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# Ammonia, Nitrous Oxide, Methane, and VOC Emissions from a Straw Flow System for Fattening Pigs and Influence of the Additive „Effective Micro-Organisms (EM)"

Final report

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# 1 Introduction

Animal husbandry must aim at being animal and environmentally friendly. Especially in pig production very often a contradiction is seen between animal welfare and environmental protection. It is said that husbandry systems can either be animal or environmentally friendly. The consumers demand pork to be produced in houses that offer animal welfare. Straw use in the house is essential. On the other hand, environmentalists want pigs to be reared in systems without straw as they expect gaseous emissions to be lower in these systems. This conflict can only be solved if systems are developed that offer animal welfare and emit only little ammonia, nitrous oxide and methane.

Various international guidelines give default emissions factors for contrasting housing systems. Ammonia emissions are estimated according to the CORINAIR guidelines (EMEP/CORINAIR 2002). Nitrous oxide and methane emissions must be reported following the „Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories” (IPCC 1996). The UN/ECE „Expert Group on Ammonia Abatement“ of the „Executive Body for the Convention on Long-Range Transboundary Air Pollution“ is developing a document on „Control Techniques for Preventing and Abating Emissions of Ammonia“ (EBAIR 2002). It proposes measures for the mitigation of ammonia emissions. The last update from July 2002 distinguishes 19 slurry based systems for fattening pigs each of which is assigned a distinct emission factor. Only two straw based systems are classified. A further disaggregation into the various straw based systems that are operated on commercial farms is not possible due to a lack in data on emissions from straw based systems. However, emissions from straw based systems are likely to be very different depending e.g. on the amount of straw used, on the area that is fouled with manure, and on the frequency of manure removal.

As the knowledge on ammonia emissions from straw based systems for fattening pigs is very limited, these systems are assigned with high default emission factors. In Germany, extensive work was done with the aim to improve the ammonia emission inventory (DÖHLER ET AL. 2002). Here, two straw based systems were differentiated: the deep litter system and the Danish system. For the deep litter system, $N_2O$ and $NH_3$ emission factors were higher than the default emission factors applied for fully slatted floors. The Danish system was assigned a higher $NH_3$ emission factor. DÖHLER ET AL. (2002), however, point to the fact that these emission factors are connected with a considerable range of uncertainty. They come to the conclusion that the data basis for emissions from straw based systems is scarce and must be improved.

The deep litter system is the most commonly use straw based system for fattening pigs. It fulfils most of the pigs` needs and is an animal friendly system. But there may be serious disadvantages (Bartussek 1993b). A high amount of straw is required. The pigs are often more dirty than in other systems and especially during summer, the potential for malodour emissions is high. There is a strong indication that deep litter systems emit more $NH_3$, $N_2O$, and $CH_4$ than conventional fully slatted floors. In deep litter systems, there is no separation between excretion and lying area. The pigs excrete on the full pen area. The pen is fouled with a mixture of straw and excreta which is likely to enhance $NH_3$, $N_2O$, and $CH_4$ emissions.

The pigs´ natural behaviour is to keep the lying area dry and clean and to excrete elsewhere. The straw flow system offers the possibility to show this natural behaviour (see figure 1). Here, only a small area is fouled with manure. Daily manure removal is easily possible. The straw on the lying area stays dry and clean. This should lead to a reduction in emissions.

An animal friendly system for pigs must provide straw or other materials where pigs can show exploratory behaviour (WECHSLER 1997). It is important to renew the material daily or every second day (AMON ET AL. 2001). The normal behaviour of pigs is to separate a lying and an excretion area (STOLBA 1983). Animal friendly systems must thus at least be separated into two functional areas. Pigs spend a considerable part of the day with resting and lying (ZERBONI & GRAUVOGL 1984). They prefer non-perforated, soft lying areas (SAMBRAUS 1991).

The straw flow system is a very promising option for an animal and environmentally friendly rearing of fattening pigs on commercial farms (BARTUSSEK ET AL. 1995, ZALUDIK 1997). The level of emissions from this system is so far not known. Influencing factors and possible mitigation options have not been investigated. Robust emission factors must be available before the straw flow system will disseminate more widely on commercial farms. This requires exact full scale measurements that will pass international evaluation.

The Division of Agricultural Engineering of the Department of Sustainable Agricultural Systems of the University of Natural Resources and Applied Life Sciences Vienna conducts the research project "Assessment and mitigation of ammonia, nitrous oxide and methane emissions from a straw flow system for fattening pig" on behalf of the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management. The research is done in close co-operation with the Federal Research Institute for Alpine Regions, Gumpenstein..

With the support of Multikraft Ltd., additional aspects could be investigated in the research project. The additive "Effective Micro-Organisms (EM)" was applied in the animal house and emissions of $NH_3$, $N_2O$, $CH_4$, and VOC were followed. VOC emissions serve as an indicator for the potential of odour emissions. It should be clarified, if EM application resulted in an emission reduction.

# 2 The Straw Flow System for fattening pigs

## 2.1 Development of the Straw Flow System

The development of the straw flow system started in Scotland on 1987 (BARTUSSEK 1993b). Straw flow systems were then installed on commercial farms in many European countries. The design of the straw flow system followed the sloped floors systems that are used in cattle husbandry. The most important difference between both systems is design of the lying and the excretion area. Whereas cattle lie and excrete in the same area and thus produce a mixture of straw and manure, pigs keep the lying area in the straw flow system dry and clean and excrete only in the rear of the pen that is equipped with slats.

In Germany, the Federal Agricultural Research Centre Braunschweig-Völkenrode carries out research on the straw flow system since 1988 (GEBBE 1991). At the Centre for Rural Buildings of the Scottish Farm Investigation Unit of the University of Aberdeen the straw flow system was investigated and optimised (BRUCE 1991). Today, the system is commonly used in Great Britain for fattening pigs, sows and weaners.

In Austria, the Federal Research Institute for Alpine Regions, Gumpenstein assesses parameters of the straw flow system and works on its further optimisation since 1990 (BARTUSSEK 1993b, BARTUSSEK ET AL. 1995, 1999). The "System Gumpenstein" was developed. Here, the excretion area in the rear of the pen is equipped with a slightly elevated slatted floor. This helped to keep the pen and the animals clean. The following description concentrate on the "System Gumpenstein".

## 2.2 Design of the Straw Flow System

A straw flow system consists of several pens each of which holds 10 – 12 pigs. The length : width relation is 1.5 : 1. The lying area has twice the surface of the excretion area and is surrounded by opaque walls. Around the excretion area, the pens are separated by grids so that the pigs can see their neighbours. The non-perforated lying area has an inclination of 6 – 10 % (Figure 1). The slatted floor in the rear of the pen is elevated. Straw from the lying area is transported towards the excretion area and falls into the dung channel under the slats. The dung channel may be additionally equipped with a scraper for daily manure removal.

Feed is supplied at the front of the pen. All pigs can eat at the same time, which is an important factor for animal welfare. 50 – 100 g non chopped straw per pig and day are provided in the rack at the front of the pen. The pigs take the straw from the rack, play with it, chew it and thus transport it slowly to the rear of the pen where it falls in the gut under the slats. As only a small amount of straw is used, it is still possible to produce slurry. Work requirement for straw supply is *c.* 7 min per produced pig (BARTUSSEK & GEISPERGER 1998). The straw supply can ideally be used to control the pigs´ condition.

Water is supplied via nipple drinkers that are installed in the excretion area. Pigs are likely to suffer from thermal stress on warm days. They may then excrete on the lying area and lie on the excretion area. To avoid this, sprinklers are installed above the slats of the excretion area. They are automatically activated at intervals.

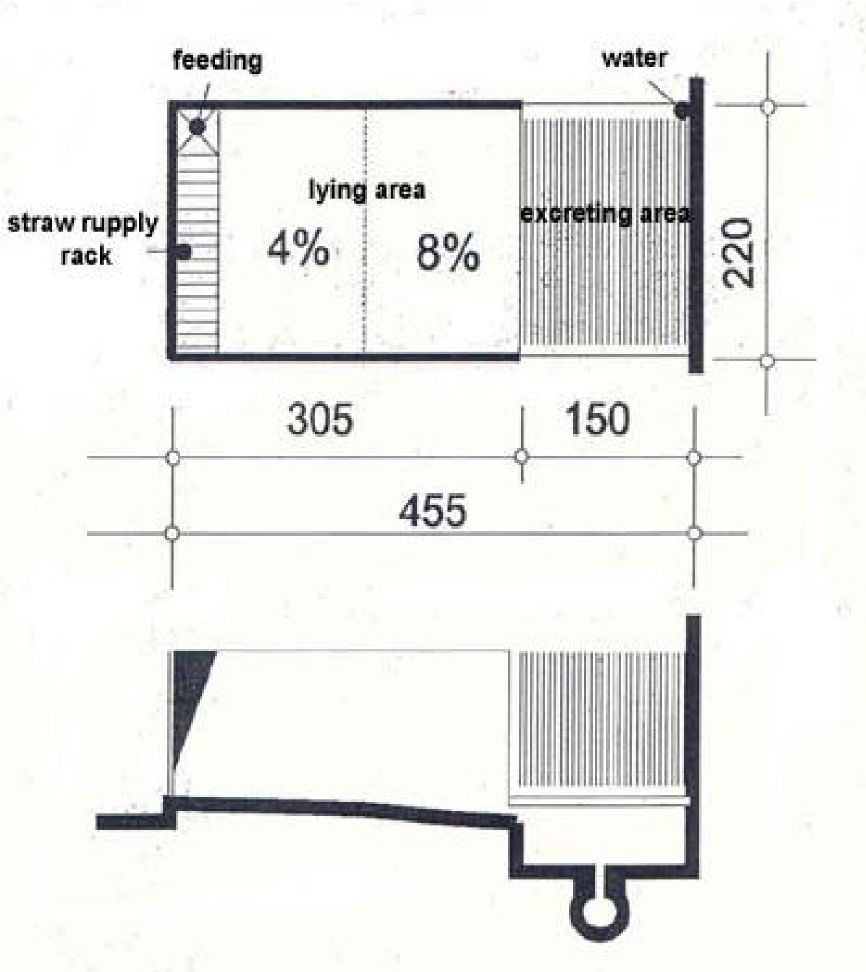


**Figure 1.** Design of the straw flow system for fattening pigs "System Gumpenstein" (after BARTUSSEK ET AL. 1995, 1999).

A straw flow pen offers 1 – 1.3 $m^2$ per pig. This is more than 40 % more than in conventional fully slatted floors and an important factor for animal welfare. Figure 2 shows the pigs` distribution at the beginning and at the end of the fattening period. Investment costs are not higher than in conventional fully slatted floors (BARTUSSEK & GEISPERGER 1998). The straw flow system can be operated economically efficient on commercial farms.

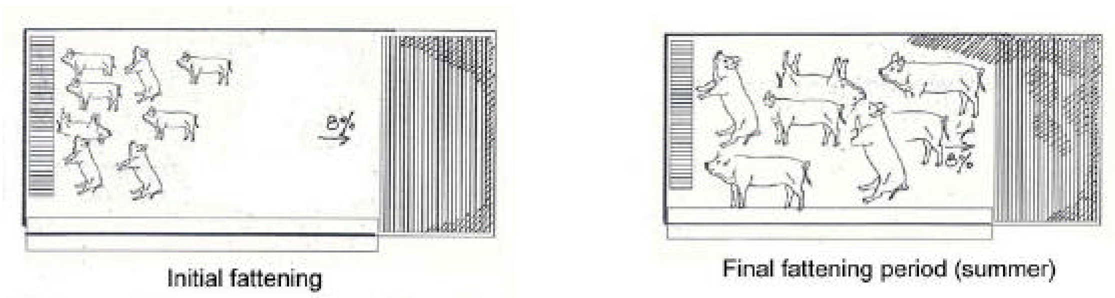


**Figure 2.** Distribution of lying pigs at the beginning and towards the end of the fattening period (after BARTUSSEK 1993b).

## 2.3 Animal welfare and technical aspects in the Straw Flow System

The straw flow system is considered to be an animal friendly and practical alternative to conventional fully slatted floors. The following section summarises the results from research on the "System Gumpenstein" (BARTUSSEK 1993b, BARTUSSEK ET AL. 1995, 1999, ZALUDIK 1997).

### 2.3.1 Separation of lying and excretion area

Pigs have an innate aversion against their excreta. They excrete in a position that prevents their bodies to be fouled with faeces and urine (ZERBONI & GRAUVOGL 1984). When pigs live in a natural habitat, they install excretion areas distant from the area where they lie, eat and are active (STOLBA 1983, WECHSLER 1997). The natural behaviour of pigs is to separate an area where they lie and an area where they excrete. This natural behaviour is as well shown in confined conditions. If the pen design – as in the straw flow system – offers a possibility to install an excretion area, the pigs will do so and will keep the lying area dry and clean. BARTUSSEK ET AL. (1995) and ZALUDIK (1997) showed that the pigs only excrete on the slats in the rear of the pen right from the beginning of the fattening. This behaviour results in a very low fouling of pigs and of the rest of the pen.

### 2.3.2 Low animal density

In an animal friendly system the pen must offer enough space for the pigs to keep a natural distance from their penmates. Only then it is possible that pigs can show their natural behaviour. For example the installation of an excretion area requires a certain distance from the lying area. If the animal density is too high, then the pigs will not distinguish a lying and an excretion area (ZERBONI & GRAUVOGL 1984). The level of aggression is as well correlated with animal density. The straw flow system offers 1 – 1.3 $m^2$ per pig. This is more than 40 % more than in conventional fully slatted floors and an important factor for animal welfare. The pigs are offered enough space to show their natural behaviour.

### 2.3.3 Straw use

Foraging and exploration are natural patterns of pig behaviour. Welfare recommendations thus require straw use in pig houses (WECHSLER 1997). Abnormal behaviour such as ear and tail biting occur more often in deprived housing systems that are operated without straw. If pigs do not have the possibility to show their innate explorative behaviour at straw or similar materials, then they direct it against their penmates (FRASER ET AL. 1991 in BARTUSSEK 2001). This may lead to serious injuries.

BARTUSSEK (1995) recommends the following:

- Medium size materials are preferred to fine chopped or coarse materials;
- Materials that can be further reduced to small pieces are preferred to non-destroyable materials;
- Organic materials are preferred to inorganic materials (exception: soil);
- The best solution is a daily application of fresh materials.

In a straw flow system, all these requirements are fulfilled. The pigs are daily offered non-chopped straw in the front of the pen. They take it out of the straw supply rack, work on it, chew it and transport it to the rear of the pen, where it falls in the dung channel under the elevated slats.

ZALUDIK (1997) wanted to find the optimum amount of straw that has to be littered down in a straw flow system. She littered down 50, and 100 g non-chopped straw per pig and day and she observed the pigs` reaction to the different amounts of straw. No difference in the length of straw directed behaviour was found between the two treatments. It may be concluded that 50 g non-chopped straw per pig and day are sufficient to allow the pigs to show their innate explorative behaviour. With this amount of straw, it is still possible to produce slurry with a viscosity that does not hinder pumping.

BARTUSSEK & GEISBERGER (1998) measured work requirement for the straw supply. Work requirement is low. Daily supply of 50 g non-chopped straw per pig requires a total of seven minutes per pig for the whole production period. Transport and processing of the straw are included in this value. The straw supply can ideally be used to control the pigs´ condition.

### 2.3.4 Non perforated lying area

Pigs prefer soft, non-perforated lying areas that should be situated calm, with not too much light and free from draught. Litter materials should be offered in the lying area (SAMBRAUS 1991). Resting behaviour takes a considerable part of the pigs daily routine. It plays an important role for the physical and psychic balance of an organism. The lying position of the pigs shows if the pen is constructed in such a way that it opens the possibility for natural lying and resting behaviour. With sufficient space and a comfortable lying area, the pigs rest in a lateral position with their legs fully stretched. This resting position is a hint for complete relaxation. In non-optimum environments, e.g. on fully slatted floors, pigs often show a dog-like sitting position that is considered an abnormal behaviour (HÖRNING 1999).

In the straw flow system, the lying area is non perforated and covered with straw. Opaque walls to the neighbouring pens and sufficient space enable and undisturbed resting behaviour.

### 2.3.5 Feeding and fattening performance

Eating behaviour of pigs is closely connected with explorative behaviour and with locomotion (HÖRNING 1999). In a straw flow system, the pigs are feed dry of liquid ad libitum. Restricted feeding is not common. All pigs can eat at the same time which is an important requirement for an animal friendly housing system.

BARTUSSEK ET AL. (1992) compared the fattening performance of pigs in a fully slatted floor system and in a Danish system with straw. They found an increase in the fattening performance when straw was applied. Similar observations were made in the straw flow system (BARTUSSEK ET AL. 1999). However, the data set was too small to allow a statistical evaluation of the results.

### 2.3.6 Sprinklers

Pigs are likely to suffer from thermal stress on warm summer days. They have no perspiratory glands. The layer of fat under the skin reduces the heat dissipation (HÖRNING 1999). Pigs that suffer from thermal stress may excrete on the lying area and wallow in their excreta. To avoid this, sprinklers are installed above the slats in the excretion area of the straw flow system “System Gumpenstein”. They are automatically activated at intervals and enable an effective cooling of the pigs (BARTUSSEK ET AL. 1995). Water requirement is low. ZALUDIK (1997) observed the positive effects of the sprinklers. Sprinkler activation avoids that pigs lie on the slats of the excretion area. The fouling of the animals and of the pen was low, animal welfare was positively influenced.

### 2.3.7 Economic efficiency

A straw flow system offers about 40 % more space than a conventional fully slatted floor system. Despite this increase in space, building costs are not higher (BARTUSSEK & GEISPERGER 1998). A straw flow system can easily be installed in existing buildings, it is not necessary to have a new building. This is another very important aspect of cost effectiveness. BARTUSSEK (1993a) found very good performances in the straw flow system. The fattening period lasted between 79.5 and 87.5 days. Daily weight gain was 788 to 895 g. Feed intake: weight gain ratio was 2.64 – 2.88.

# 3 Emissions from a Straw Flow System for fattening pigs

Emissions of $NH_3$, $N_2O$, $CH_4$ and VOC were measured from a commercial straw flow system for fattening pigs before and after spraying of "Effective Micro-Organisms (EM)" in the animal house. This section describes the experimental design and gives an overview on the results.

## 3.1 Experimental design

### 3.1.1 Straw Flow System

Emissions of $NH_3$, $N_2O$, $CH_4$, and VOC were measured at a commercial farm in Upper Austria. The animal house consists of three fully separated compartments. Each compartment is forced ventilated by one central exhaust fan. Ventilation rate is automatically regulated to keep indoor temperature constant. The compartments are separated into 16 pens that hold 10 – 12 pigs. The pens are grouped to the right and left side of a central feeding alley. The upper part of the non-perforated concrete area is 1.6 m long and has a slope of 3 %. The lower part is 1.6 m long and has a slope of 8 %. The elevated slats in the rear of the pen are 1.5 m long. This sums up to a total length of 4.7 m. The pen width is 2 m.

The feeding trough is situated at the long side of the non perforated area. It offers a length of 35 cm per pig so that all pigs can eat at the same time which is an important pre-requisite for an animal friendly housing system for pigs. A nipple drinker is installed above the slats. The lying area is surrounded by opaque walls. Around the excretion area, the pens are separated by grids so that the pigs can see their neighbours. The slatted area in the rear of the pen is elevated. The slit between the elevated slats and the lying area must be 10 – 12 cm high and must cover the whole width of the pen (BARTUSSEK 1993a). Straw from the lying area is transported towards the excretion area and falls into the dung channel under the slats. The dung channel is equipped with a scraper in two of the three compartments. The scraper removes the manure to an outside store once a day. In the third compartment, the manure flows by gravity to the outside store.

Pigs are likely to suffer from thermal stress on warm days. They may then excrete on the lying area and lie on the excretion area. To avoid this, sprinklers are installed above the slats of the excretion area. They spray 0.8 l water per minute at a pressure of 3 bar. On warm days, the sprinklers are automatically operated every two hours for three minutes. This not only helps the pigs to avoid thermal stress, but as well keeps dust levels in the house on a low level.

A straw supply rack is situated at the front of the pen that faces the feeding alley. 50 g non chopped straw per pig are supplied every day. The pigs take the straw out of the straw supply rack, work on it, chew it and transport it to the rear of the pen, where it falls in the dung channel under the elevated slats. The limited straw supply and the intensive reduction to small pieces by the pigs make it possible to produce liquid slurry in a straw based housing system for fattening pigs.

The pigs in each compartment are of nearly the same age. The pigs´ age and weight varies between different compartments. This makes it possible to measure emissions from different stages of fattening under the same conditions and under the same climate. The influence of the pigs´ age and weight on the emissions can be found out with this experimental design.

Liquid feed is supplied to the pigs. It consists of 54 % maize, 21.7 % cereals, 21.7 soya, and 2.8 % minerals. The feed composition is not adjusted to the stage of fattening. No phase feeding is carried out.

### 3.1.2 Emission measurements

Emission measurements were done with the measuring device of the Division of Agricultural Engineering (ILT). The device was developed by ILT and has been internationally evaluated. It looks back to several successful applications in various ILT research projects.

Exhaust air gas samples were taken in the central exhaust fans in each compartment. A pump transported the samples through a heated gas probe to the gas analysers. It is essential to temperate the gas probe above ambient air temperature to avoid condensing of $NH_3$ on the way from the central exhaust fan to the gas analysers. Condensing would result in wrong data on the level of $NH_3$ emissions.

Air flow was continuously recorded in each central exhaust fan. Gaseous losses are quantified by the multiplication of air flow and gas concentration. A computer based macro controls the measurements. Emissions were continuously measured 24 hours a day. Climatic parameters were measured every hour inside and outside the animal house.

**FTIR spectroscope.** If environmental impacts of manure management systems are to be assessed, it is important to follow a whole-systems-approach. This means, that all gaseous compounds that have negative environmental impacts have to be measured simultaneously. FTIR spectroscopy offers a reliable possibility for continuous online detection of $NH_3$, $N_2O$, $CH_4$ and $CO_2$ in the field.

FTIR spectroscopy is based on the principle that individual gases have distinct infrared absorption features. This enables the simultaneous measurement of several gases with one instrument since every IR spectrum contains the information of all IR radiation absorbing gases between a radiation source and a detector.

Exhaust air from animal houses or manure stores is a mixture of up to 200 different gaseous components. In order to avoid cross-sensitivities that would result in wrong concentration values, the spectral resolution of the FTIR spectroscope has to be high. The applied FTIR spectroscope has a spectral resolution of 0.25 $cm^{-1}$. It is operated with a White cell with 8 m light path (WHITE 1942). The detection limit is 0.5 ppm for ammonia and ambient air level for carbon dioxide, methane, and nitrous oxide. Gas concentrations in absorption spectra collected by the FTIR spectroscope are quantified by multivariate calibration methods.

**Volatile Organic Carbons Analyser.** VOC concentrations were analysed by a flame ionisation detector (J.U.M Engineering®, VOC analyser Model VE 7). Gas samples are pumped into the analyser and burned at 190 °C. Organic carbon is oxidised and detected as carbon ion. VOC concentration was measured every 5 minutes. Every second day, the VOC analyser was calibrated with zero gas ($N_2$) and 50 ppm $CH_4$. VOC emissions are expressed as $CH_4$ equivalents.

The VOC content can give a hint on potential odorous emissions from substrates. The higher the VOC content the higher the potential for odorous emissions. However, it is at the moment not possible to quantitatively correlate VS emissions with odour emissions.

**PC based programme for data collection.** Continuous gas concentration analysis was enabled by a computer based programme. The programme controls the multi-point sampler and the FTIR spectroscope. It starts with the collection of fresh air outside the animal house. Fresh air is continuously sucked through the FTIR gas cell at a rate of 1l $min^{-1}$. Three absorption spectra are collected for gas concentration analysis of fresh air. Then the PC based programme opens the exhaust air valve of the multi-point sampler. The FTIR gas cell is purged with exhaust air for ten minutes before collection of three absorption spectra starts. When three exhaust air spectra have been collected, the fresh air valve of the multi-point sampler is opened again. The FTIR gas cell is purged for 10 minutes with fresh air and then the cycle starts again from the beginning. The cycle is continuously repeated until the PC based programme is stopped by hand.

**Calculation of the emission rate**. The emission rate g $h^{-1}$ is calculated by multiplying gas concentration (g $m^{-3}$) and ventilation rate ($m^3$ $h^{-1}$). FTIR spectroscope and VOC analyser give gas concentrations in ppm. Gas concentrations given in ppm can be transferred to gas concentrations in mg $m^{-3}$, if molecular weight and molar volume are known. Molar volume depends on atmospheric pressure and on temperature. The temperature in the gas probes and in the gas cell was constantly kept at 45 °C. Atmospheric pressure was measured on an hourly basis and included in the calculation of gas concentrations.

Gas concentrations were alternately measured in the fresh air outside the animal house and in the exhaust air taken from the central exhaust fans. Fresh air concentrations were measured three times and then exhaust air concentrations were measured three times. Emission rate is calculated from the mean exhaust air gas concentration minus the mean fresh air concentration multiplied by the air flow rate that is measured by the fan based flow meter.

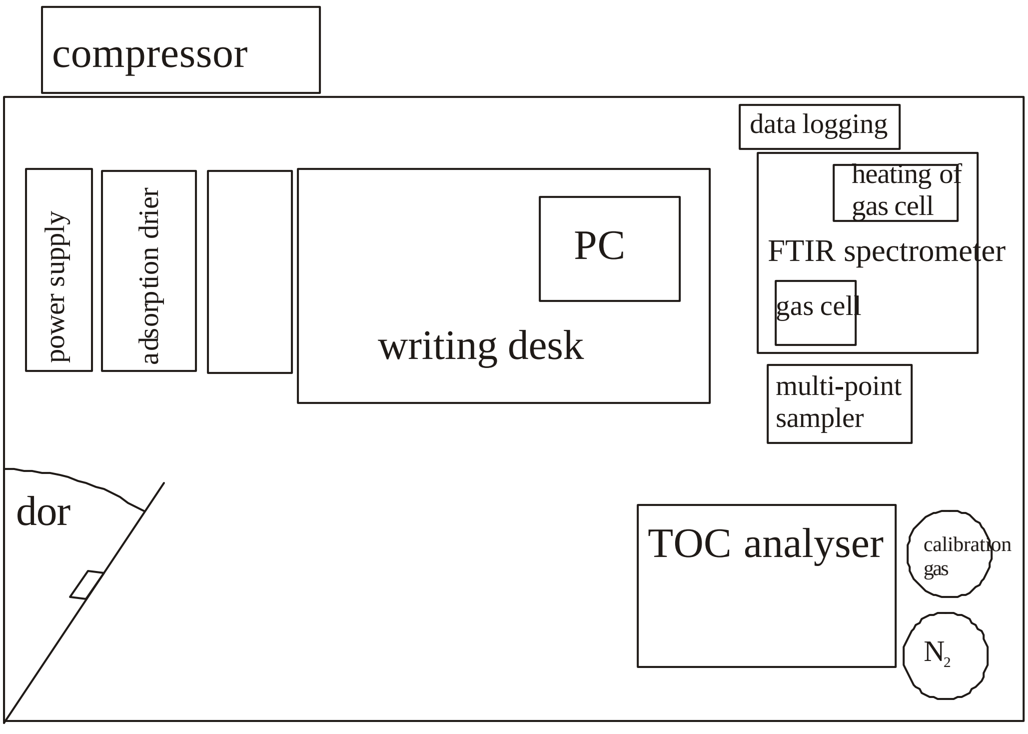


**Figure 3.** Mobile office for quantification of $NH_3$, $N_2O$, and $CH_4$ emissions in the field

**Mobile office.** Online measurements in the field require measurement instruments and PC to be installed in the field. ILT constructed a "mobile office" in a trailer that can be moved near the emitting sources. The trailer contains a writing desk, a PC, the FTIR spectroscope, the VOC analyser, the multi-point sampler, and the automatic data logging for slurry temperature and air flow rate (figure 3).

The FTIR spectroscope is securely situated in the back corner of the trailer and sheltered from dust and dirt by a wooden cover. Gas cell and sampling probes are constantly heated at 45 °C by a heater that stands near the FTIR spectroscope. The multi-point sampler is installed close to the FTIR spectroscope. The FTIR spectroscope has to be continuously purged with dry, $CO_2$ free air. An adsorption drier that is connected to a compressor filters water and $CO_2$ from ambient air and purges the FTIR spectroscope with the clean air. The VOC analyser stands beside the FTIR spectroscope. Calibration gas and $N_2$ needed for calibrating the VOC analyser are fixed to the wall of the trailer.

### 3.1.3. Course of emission measurements

Table 1 gives an overview on the course of emission measurements from the commercial straw flow system for fattening pigs. Prior to the experiments, the ILT measurement device was installed on the research station of the University of Natural Resources and Applied Life Sciences, in Gross Enzersdorf (Lower Austria). On 2003-07-07 the measurement device was transported from Gross Enzersdorf to the commercial pig farm in Upper Austria were it was installed on the same day. The FTIR spectrometer is a sensitive instrument that requires constant power supply and purging with dry and clean air. It may be taken out of operation only for a few hours.

**Table 1.** Course of emission measurements from the commercial straw flow system for fattening pigs.

| *Date* | *Action* |
|---|---|
| 2003-0707 | Transport of ILT measurement device from the research station at Gross Enzersdorf (Lower Austria) to the straw flow system for fattening pigs in Weng (Upper Austria)<br>Installation of the measurement device at the straw flow system |
| 2003-07-08<br>to<br>2003-07-13 | Test run for the emission measurements at the commercial straw flow system |
| 2003-07-14<br>to<br>2004-04-20 | Continuous emission measurements at the straw flow system for fattening pigs;<br>24 hours a day<br>Measuring cycle: 2 days compartment 1 – 2 days compartment 2 – 2 days compartment 3 |
| 2004-04-231 | De-installation of the measurement device at the straw flow system in Upper Austria and transport back to Gross Enzersdorf |

The measurement device was installed on the commercial farm in Upper Austria by ILT staff and by staff from the Federal Research Institute for Alpine Regions, Gumpenstein (BAL). The farmers´ family was very helpful, as well. In the first place, the mobile office was equipped again with all the necessary staff. Compressor and adsorption dryer were put into operation. Then, gas probes for fresh air and for the exhaust air from the three compartments were laid. BAL staff installed the air flow measurement in the three exhaust fans and the recording of climatic parameters inside and outside the animal house.

A test run for the emission measurements at the commercial straw flow system started on 2003-07-08. An overview on the emission level and on their variability in course of the day was gained. Data were continuously analysed and checked for their plausibility.

After the test phase, emission measurements started on 2003-07-14. Emissions were continuously measured 24 hours a day until 2004-04-20. Data were processed at maximum three days after they had been measured. Thus, an up to date on the emissions was gained and a plausibility check was carried out. With this procedure it was possible to immediately analyse inconsistencies in the data and react to possible faults in the measurement device. Pig weight was noted at weekly intervals through the farmers´ computer system.

Emission measurements at one compartment were done on two consecutive days. Then, the gas probe was moved to the next compartment, where continuous measurements were carried out for *c.* 48 hours. The experimental design measured each compartment at least once a week for two days. Emission data were gained for each season and each stage of fattening in the three compartments. The most important influences on the emission level could be quantified.

A high data quality requires an actual background spectrum for the FTIR spectrometer. The background spectrum forms the basis for the gas concentration analysis. A background spectrum was recorded three times a week. The VOC analyser was calibrated three times a week, as well. Data were immediately transferred to ILT were they were processed and checked for their plausibility. This intensive supervision made sure that nearly all of the recorded data could be used in the final data analysis. Other authors report of data losses of 40 – 70 % due to inconsistencies and / or failures in the emission data (BROSE 2000, RATHMER 2002, NIEBAUM 2001).

Emission measurements were terminated on 2004-04-20 and the measurement device was transported back to Gross Enzersdorf on 2004-04-21.

Details on emissions measurements in the three compartments can be taken from Table 2. Two contrasting systems for manure removal were investigated: dung channel with manure flow by gravity (compartment 1) and daily manure removal via scraper (compartments 2 and 3). The influence of the addition of "Effective Micro-Organisms (EM)" was investigated, as well. Details can be found in chapter 3.1.4. The whole duration of the experiment was divided in three periods. Comparisons of emissions were made between these three periods.

Warm to moderately warm conditions prevailed during the first measurement period from July to November 2003. Period 1 covered a whole fattening period. Mean indoor temperature was about 23 °C in all three compartments. Mean outdoor temperature was 23 °C.

The second period covered winter conditions from October 2003 to March 2004. Mean outside temperature was considerably lower than in period 1. Due to the insulated housing and the reduced air flow rate, mean indoor temperature was only 3 °C lower than in period 1. EM was sprayed in compartment 1 from January to February 2004 (see chapter 3.1.4).

Emissions from young fatteners were measured in period_3 from March to April 2004. Mean indoor temperature was about 21 °C, mean outdoor temperature ranged between 6 and 9 °C. EM was sprayed in compartment 1 throughout the whole period_3.

**Table 2.** Details on emission measurements in the three compartments of the commercial straw flow system.

| | *Dung channel* compartment 1 | *Daily manure removal* compartments 2 and 3 |
|---|---|---|
| *period_1* | | |
| date | July to Oct. 2003 | July to Nov. 2003 |
| weight [kg $pig^{-1}$] | 47.5 – 110.0 | 31.0 – 110.0 |
| mean indoor temperature [°C] | 23.5 | 22.6 |
| mean outdoor temp. [°C] | 16.8 | 13.7 |
| *period_2* | | |
| date | Oct. 2003 to Feb. 2004 | Nov. 2003 to March 2004 |
| weight [kg $pig^{-1}$] | 30.0 – 110.0 | 31.0 – 110.0 |
| mean indoor temperature [°C] | 20.9 | 20.4 |
| mean outdoor temp. [°C] | 1.6 | 0.5 |
| EM addition | Jan. to Feb. 2004 | no EM addition |
| *period_3* | | |
| date | March to April 2004 | April 2004 |
| weight [kg $pig^{-1}$] | 31.0 - 65.0 | 31.0 – 40.0 |
| mean indoor temperature [°C] | 20.8 | 21.7 |
| mean outdoor temp. [°C] | 6.4 | 9.3 |
| EM addition | March to April 2004 | no EM addition |

### 3.1.4 Addition of "Effective Micro-organisms (EM)"

The additive "Effective Micro-Organisms (EM)" is distributed in Austria by Multikraft Ltd. EM is widely applied in horticulture, as feed additive (as EM FKE), in animal houses, as slurry additive, etc. EM consists of several micro-organisms and it is anticipated that these reduce ammonia ($NH_3$), nitrous oxide ($N_2O$), methane ($CH_4$), and odour emissions from animal houses and / or slurry stores. EM contains the micro-organisms listed in Table3 (after an internal communication of KNEIFEL ).

Multikraft Ltd. financed experiments that investigated the influence of EM addition in a straw flow system for fattening pigs. The EM effect was monitored in compartment 1 that was equipped with a dung channel system. An aqueous solution with EM was sprayed in the whole compartment. The commercial straw flow system had never before applied EM. This made it necessary to use a higher concentrated solution at the beginning. From 2004-01-03 to 2004-01-20 7 litres EM and 7 litres water were mixed and sprayed in the pig house every day. From 2004-01-21 onwards, 4 litres EM mixed in 4 litres of water were sprayed on a daily basis.

From 2004-03-08 onwards, EM-FKE was added to the pigs feed. 3 litres EM-FKE were added to 1000 litres liquid feed. Pigs were fed three times a day. The daily EM spraying continued parallel to the feeding of EM.

**Table 3.** Micro-Organisms identified in EM

| *Micro-Organisms* | *Species / metabolism* |
|---|---|
| Lactic Acid Bacteria | Lactobacillus plantarum<br>Lactobacillus casei<br>→ homo fermentative; mainly lactic acid from sugars |
| Sulfur, non-sulfur-purple bacteria | Rhodopseudomonas palustris<br>→ photohetero-, photoautotroph; oxidise hydrogen sulfide to elemental sulfur |
| Top-fermented yeast | Saccharomyces cerevisiae<br>→ Ethanol from sugar, alternation of aerobic and anaerobic metabolism |
| moulds | Decomposition of cellulose and lignin |
| Other micro-organisms | Ubiquitous micro-organisms, that are found in natural habitats below pH 3.5 |

## 3.2 Results

### 3.2.1 Indoor and outdoor temperature

Indoor temperature and relative humidity were hourly measured at two places in each compartment. Outdoor temperature and relative humidity were measured at one place near the animal house. The mean daily temperature and relative humidity were calculated from the measured values. Mean daily indoor and outdoor temperatures are shown in Figure 4. Outdoor temperature varied in course of the year. During summer, values above 25 °C were reached. In winter, mean daily temperatures of –10 °C were measured. The animal house was insulated and the ventilation rate was automatically adjusted to keep indoor temperature at an almost constant level. Thus, the variation in the outdoor temperature does not show up in the indoor temperature. Only during the hot summer season, indoor temperature was *c.* 5 °C higher than during the rest of the year.

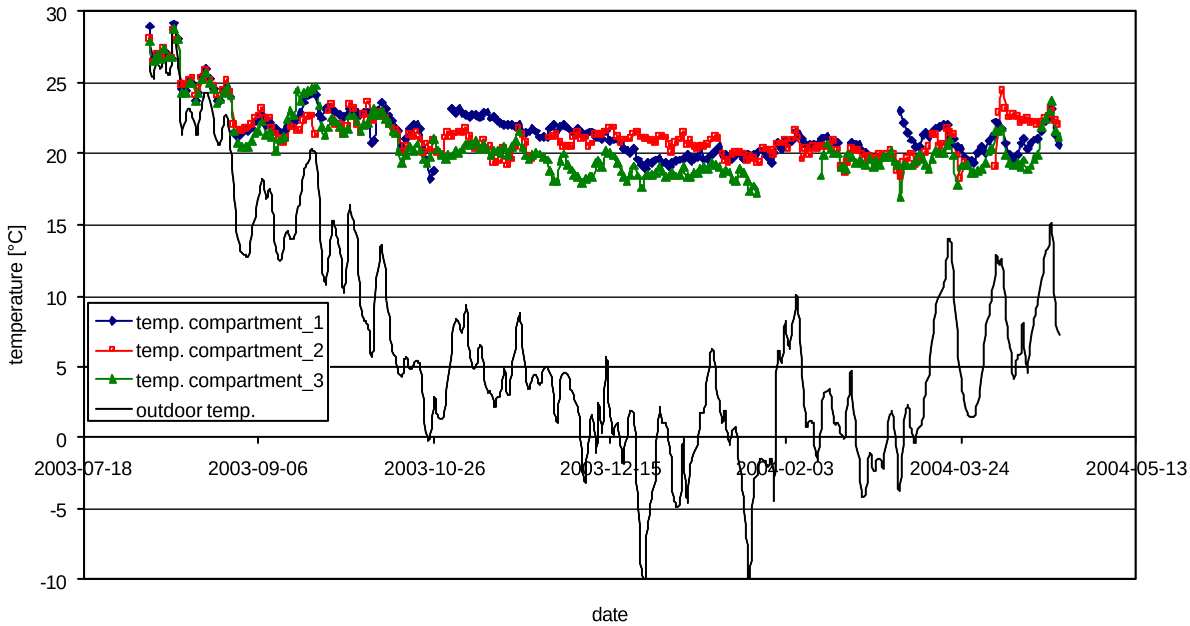


**Figure 4.** Mean indoor and outdoor temperature during the emission measurements at a straw flow system for fattening pigs.

### 3.2.2 Development of the pigs´ weight during the measurement period

Emissions were measured in the central exhaust fans in each compartment. The pigs` weight varied in course of the measurement period. Emissions from the straw flow system must be related to the pigs` weight in order to allow a comparison between the three compartments and with data on emissions from other pig houses that were found in other studies. The farms´ computer system gives weekly data on the pigs` weight. Weekly, the mean pig weight in each compartment was multiplied by the number of pigs to receive the total weight of pigs in each compartment. Development of total pig weight in each compartment is given in Figure 5.

At the beginning of the fattening period, total pig weight continuously increased. Towards the end, total pig weight drops down in several stages. Not all pigs of each compartment are slaughtered at the same time. Towards the end of the fattening period, pigs are slaughtered in groups. This leads to a decrease in pig weight by leaps and bounds. When a fattening period is finished, each compartment stays empty for a few days before new, small pigs are housed. The fattening period starts with a weight of *c.* 30 kg.

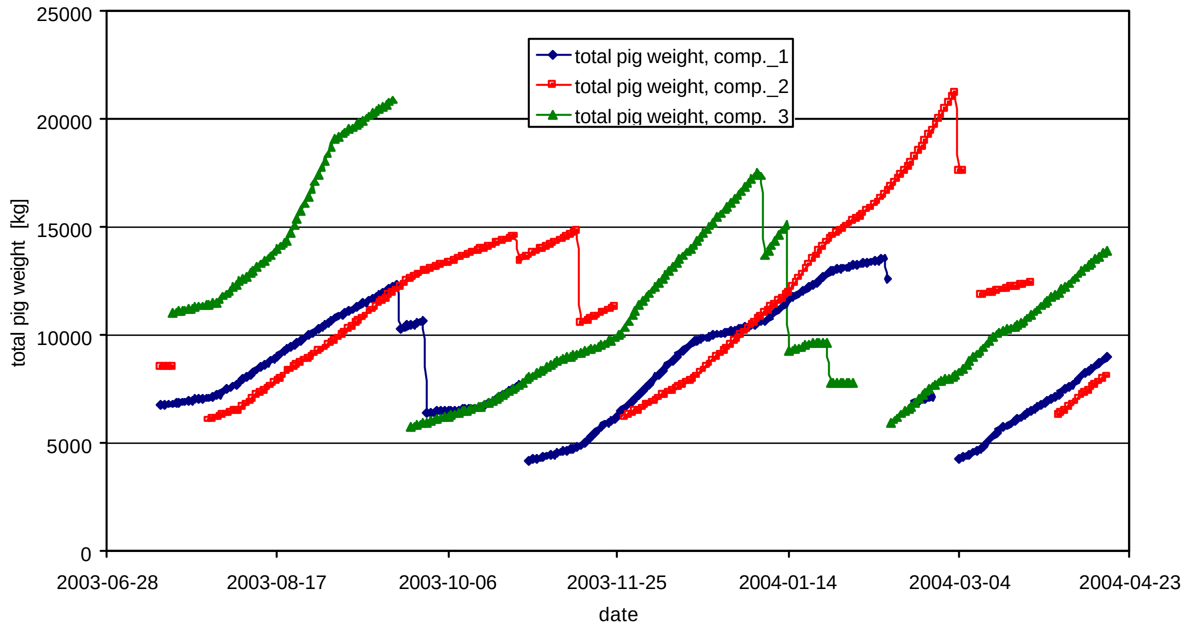


**Figure 5.** Total pig weight in each compartment in course of the measurement period.

## 3.2.3 Emissions from compartment 1 (dung channel)

Fresh air concentrations were measured two times and exhaust air concentrations four times per hour. The difference between exhaust air and fresh air concentration multiplied by the ventilation rate gives the amount of gaseous losses from the compartment. Emission rates from one compartment were continuously measured for about 48 hours. Then measurements moved on to the next compartment. Hourly emission rates were summarised to emissions per day. Net total emissions from each compartment were divided by the amount of pig weight present at each measurement occasion. Emissions per kg pig weight and days were received. These are shown in figures 6 and 7.

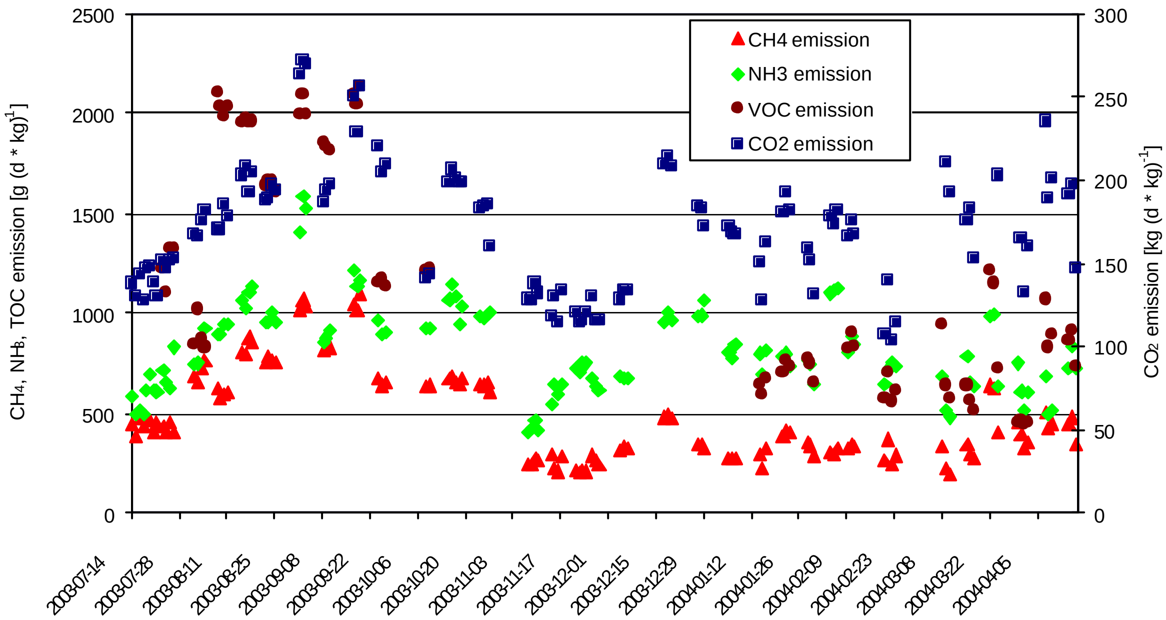


**Figure 6.** $CH_4$, $NH_3$, VOC, and $CO_2$ emissions per day and kg pig weight from compartment 1 (dung channel)

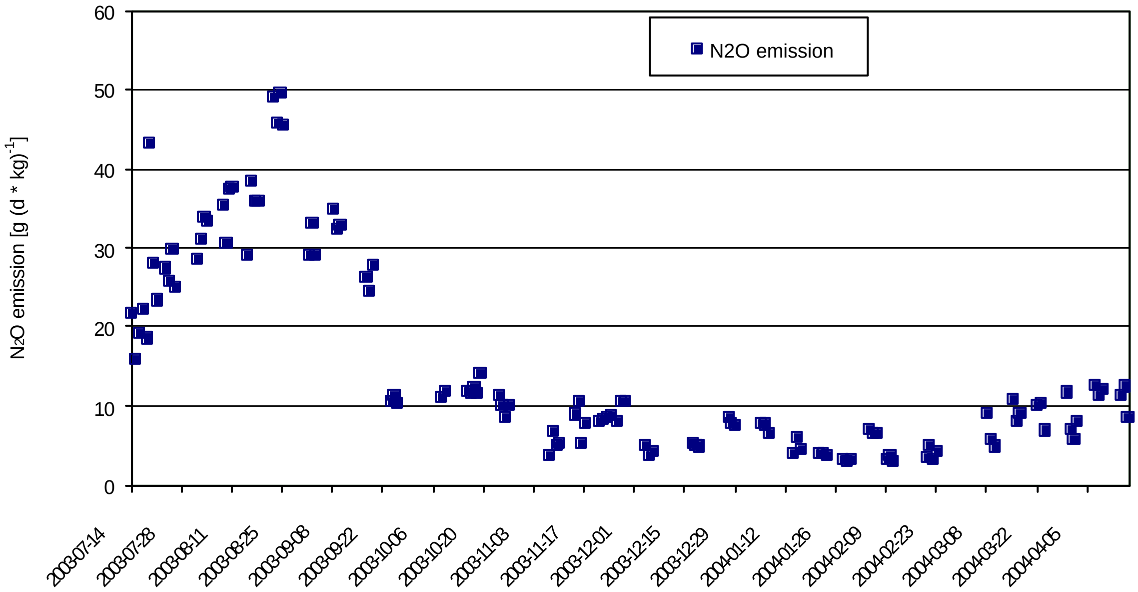


**Figure 7.** $N_2O$ emissions per day and kg pig weight from compartment 1 (dung channel)

Mean emissions per pig and day were calculated from the whole emission data set (Table 4). With 2.5 fattening periods per year (DÖHLER ET AL. 2002, UBA 2001), mean emissions per pig and day sum up to emissions per pig place and year that are shown in the right column of Table 4.

**Table 4.** Mean emissions and emissions per pig place and year from compartment 1 (dung channel)

| *Emissions of …* | *Mean emission* [g/ (kg pig * day)$^{-1}$] | *Emission per pig place* [kg (pig place* yr)$^{-1}$] |
|---|---|---|
| $CO_2$ | 168.22 * $10^3$ | 426.39 |
| $CH_4$ | 469.32 | 1.19 |
| $NH_3$ | 791.02 | 2.01 |
| $N_2O$ | 14.72 | 37.32 * $10^{-3}$ |
| TOC | 1163.65 | 2.95 |

## 3.2.4. Emissions from compartment 2 (daily manure removal)

Emissions from compartment 2 were calculated in the same way as for compartment 1 (see chapter 3.2.3). Figures 8 and 9 give daily emissions per kg pig weight from compartment 2 for the whole measurement period.

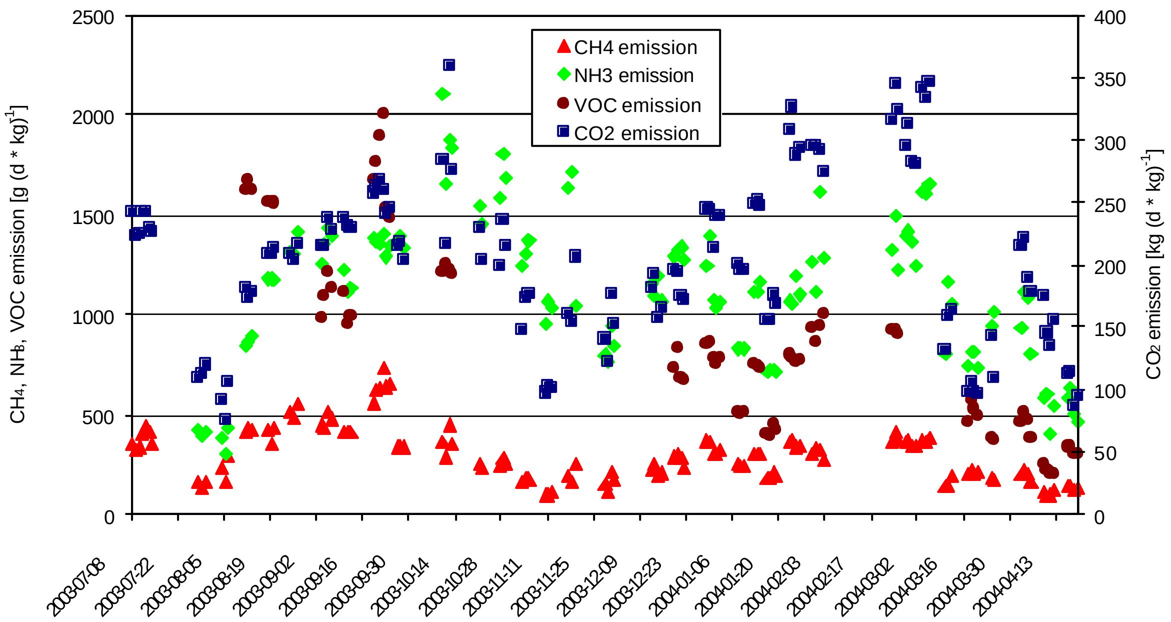


**Figure 8.** $CH_4$, $NH_3$, VOC, and $CO_2$ emissions per day and kg pig weight from compartment 2 (daily manure removal)

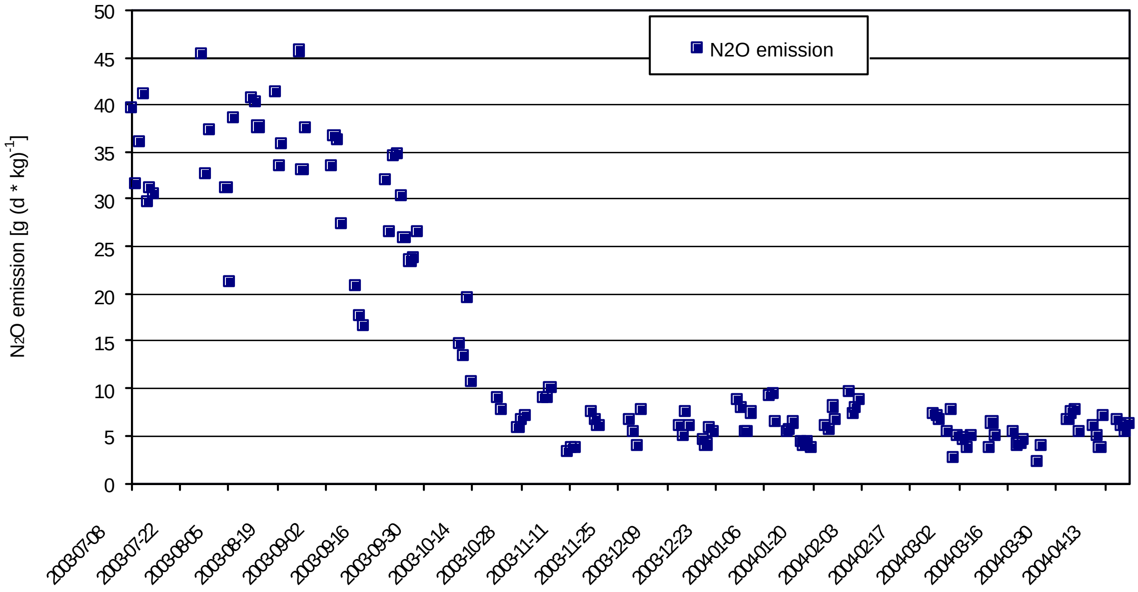


**Figure 9.** $N_2O$ emissions per day and kg pig weight from compartment 2 (daily manure removal)

Mean emissions per pig and day were calculated from the whole emission data set (Table 5). With 2.5 fattening periods per year (DÖHLER ET AL. 2002, UBA 2001), mean emissions per pig and day sum up to emissions per pig place and year that are shown in the right column of Table 5.

**Table 5.** Mean emissions and emissions per pig place and year from compartment 2 (daily manure removal)

| *Emissions of …* | *Mean emission* [g/ (kg pig * day)$^{-1}$] | *Emission per pig place* [kg (pig place* yr)$^{-1}$] |
|---|---|---|
| $CO_2$ | $205.12 * 10^3$ | 519.92 |
| $CH_4$ | 298.96 | 0.76 |
| $NH_3$ | 1,150.80 | 2.92 |
| $N_2O$ | 15.04 | $38.11 * 10^{-3}$ |
| TOC | 915.04 | 2.32 |

### 3.2.5. Emissions from compartment 3 (daily manure removal)

Emissions from compartment 3 were calculated in the same way as for compartment 1 (see chapter 3.2.3). Figures 10 and 11 give daily emissions per kg pig weight from compartment 2 for the whole measurement period.

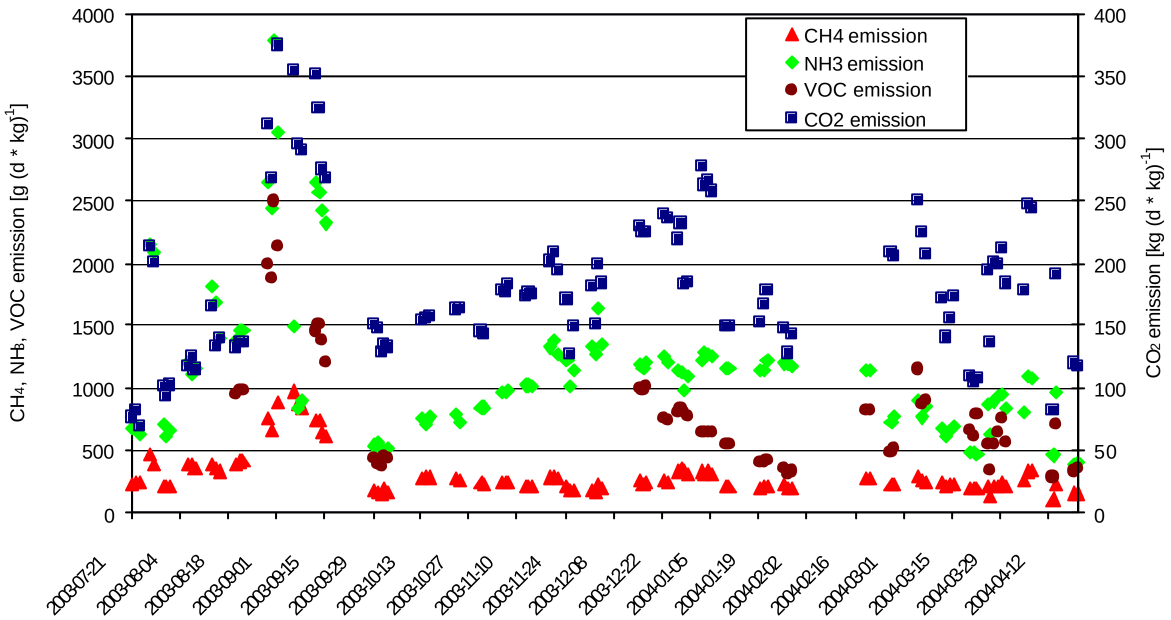


**Figure 10.** $CH_4$, $NH_3$, VOC, and $CO_2$ emissions per day and kg pig weight from compartment 3 (daily manure removal)

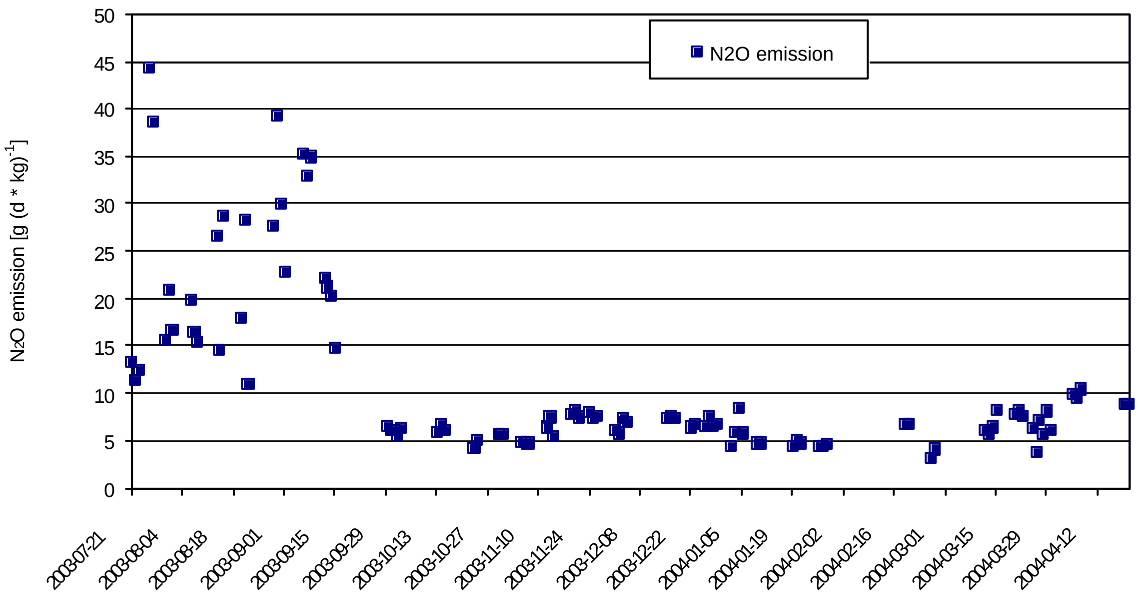


**Figure 11.** $N_2O$ emissions per day and kg pig weight from compartment 2 (daily manure removal)

Mean emissions per pig and day were calculated from the whole emission data set (Table 6). With 2.5 fattening periods per year (DÖHLER ET AL. 2002, UBA 2001), mean emissions per pig and day sum up to emissions per pig place and year that are shown in the right column of Table 6.

**Table 6.** Mean emissions and emissions per pig place and year from compartment 3 (daily manure removal)

| *Emissions of …* | *Mean emission* [g/ (kg pig * day)$^{-1}$] | *Emission per pig place* [kg (pig place* yr)$^{-1}$] |
|---|---:|---:|
| $CO_2$ | 190.35 * $10^3$ | 482.50 |
| $CH_4$ | 312.86 | 0.79 |
| $NH_3$ | 1,138.81 | 2.89 |
| $N_2O$ | 11.13 | 28.22 * $10^{-3}$ |
| TOC | 796.91 | 2.02 |

### 3.2.6. Emissions from compartments 1, 2, and 3 and influence of EM

Figures 12 to 15 give emissions per pig and year as measured from the straw flow system for fattening pigs. Chapters 3.2.3 to 3.2.4. contain details on emissions per day and kg pig weight. Mean emissions per day and kg pig weight were calculated from the values measured in course of the experiments. These emissions were converted to emissions per livestock unit (LU = 500 kg life weight). One pig corresponds to 0.12 LU. 2.5 fattening periods per year are carried out. Pig houses are occupied with pigs on 330 days per year (DÖHLER ET AL. 2002, UBA 2001). These values were taken to calculate emissions per pig and year as shown in the following figures. Emissions were differentiated in emissions from the dung channel and from the daily manure removal system. The influence of EM application in the first and in the second half of a fattening period is illustrated, as well. For comparison reasons, the figures give current default values for emissions from fully slatted forced ventilated pig houses.

Figure 12 gives $CH_4$ emissions per pig and year. Fully slatted forced ventilated pig houses are currently estimated to emit 4 kg $CH_4$ per pig and year (UBA 2001). $CH_4$ emissions from the straw flow system were always below this value. This is probably due to the fact that less manure is stored inside the warm pig house. Temperatures inside pig houses are in the range of 20 °C. At this warm temperature, anaerobic decomposition of the organic substance in the manure is promoted. The more manure in the house, the higher the $CH_4$ emissions.

The dung channel system stores a greater amount of manure inside the pig house than the daily manure removal system. This is probably the reason why $CH_4$ emissions are higher from the dung channel system.

EM was sprayed in the compartment with the dung channel system. In the first half of the fattening period, a slight increase in $CH_4$ emissions was observed. In the second half of the fattening period, EM application strongly reduced $CH_4$ emissions. Considering the whole fattening period, 1.26 kg $CH_4$ per pig and year were emitted without EM application. EM application resulted in a reduction of $CH_4$ emissions by 33 % to 0.84 kg $CH_4$ per pig and year.

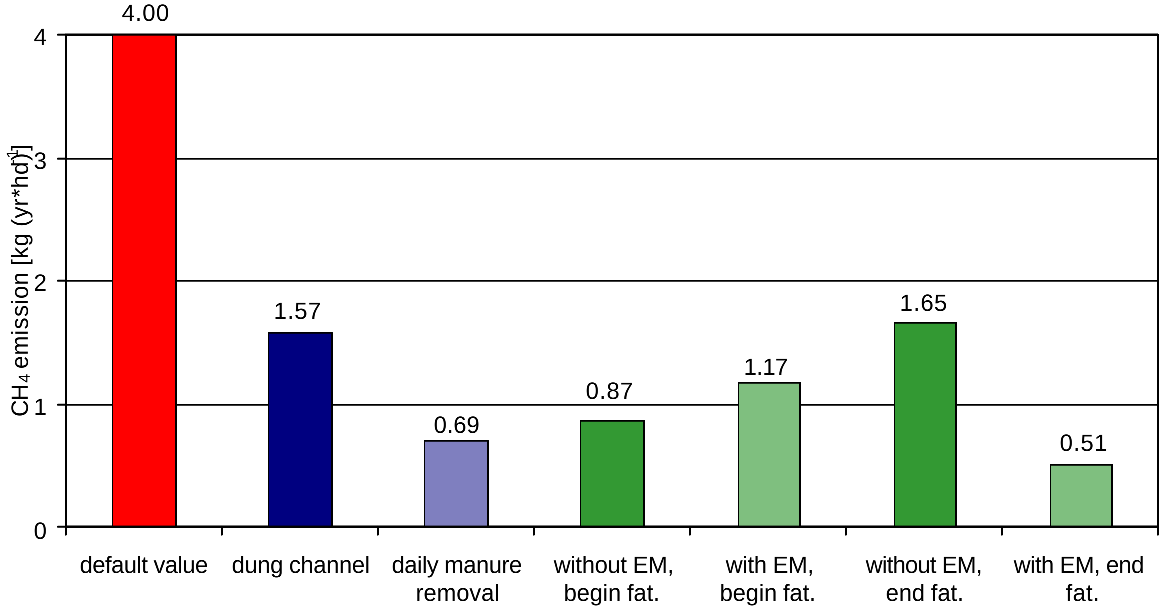


**Figure 12.** $CH_4$ emissions from a straw flow system for fattening pigs with and without EM application and default emission factor for fully slatted forced ventilated pig houses.

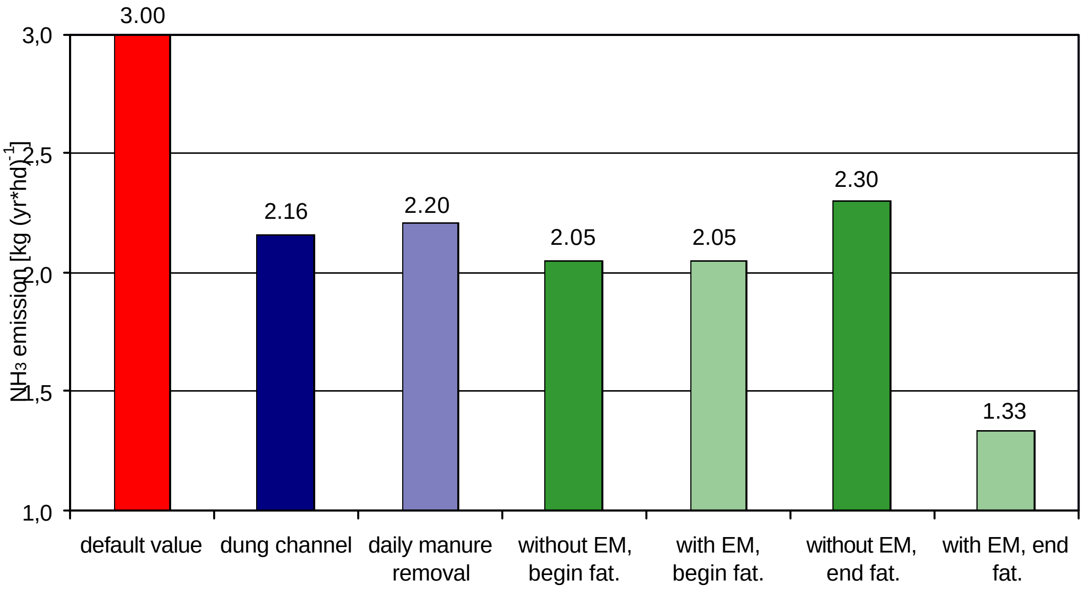


**Figure 13.** $NH_3$ emissions from a straw flow system for fattening pigs with and without EM application and default emission factor for fully slatted forced ventilated pig houses.

Results on $NH_3$ emissions from the straw flow system can be taken from figure 13. DÖHLER ET AL. (2002), and UBA (2001) give a default value of 3 kg $NH_3$ per pig and year from fully slatted floors. The straw flow system emits considerably less $NH_3$. The surface that is fouled with manure is much smaller in a straw flow system than in a fully slatted floor system. The pigs keep the lying area dry and clean. Reducing the fouled area results in a reduction in $NH_3$ emissions.

Only little differences in $NH_3$ emissions were observed between the dung channel and the daily manure removal system. EM application in the first half of the fattening period did not alter $NH_3$ emissions. In the second half of the fattening period, a district reduction in ammonia emissions was observed with EM application. For a full fattening period, emissions of 2.17 kg $NH_3$ per pig and year were measured. With EM application, ammonia emissions were reduced by 22 % to 1.69 kg $NH_3$.

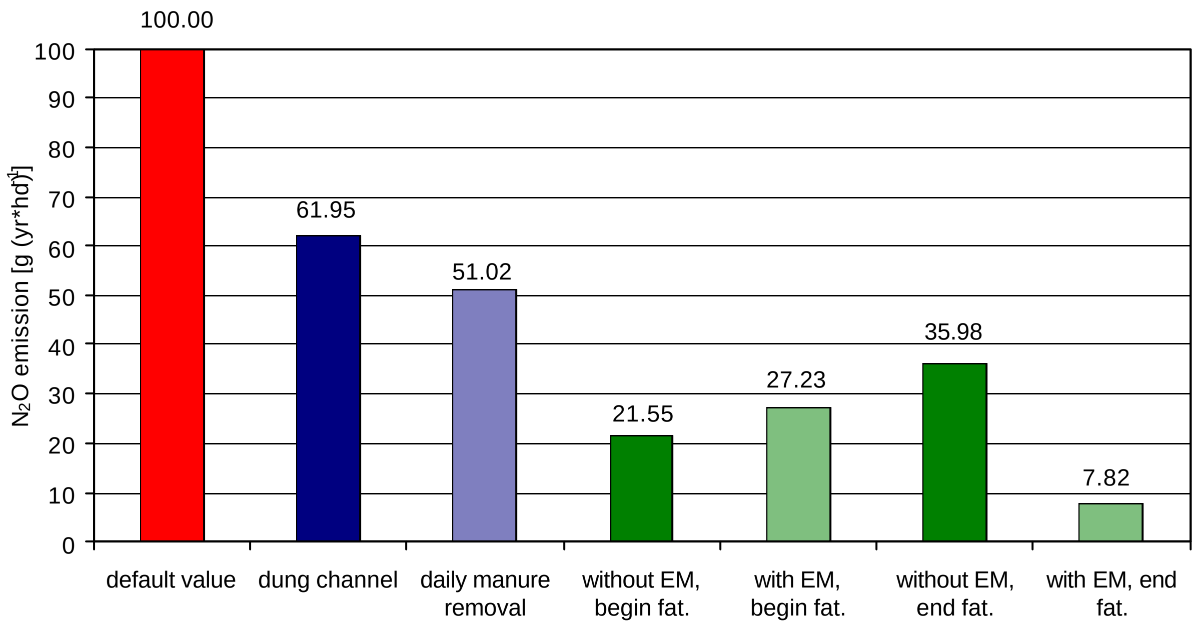


**Figure 14.** $N_2O$ emissions from a straw flow system for fattening pigs with and without EM application and default emission factor for fully slatted forced ventilated pig houses.

The current default value for $N_2O$ emissions from fully slatted floors is 100 g $N_2O$ per pig and year. Due to the very limited data availability, this default value comprises a high range of uncertainty. $N_2O$ emissions may vary between 20 and 310 $N_2O$ per pig and year (UBA 2001). $N_2O$ emissions from the straw flow system ranged between 7.82, and 61.95 g per pig and year (Figure 14). The dung channel system emitted more $N_2O$ than the daily manure removal system. As with $CH_4$ emissions, this is probably due to the bigger amount of manure stored inside the pig house.

In the first half of the fattening period, EM addition resulted in a slight increase in $N_2O$ emissions. In the second half, a strong reduction in $N_2O$ emissions was measured. Considering the whole fattening period, $N_2O$ emissions were 40 % lower with EM addition. Without EM, $N_2O$ emissions were 28.77 g per pig and year. EM addition resulted in $N_2O$ emissions of 17.52 g per pig and year.

Emissions of $CH_4$ and $N_2O$ were summarised to greenhouse gas emissions that are expressed as $CO_2$ equivalents. The global warming potential (GWP) of $CH_4$ is 21times the GWP of $CO_2$. $N_2O$ has a 310times higher GWP than $CO_2$ (IPCC 1996). Figure 15 gives net total greenhouse gas emissions (GHG). The default value for fully slatted floors is considerably higher than GHG emissions measured from the straw flow system. Daily manure removal could further reduce GHG emissions compared to the dung channel system. In the second half of the fattening period, spraying of EM strongly reduced GHG emissions. Considering a full fattening period, EM application resulted in a 35 % reduction of GHG emissions.

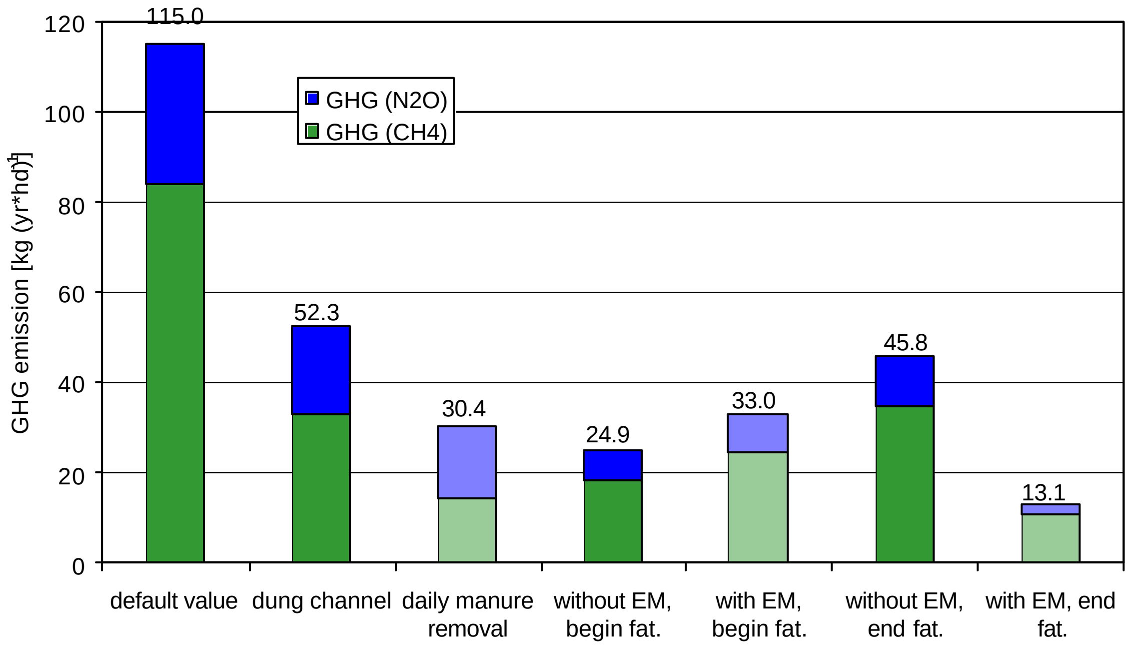


**Figure 15.** Greenhouse gas emissions from a straw flow system for fattening pigs with and without EM application and default emission factor for fully slatted forced ventilated pig houses.

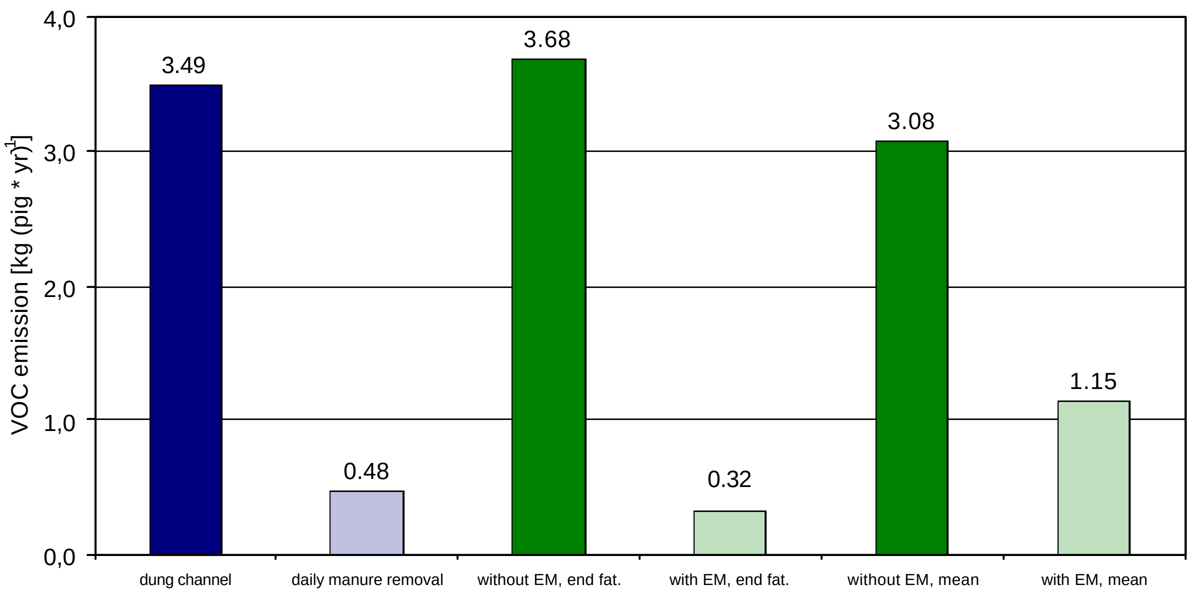


**Figure 16.** VOC emissions from a straw flow system for fattening pigs with and without EM application.

From figure 16, VOC emissions can be taken that were measured from the straw flow system for fattening pigs. VOC emissions can serve as an indicator of the potential for odours emissions. The higher the VOC emissions the higher the potential for odours emissions.

The dung channel system emitted considerably more VOC than the daily manure removal system. This is probably due to the greater amount of manure that is stored inside the warm pig house. The influence of EM application was investigated in the dung channel system. EM application resulted in a strong reduction in VOC emissions both in the first, and in the second half of the fattening period. Without EM, mean VOC emissions of 3.38 kg per pig an year were measured over a full fattening period. Spraying of EM reduced VOC emissions by 78 % to 0.73 kg per pig an year.

# 4 Conclusions

- The straw flow system for fattening pigs is an animal friendly system that can be operated economically efficient on commercial farms.
- $CH_4$, $NH_3$, and $N_2O$ emissions both from the dung channel and from the daily manure removal system were always below current default values for fully slatted, forced ventilated pig houses.
- Through daily manure removal $CH_4$, and $N_2O$ emissions could further be reduced compared to the dung channel system.
- Over a full fattening period, EM application resulted in a reduction of $CH_4$, $NH_3$, $N_2O$, and greenhouse gas emissions. $CH_4$ emissions were reduced by 33 %. A mitigation of $NH_3$ emissions of 22 % was measured. EM application lowered $N_2O$ emissions by 40 %. Net total GHG emissions were 35 % lower when EM was sprayed in the pig house.
- VOC emissions were measured as an indicator for the potential for odour emissions from a straw flow system. VOC emissions were lower in the daily manure removal system than in the dung channel system. When EM was sprayed in the dung channel system, VOC emissions were reduced by 78 %.

# References

AMON, T., JEREMIC, D., GALLOB, M., AMON, B., BOXBERGER, J., SÖLKNER, J., KONRAD, S., MEIXNER, O. (2001). Schweinefleischerzeugung im Stolba-Familienstall: Ermittlung von Kennzahlen von der Erzeugung bis zur Vermarktung und Optimierung des Systems, Endbericht zum Forschungsprojekt, Universität für Bodenkultur, Wien.

BARTUSSEK, H. (1993a). In der Schweinemast: Verdrängen Schrägböden die Vollspalten-bucht? Traktor Aktuell, 2, 22-25.

BARTUSSEK, H. (1993b). Vollspaltenböden oder Tieflaufstall bei Mastschweinen? – Weder – noch! Der fortschrittliche Landwirt, 1993, 8, S. 18-19 und 1993, 9, S. 18-19.

BARTUSSEK, H. (2001). Möglichkeiten der geeigneten Beschäftigung von Schweinen. Gum-pensteiner Bautagung 2001. BAL Gumpenstein, Irdning. S. 49-57.

BARTUSSEK, H., GEISBERGER, W. (1998). Schweine auf der schiefen Bahn: Schrägboden-buchten für Mastschweine bewähren sich. DLZ-Agrobonus, 1998, 3, S. 16-21.

BARTUSSEK, H., HAUSLEITNER, A.., SCHAUER, A., STEINWENDER, R., SÖLKNER, H. (1992). Die Leistung von Mastschweinen in Gruppen auf Vollspalten und in dänischen Buchten mit Stroh –im Warm- und Kaltstall. Veröffentlichungen der BAL Gumpenstein, Heft 17, Irdning, 1992.

BARTUSSEK, H., HAUSLEITNER, A., SCHAUER, A., STEINWENDER, R., UBBELOHDE J. (1995). Schrägbodenbuchten für Mastschweine. Veröffentlichungen der BAL Gumpenstein, Heft 23, Irdning, 1995.

BARTUSSEK, H., HAUSLEITNER, A., ZALUDIK, K. (1999). Schrägbodenbuchten in der Schwei-nemast: Die funktionssichere und kostengünstige tierschutzalternative zum Vollspaltenboden, In: Bericht zur Tagung Bau-Technik und Umwelt in der landwirtschaftlichen Nutztierhaltung, München-Freising, 1999.

BROSE, G. (2000). Emissionen von klimarelevanten Gasen, Ammoniak und Geruch aus einem Milchviehstall mit Schwerkraftlüftung. Forschungsbericht Agrartechnik, VDI-MEG Schrift 362, Dissertation Universität Hohenheim, ISSN 0931-6264.

BRUCE, J.M. (1990): Straw-Flow welfare systems for pigs. Farm Building Progress, 100, 6-7.

BRUCE, J.M. (1991). Characteristics of waste from Straw-Flow. Farm Building Progress, 106, 15-20.

DÖHLER, H., DÄMMGEN, U., BERG, W., BERGSCHMIDT, A., BRUNSCH, R., EURICH-MENDEN, B., LÜTTICH, M., OSTERBURG, B. (2002). Anpassung der deutschen Methodik zur rechnerischen Emissionsermittlung an internationale Richtlinien und Prognose der Ammoniak-Emissionen der deutschen Landwirtschaft und Szenarien zu deren Minderung bis zum Jahre 2010. Final Report for Bundesministerium für Verbraucherschutz, Ernährung und Landwirtschaft and Umweltbundesamt.

EB.AIR/GE.1/2002/7. ECONOMIC COMMISSION FOR EUROPE, EXECUTIVE BODY FOR THE CONVENTION ON LONG-RANGE TRANSBOUNDARY AIR POLLUTION, Steering Body to the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP) (2002). DRAFT GUIDELINES FOR ESTIMATING AND REPORTING EMISSIONS DATA, Prepared by the Task Force on Emission Inventories and Projections and the secretariat, Twenty-sixth session, Geneva, 2-4 September 2002.

EMEP/CORINAIR Atmospheric Emission Inventory Guidebook (Third edition 2002). http://reports.eea.eu.int/EMEPCORINAIR/en.

FRASER, D., PHILLIPS P.A., TENNENSEN, T. (1991): Effect of straw on the behaviour of growing pigs. Applied Animal Behaviour Science, 17, 61-68.

GEBBE, N. (1991): Schweinemast auf 10 % Gefälle. DLG-Mitteilung/ agrar-inform, 8/1991, 54-56.

HÖRNING, B. (1999). Artgemäße Schweinehaltung. Beratung Artgerechte Tierhaltung. Stiftung Ökologie und Landbau. Schweisfurth-Stiftung, München. Verlag C.F. Müller, Karlsruhe.

IPCC Guidelines for National Greenhouse Gas Inventories (Revised 1996), http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

IPCC (1996). Climate Change 1995: The Science of Climate Change. In: Intergovernmental Panel on Climate Change; J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell, (Ed.), Cambridge University Press, Cambridge, U.K.

NIEBAUM, A. (2001). Quantifizierung gasförmiger Emissionen aus quer gelüfteten Außenklimaställen für Mastschweine mit Hilfe der Tracergas-Technik. Forschungsbericht Agrartechnik, VDI-MEG Schrift 370, Dissertation Georg-August Universität Göttingen, ISSN 0931-6264.

RATHMER, B. (2002). Vergleich klima- und umweltrelevanter Emissionen aus Haltungssystemen für Mastschweine. Forschungsbericht Agrartechnik, VDI-MEG Schrift 386, Dissertation Technische Universität München, ISSN 0931-6264.

SAMBRAUS, H.H. (1991): Nutztierkunde. Verlag Eugen Ulmer, Stuttgart.

STOLBA A. (1983). Verhaltensmuster von Hausschweinen in einem Freigehege. In: Aktuelle Arbeiten zur artgemäßen Tierhaltung 1983. KTBL-Schrift 299, Landwirtschaftsverlag GmbH., Münster-Hiltrup.

UMWELTBUNDESAMT DER BRD (2001). Entwurf: Erstellung eines Gutachtens für einen deutschen Beitrag zur Vollzugsvorbereitung zum Umsetzung der IVU-Richtlinie für den Bereich Intensivtierhaltung, UBA Vorhaben FKZ 360 08 001, Stand November 2001, KTBL Darmstadt, Umweltbundesamt Berlin; In: UBA-Text 75/02 „Beste verfügbare Techniken in der Intensivtierhaltung“.

WECHSLER, B. (1997). Schwein. In: Sambraus, H.H., Steiger, A. (Hrsg.): Das Buch vom Tierschutz. Ferdinand Enke Verlag. Stuttgart, S. 173-185.

ZALUDIK, K. (1997). Untersuchungen zum Schrägbodensystem für Mastschweine. Diplomarbeit an der Universität für Bodenkultur, Wien.

ZERBONI, H.N., GRAUVOGL, A. (1984). Schwein. In Bogner. H., Grauvogl, A. (Hrsg): Verhalten landwirtschaftlicher Nutztiere. Verlag Ulmer, Stuttgart.

WHITE, J.U. (1942). Long optical paths of large aperture, J. O. S. A. 32, 285 – 288.