: amoniak, gazy cieplarniane, emisja, kurnik ściółkowo-rusztowy, kury nieśne*

1. Introduction

Agriculture, including poultry houses, is a source of gaseous air pollutants. Laying and breeding hens are kept mainly in large commercial farms. This effectively reduces unit costs of production, but entails a negative environmental impact, not only in the vicinity of the farms [13, 14]. High stock density in modern buildings for poultry may reduce indoor air quality and emissions of ammonia (NH_3), nitrous oxide (N_2O), methane (CH_4), dust, pathogens and other micro-organisms [2]. In poultry production, the ammonia has been recognized as a major aerial pollutant, especially for laying and breeding hens. The release of NH_3 is one of the main ways of nitrogen emissions into the atmosphere and contributes to its subsequent deposition. The emitted ammonia undergoes the chemical transformation, which may cause negative effects, both in soil (acidification) and water (eutrophication) [20]. Moreover it leads to poor indoor air quality that affects the health of animals and workers. It has been reported that NH_3 concentrations and emissions in poultry houses are usually higher than those from other animal species, e.g.: dairy cattle and swine [8]. Greenhouse gases, including N_2O and CH_4 are other significant gaseous air pollutants. Methane and nitrous oxide emission from poultry facilities are lower if compared to other livestock productions, although both are greenhouse gases with a higher warming potential than carbon dioxide (CO_2) [1, 21].

Hens, depending on the type of production, are kept in cage or floor systems (deep litter or deep litter/slatted floor). Housing system and resulting from its choice: manure removal and storage system, the type of ventilation system, the use of litter and stock density have an impact on the formation and release of harmful gases. The composition and type of forage, weather conditions and geographical location may also affect gases emission [23].

The deep litter/slatted floor housing system for hens is a combination of bedding and non-litter systems. Limiting the littered area reduces the emission of harmful gases, mainly ammonia. On the other hand, the use of litter in part of hen house has a positive influence on the welfare of hens. There are many papers published in the last decades concerning ammonia and greenhouse gases emission from poultry houses. Most of them are about battery cage poultry houses [1, 6, 13, 24] less deep litter systems [5, 8, 16] and few deep litter/slatted floor housing systems [10, 17]. The studies were carried out mainly in western and northern Europe, North America and China. In the Polish literature, there is no long-term research of harmful gases emission from commercial facilities for laying and breeding hens.

The objective of this paper was to report a characterization of NH_3, N_2O and CH_4 concentrations and emissions from a commercial farm of breeding hens under Polish conditions.

2. Material and methods

Research facility

The research was conducted in the deep litter/slatted floor poultry house located in the Great Poland Region, where breeding hens (line ROSS 308) were housed from 18 to 58 week of age. The studied object had 110.4 m length and 15.2 m width. It was designed for 11,800 units (11,000 hens and 800 roosters) (Fig. 1).

Source: Authors' photos / Źródło: fot. autorów

Fig. 1. Studied poultry house
Rys. 1. Badany kurnik

The ratio of litter area (rye straw or wheat-rye straw) to area of the slatted floor was 2:1.The manure bin under slatted floor and nests (automatic eggs handling) were situated in the central part of the building along its axis (Fig. 2). The droppings and manure were removed after the end of production cycle. Animals were fed *ad libitum* (Tab. 1) and the processes of feeding and drinking were automated. The building was heated by 250 kW water boiler for solid fuel (coal dust or coal peas) and 6 heat exchangers (water-air) with a heating power of 45 kW each.

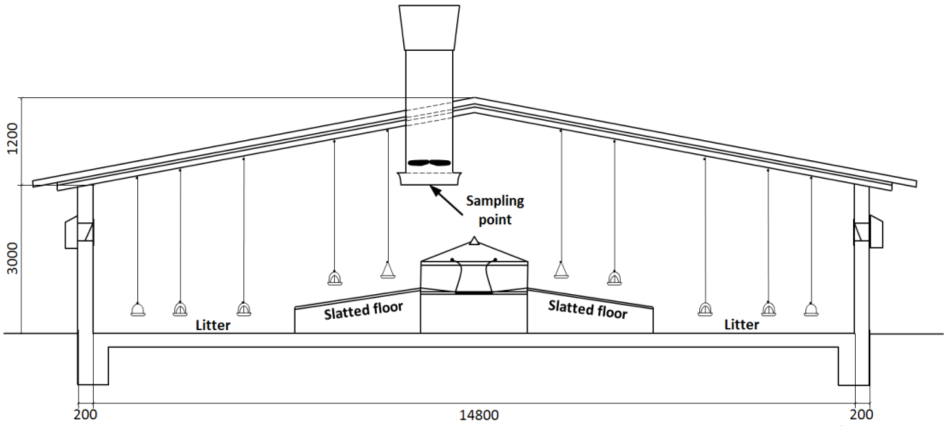
Table 1. Chemical composition of feed
Tab. 1. Skład chemiczny paszy

Feed composition	Content
Crude protein	16.5 %
Crude fat	3.30 %
Ash	11 %
Crude fiber	4 %
Metabolic energy	11.50 $MJ \cdot kg^{-1}$

Source: own elaboration / Źródło: opracowanie własne

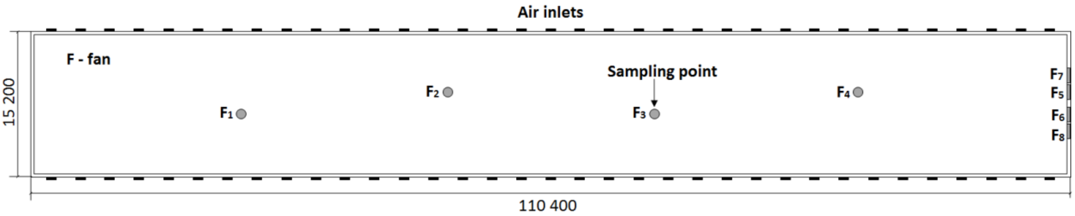
Ventilation rate

The studied poultry house was equipped with a negative pressure mechanical ventilation. The air was removed from the building by 4 roof fans (Big Dutchman FC080-6E), each with a nominal efficiency of 23,000 $m^3 \cdot h^{-1}$ and 4 wall fans (Big Dutchman Air Master EM 50), each with a nominal efficiency of 37,430 $m^3 \cdot h^{-1}$. The fresh air was provided by 70 wall inlets with regulation of flow rate (Fig. 3). The microclimate controller (Big Dutchman Viper) (Tab. 2), managed the work of fans and the degree of opening of the air inlets, based on the temperature of the air inside the poultry house and according to user settings.



Source: own elaboration / Źródło: opracowanie własne

Fig. 2. The cross-section of the poultry house
Rys 2. Przekrój budynku



Source: own elaboration / Źródło: opracowanie własne

Fig. 3. The layout of the poultry house
Rys. 3. Rzut przyziemia budynku

Table 2. The user setting of fans
Tab. 2. Ustawienie matrycy sterownika wentylacji

Ventilation mode	Temperature (ºC)	Operating time (s)	Break time (s)	Fans						Air flow by inlets (%)
				F_1	F_2	F_3	F_4	$F_{5,6}$	$F_{7,8}$	
0	20.0	60	240	c	c	c	c	•	•	32
1	20.1	130	170	c	c	c	c	•	•	32
2	20.6	900	60	c	c	c	c	•	•	33
3	21.1	-	-	f	f	f	f	•	•	42
4	22.0	-	-	f	f	f	f	•	•	52
5	23.0	-	-	f	f	f	f	f	•	62
6	23.7	-	-	f	f	f	f	f	•	72
7	24.7	-	-	f	f	f	f	f	•	81
8	25.5	-	-	f	f	f	f	f	•	85
9	26.5	-	-	f	f	f	•	f	f	90
10	27.8	-	-	f	f	f	•	f	f	100

c – operating mode on/off; f – continuous operation; • – fan off

Source: own elaboration / Źródło: opracowanie własne

The microclimate controller displayed the inside temperature, pressure inside the poultry house, the opening angle of flaps in air inlets and working fans. However, it was not equipped with the output for recording devices. Therefore, the ventilation rate was determined on the basis of temperature measurements, the user setting of fans and characteristics of used ventilation fans. During each 24-hour measurement series, the air temperature inside the poultry house was measured every 5 minutes by the logger Testo 175 H2. It was located close to the temperature sensor of microclimate controller.

Concentration and emission of gases

During 18 months, 13 series of measurements were made. The concentrations of ammonia, nitrous oxide and methane were measured every 5 minutes, in each of 24-hour series. The photo-acoustic spectrometer Multi Gas Monitor Innova 1312 was used to measure the concentrations of the gases inside and outside the building. It was equipped with the filters: type UA 0976 for NH_3 (detection limit 0.15 $mg\cdot m^{-3}$), type UA 0985 for N_2O (detection limit 0.06 $mg\cdot m^{-3}$) and type UA 0969 for CH_4 (detection limit 0.28 $mg\cdot m^{-3}$). Daily measurements were preceded by preliminary tests. The concentrations of studied gases were measured at the inlet to each of the air removing ducts in the building (Fig. 2). These values did not differ by more than 5%. Therefore, the point located at the inlet of air duct located in the central part of the poultry house was chosen as a representative sampling point (Fig. 3).

The emission of ammonia and greenhouse gases Eg ($g\cdot h^{-1}$) from studied poultry house calculated according to the equation (1):

$$E_g = VR\cdot(C_{in} - C_{out})\cdot 10^{-2} \tag{1}$$

where:
VR – ventilation rate ($m^3\cdot h^{-1}$),
C_{in} – gas concentration inside the building ($mg\cdot m^{-3}$),
C_{out} – gas concentration outside the building ($mg\cdot m^{-3}$).

The determined emission values were expressed per hen and per LU – emission factor EF ($g\cdot day^{-1}\cdot hen^{-1}$; $g\cdot day^{-1}\cdot LU^{-1}$). The livestock unit is 500 kg of animal body mass).

Statistical analyses

To determine the relationships between gases concentration and ventilation rate were calculate the Spearman's rank correlation coefficients. Spearman rank correlation test does not assume any assumptions about the distribution of the data and is the appropriate correlation analysis when the variables are measured on a scale that is at least ordinal. The significance level of regression coefficient was 0.05. The statistical analysis was made using the Statistica 12 software.

3. Results and discussion

Weather conditions have a direct impact on emissions of air pollutants. They affect the microclimate parameters in poultry houses, such as temperature and relative humidity, which determine the concentration of pollutants and air exchange in the building. Values of selected microclimate parameters and the mass and number of animals are shown in Tab. 3.

Concentrations of gases in the studied poultry house were correlated with the ventilation rate. For NH_3 and N_2O it was a negative correlation, and coefficients were -0.92 and -0.66 respectively. The strong positive correlation ($r = 0.86$) was noted for CH_4.

The mean concentration of NH_3 during the whole study was 21.3±11.6 $mg\cdot m^{-3}$ and it was greater than the published values (Tab. 4). Several times lower concentrations were measured in battery cage poultry houses, both with the belt system for manure removal [1, 10] and the deep-pit system [13, 24]. Low concentrations of NH_3 in those buildings may be due to the removal of droppings (emission source) to outside storages, in manure belt systems or the limited access to oxygen in deep-pit systems. Higher than in battery cage poultry houses the NH_3 concentration noted Dekker et al. [3] in aviary systems for hens with belt removal of the manure. In those buildings litter was used (floor, paddock, aviary), which contributed to the formation of NH_3. Nimmermark and Gustafsson [17] and Hayes et al. [10] conducted research in deep litter/slatted floor poultry houses. Nimmermark and Gustafsson [17] noted NH_3 concentration similar to the results of this study. The NH_3 concentration measured by Hayes et al. [10] was much lower than presented value in this work, but studied facility had the paddock, where manure was stored. Emission from the outside area was not included in total emission from hen house.

For N_2O, mean concentration was equal to 2.50±1.23 $mg\cdot m^{-3}$. This value was several times higher than the results presented in published papers (Tab. 4). The release of the gas has a random nature and depends on many factors which can not always be identified [19]. The high concentration of NH_3. may be one of the reasons. Ammonia is converted to N_2O during the incomplete nitrification and denitrification processes. The statistical analysis confirmed it in studied poultry house. The correlation coefficient between the concentration of N_2O and NH_3 was 0.80.

For CH_4, the housing system, manure removal system, feed composition, etc. had no significant effect on its concentration. Mean value of CH_4 concentration in these studies was 6.3±3.4 $mg \cdot m^{-3}$. It was similar to the results of other studies (Tab. 4).

Table 3. Selected parameters and indoor concentration of studied gases, mass and number of animals

Tab. 3. Wybrane parametry mikroklimatu, masa i liczba zwierząt

Day	Hen number	Mass of hen (kg)	Total mass (kg)	Indoor temperature (°C)	Ventilation rate ($m^3 \cdot s^{-1}$)	Indoor concentration ($mg \cdot m^{-3}$)		
						NH_3	N_2O	CH_4
I	9,682	3.10	30,050	24	17.16	13.5	1.03	3.2
II	9,621	3.12	30,050	29	26.61	9.5	1.06	7.7
III	9,583	3.71	35,600	28.8	26.61	10.5	1.92	11.5
IV	9,562	3.72	35,600	22.5	17.16	19.7	1.71	7.4
V	9,522	3.74	35,600	21.5	17.16	17.8	1.82	7.5
VI	9,504	3.86	36,640	20.1	15.77	12.2	1.92	9.0
VII	10,695	3.82	40,862	19.7	5.79	33.5	3.00	2.9
VIII	10,672	3.87	41,343	19.7	5.79	42.6	5.13	1.0
IX	11,716	2.96	34,704	24.1	18.98	19.4	4.16	9.7
X	11,582	3.22	37,345	24.2	28.93	10.7	2.22	11.3
XI	11,506	3.69	42,415	22.8	18.98	13.7	2.00	6.0
XII	11,461	4.10	47,030	21.7	8.3	32.8	3.35	3.0
XIII	11,403	4.13	47,142	20.6	2.3	41.7	3.60	2.2

Source: own elaboration / Źródło: opracowanie własne

Table 4. The published concentration of NH_3, N_2O and CH_4

Tab. 4. Stężenia NH_3, N_2O i CH_4 dostępne w literaturze przedmiotu

Gas concentration ($mg \cdot m^{-3}$)			Housing system	Source
NH_3	N_2O	CH_4		
6.7±4.0	-	-	Battery system with deep-pit	[13]
4.2±2.3	0.69±0.24	5.2±2.9	Battery system with deep-pit	[24]
1.7±0.1	-	-	Battery system with manure belts	[10]
2.0±1.4	0.50±0.20	4.6±1.8	Battery system with manure belts	[1]
13.9±7.5	0.52±0.10	4.0±1.9	Aviary system with manure belts, an outdoor run and a winter garden	[3]
6.5±6.3	-	7.1±4.8	Aviary system with manure belts	[11]
15.7±11.7	-	-	Depp litter system, slatted floor	[17]
5.7±0.1	-	-	Depp litter system, slatted floor, an outdoor run	[10]
21.3±11.6	**2.50±1.23**	**6.3±3.4**	**Depp litter system, slatted floor**	**Own study**

Source: own elaboration / Źródło: opracowanie własne

On the basis of the outside and inside concentration of studied gaseous pollutants and ventilation rate were calculated emission factors (E_F), expressed per hen and per LU were calculated (Tab. 5).

Table 5. The emission factors of NH_3, N_2O and CH_4

Tab. 5. Wskaźniki emisji NH_3, N_2O i CH_4

Day	Emission factor (E_F)					
	($g \cdot day^{-1} \cdot hen^{-1}$)			($g \cdot day^{-1} \cdot LU^{-1}$)		
	NH_3	N_2O	CH_4	NH_3	N_2O	CH_4
I	1.94	0.009	0.40	312	1.5	64
II	2.17	0.045	1.64	348	7.3	262
III	2.25	0.199	2.50	302	26.8	336
IV	2.93	0.026	0.91	393	3.5	123
V	2.59	0.153	1.04	346	20.4	138
VI	1.63	0.086	1.09	211	11.2	142
VII	1.52	0.052	0.05	199	6.8	6
VIII	1.93	0.202	0.01	249	26.0	1
IX	2.57	0.332	1.11	434	56.0	187
X	2.07	0.119	2.08	322	18.4	322
XI	1.84	0.135	0.70	250	18.3	95
XII	1.98	0.135	0.11	242	16.5	13
XIII	0.71	0.043	0.02	86	5.3	2

Source: own elaboration / Źródło: opracowanie własne

Table 6. The published emission factors of NH_3, N_2O and CH_4
Tab. 6. Wskaźniki emisji NH_3, N_2O i CH_4 dostępne w literaturze przedmiotu

Emission factor ($g\cdot day^{-1}\cdot hen^{-1}$; $g\cdot day^{-1}\cdot LU^{-1}$)			Housing system	Source
NH_3	N_2O	CH_4		
0.99; 330*			Battery system with deep-pit	[13]
ND; 298			Battery system with deep-pit	[12]
ND; 144*		ND; 25*	Battery system with deep-pit	[14]
0.13; 31*	0.009; 2.31*	0.11; 29*	Battery system with deep-pit	[24]
ND; 287			Battery system with manure scraper	[15]
ND; 197			Battery system with deep-pit	[22]
0.10; ND			Battery system with manure belts	[10]
0.12; 29*	0.005; 1.25*	0.09; 23*	Battery system with manure belts	[1]
0.41; 107*	0.003; 0.82*	0.08; 21*	Aviary system with manure belts, an outdoor run and a winter garden	[3]
0.15; 41		0.09; 25	Aviary system with manure belts	[11]
ND; 177			Deep litter system (England)	[8]
ND; 227			Deep litter system (Netherlands)	[8]
ND; 261			Deep litter system (Denmark)	[8]
	0.423*; ND	0.93*; ND	Deep litter system	[16]
0.32; ND			Depp litter system	[5]
0.38; ND			Depp litter system, slatted floor	[17]
0.50; ND			Depp litter system, slatted floor, an outdoor run	[10]
2.01; 284	**0.118; 16.8**	**0.90; 130**	**Depp litter system, slatted floor**	**Own study**

ND - no data; *recalculated data

Source: own elaboration / Źródło: opracowanie własne

The mean NH_3 emission factor was 2.01±0.53 $g\cdot day^{-1}\cdot hen^{-1}$ (284±88 $g\cdot day^{-1}\cdot LU^{-1}$). It is similar to the results of research in systems where manure was stored in the poultry house (battery cage system with deep-pit, deep litter system) [8, 12, 13, 15]. Lower emission factors were determined during studies in poultry houses with manure belt removal [1, 3, 10, 11]. But in those houses small amount of manure is in the buildings, most of it is stored outside. Therefore during the comparisons of such buildings with other systems the emission should also include that from outside storages. The lower values of NH_3 emission factor noted Eurich-Menden et al. [5], Nimmermark and Gustafsson [17] and Hayes et al. [10], in poultry houses with litter systems or deep litter/slatted floor systems. However, for litter systems, the differences may be due to many factors: the type and amount of litter, bedding frequency, animal activity, temperature of air and litter, air humidity, etc. [7, 9] (Tab. 6).

The mean emission factor of N_2O from studied object was equal to 0.118±0.087 $g\cdot day^{-1}\cdot hen^{-1}$ (16.8±13.9 $g\cdot day^{-1}\cdot LU^{-1}$). It is much higher than the results of studies conducted in battery cage poultry houses or aviary systems [1, 3, 24]. Higher emissions of N_2O from the studied poultry house may result from the using of litter, where is high content of NH_4^+, high pH and temperature. This affects the activity of nitrifying and denitrifying bacteria, what causes the release of that gas [4, 18]. Similar value of N_2O emission factor obtained Mennicken [16], conducting research in the poultry house with litter.

The determined mean emission factor of CH_4 was 0.90±0.77 $g\cdot day^{-1}\cdot hen^{-1}$ (130±114 $g\cdot day^{-1}\cdot LU^{-1}$), and the same as for N_2O, it was much higher than the emission factors obtained during research in battery cage poultry houses or aviary systems [1, 3, 24] and comparable with the results of research conducted in the poultry house with litter by Mennicken [16].

4. Conclusions

Mean concentrations of gases in the studied poultry house were 21.3±11.6 $mg\cdot m^{-3}$ for NH_3, 2.50±1.23 $mg\cdot m^{-3}$ for N_2O and 6.3±3.4 $mg\cdot m^{-3}$ for CH_4.

Gas concentrations in the studied poultry house were correlated with the ventilation rate. The correlation coefficients were: $r_{NH3} = -0.92$, $r_{N2O} = -0.66$ and $r_{CH4} = 0.86$ ($p \leq 0.05$).

The emission factors of studied gaseous pollutants were on average: 2.01±0.53 $g\cdot day^{-1}\cdot hen^{-1}$ (284±88 $g\cdot day^{-1}\cdot LU^{-1}$) for NH_3, 0.118±0.087 $g\cdot day^{-1}\cdot hen^{-1}$ (16.8±13.9 $g\cdot day^{-1}\cdot LU^{-1}$) for N_2O and 0.90±0.77 $g\cdot day^{-1}\cdot hen^{-1}$ (130±114 $g\cdot day^{-1}\cdot LU^{-1}$) for CH_4.

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