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Susanne Elmholt

Koordinator for
myndighedsrådgivning

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Direkte tlf.: 8999 1858
E-mail:
Susanne.Elmholt@agrsci.dk

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Rapporten er udarbejdet af seniorforsker Henry Jørgensen, Institut for Husdyrbiologi og -sundhed.

Med venlig hilsen

Susanne Elmholt
Seniorforsker, koordinator for DJF’s myndighedsrådgivning

Det Jordbrugsvidenskabelige Fakultet
Aarhus Universitet

Blichers Allé 20
Postboks 50
8830 Tjele

Tlf.: 8999 1900
Fax: 8999 1919
E-mail: djf@agrsci.dk
http://agrsci.au.dk/

Report

Methane emission from pigs

Henry Jørgensen

Aarhus University, Faculty of Agricultural Sciences
Department of Animal Health and Bioscience, Research Centre Foulum
Blichers Allé 20, DK-8830 Tjele, Denmark

Summary

The present report summarises our current knowledge concerning dietary and intrinsic factors that may influence the methane (CH_4) production in pigs. The data compilation is based on all relevant experiments carried out with piglets, growing pigs and sows in the respiration chambers at Research Centre Foulum during the last 20 years. Although none of the studies have been specifically designed to investigate dietary and intrinsic factors that may influence the CH_4 production in pigs it is possible to draw general conclusions. The main dietary contributor to the CH_4 production at all live weight of pigs is the dietary concentration of fibre, whereas neither dietary fat nor protein had any significant impact. The production of CH_4 varies with the live weight/feed intake; for piglets it amounts to only 0.1 % of gross energy (GE), for growing pigs it varies form 0.2 to 0.5 % of GE with normal concentrated diets but could be as high as 1 % with high-fibre diets, for gestating sows it varies from 0.6 to 2.7 % of GE depending on feeding level and fibre type, whereas the CH_4 production was estimated to be approximately 0.6 % of GE in lactating sows.

Key words: pigs, methane, fibre, fat, feed intake, weight.

Sammendrag

Denne rapport summerer vores nuværende viden vedrørende fodringsmæssige og dyrefaktorer der har betydning for metan (CH_4) produktionen hos grise. Datasammenstillingen er baseret på alle relevante forsøg, der har været gennemført med smågrise, slagtesvin og søer i respirationskamrene i Foulum i løbet af de sidste 20 år. Selv om ingen af studierne har været specifikt designede til at måle CH_4 produktionen hos grise, er det muligt at drage nogle generelle konklusioner. Den væsentligste faktor ved foderet, der er af betydning for CH_4 produktionen, er koncentrationen af fibre, hvorimod hverken koncentrationen af fedt eller protein havde nogen effekt. Produktionen af CH_4 varierede med kropsvægten/foderindtag og androg 0.1 % af brutto energien for smågrise, for voksende grise varierede det mellem 0.2 og 0.5 % af bruttoenergien når grisene blev fodret med normale koncentrerede blandinger og op til 1 % ved højfiber blandinger, for drægtige søer varierede det mellem 0.6 og 2.7 % afhængig af blandingernes fiberniveau, hvorimod CH_4 produktionen androg 0.6 % af bruttoenergien hos diegivende søer.

Nøgleord: grise, metan, fibre, fedt, foderindtag, vægt.

1. Introduction

The modern pig industry rely on relatively few feedstuffs mostly from cereals (corn, wheat, barley, oats, rye and rice), cereal co-products (different milling fractions, residues from biofuel and alcohol industries, etc.), cereal substitutes (tapioca, maniocca), legumes (peas, beans, lupins), protein concentrates (meal or cakes of soybean, rape, sunflower, cotton) and co-products from the sugar and starch industries to produce compounds feeds. The classical pig diet can also be characterised as relatively concentrated but an increased demand of high energy cereals for direct human use and increased availability of fibre rich ingredients from, for instance, the feed milling or starch extraction/fermentation industries have promoted an increased utilisation of fibre rich co-products in the pig feeds. Especially pregnant sows may be supplied with fibre rich diets without compromising their reproductive performance. The direct use of forage crop is also developing although at a rather limited scale and primarily in organic farming. Other benefits, such as increased well being of animals, improvement of the gut transit or reduction of stomach ulcers also favour an increased utilisation of fibre rich ingredients in pig feeds. An increased dietary fibre concentration is on the other hand associated with reduced available energy content of the diet if not combined with high energy ingredients such as animal fat or vegetable oil. The consequence is that the amount of feed required per kg meat produced is increased.

The present report will summarise our current knowledge concerning dietary and intrinsic factors that may influence the CH_4 production in pigs. The data compilation is based on all experiments carried out in the respiration chambers at Research Centre Foulum during the last 20 years. It should, however, be stressed that none of the studies were specifically designed to investigate dietary or intrinsic pig factors that may influence the CH_4 production.

2. Sites for intestinal gas production

The majority of carbohydrates are digested by endogenous enzymes in the small intestine but the dietary fibre fraction will be fermented primarily in the lower gut resulting in production of short chain fatty acids (acetic-, propionic- and butyric acid), gasses (carbon dioxide (CO_2), hydrogen (H_2) and methane (CH_4)), urea and heat. However, the stomach and small intestine is also colonised by microorganism, which lead to production of primarily H_2. This is illustrated in **Figure 1A&B** that shows the results from a study in which the gas concentration has been measured in the gastrointestinal tract at 12 sites (**Figure 1A**) after feeding a low and high fibre diet with 6 and 27 % dietary fibre per kg DM, respectively (Jensen & Jørgensen, 1994). The gas composition in the various segments shows similar trends for the two groups of pigs (**Figure 1B**). In both groups, low levels of H_2 were detected in the gas from the stomach, followed by a steady increase along the small intestine reaching a maximum (21 to 28 %) in the last third of the small intestine. Gas from the caecum and the first segment from the large intestine also contained substantial amounts of H_2, while the amounts of gas from the other segments of the large intestine were small in spite of the fact that hydrogen production is an obligate part of anaerobic fermentation (Miller & Wolin, 1974; Jensen, 1996). The produced short chain fatty acids can be utilised as an energy source and contributes with a significant part of energy for maintenance (Jørgensen et al. 1997). From an energy point of view, only CH_4 and H_2 are important as they correspond to combustible gases and represent a loss of energy. However, information on how dietary composition and intrinsic animal factors influence gas production in pigs is rather limited. From an environmental point of view CH_4 is of great interest as it is the major contributor to the greenhouse gas emission. The CH_4 production by pigs varies with their age or live weight and the type of diet they receive.

3. Dietary and intrinsic factors influencing methane production

3.1 Material and Methods

3.1.1 Overview of data

The respiration chamber was established at Foulum in 1990 and numerous experiments have been carried out on growing – finishing pigs from 30 – 150 kg live weight. Other experiments with sows at different physiological stages (dry, pregnant and lactating sows including their piglets) have been carried out. In order to measure suckling piglets without contribution of the lactating sow, experiments have been carried out where milk replacer has been fed to the piglets.

The whole dataset (**Table 1**) comprises one experiment with piglets fed with milk replacer and a total of 16 experiments with growing pigs covering the weight range from 25–150 kg live weight and 8 experiments with adult sows either dry, pregnant or lactating sows (including the litter). The main purpose of the various experiments has been influence/effect on the energy utilization of different diets or treatments. In **Table 2** is shown the mean of 140 diets/treatments, which are based on 765 measurements of energy balance.

3.1.2 Nitrogen and Energy balances

In most cases both nitrogen (N) and energy balances have been performed. In brief, a typical balance experiment comprises a total period of 12 days, including 5-7 days for adaptation to the feed, metabolic cage and environmental conditions. Daily faeces and urine are collected quantitatively during the last 5-7 days as described by Just et al. (1983). During the collection period, the metabolic cage with the pigs is placed in the respiration chambers and the amount of

CH_4, CO_2 and H_2 produced and oxygen (O_2) consumed is measured and heat production is calculated during 2 x 24 h periods.

3.1.3 Measurements of methane and carbon dioxide

The respiration chambers consist of climatic controlled airtight rooms where the animals' energy metabolism can be measured as illustrated in **Figure 2**. The measured parameters are heat production and the animals' consumption of oxygen and production of carbon dioxide, CH_4 and H_2. The technique applied is the so called indirect principle which means that the atmospheric air is ventilated through the chambers and the amount of air is measured together with the concentration of oxygen, carbon dioxide and methane in both in-going and out-going air (Jørgensen, 2001; Jørgensen et al. 1996). When the consumed amount of oxygen and produced amount of carbon dioxide and methane is known, the heat production can be calculated (Christensen and Thorbek, 1987; Jakobsen et al. 2005).

3.1.4 Presentation of results – expression of methane production

Methane production is in literature expressed in different ways. It is not only an animal's daily production that is of interest but more the production in relation to feed intake either in kg or as expressed of the part of the diet that can be utilized by the animal. To aid in presentation of the presented results in this report and also in comparing to other literature sources reporting methane the following expression is used: 1. Litre per day which is the results measured. 2. Litre per kg dry matter (DM) or gross energy (GE) intake as not only the size (kg) of an animal is important but the amount of substrate for fermentation. And here is where 3. the expression - per g fermented fibre - comes in. 4. Finally methane is also expressed per unit of digestible energy (DE) because it might be more relevant to relate the methane production to the amount of energy that is needed for the animal production.

3.2 Results and discussion

3.2.1 The variation in the chemical composition of feed and main results

Chemical composition of diets and main results are presented in **Table 2**. In total, CH_4 excretion amounted from 0.1 L/day with piglets reared artificially to 28.7 L/day corresponding to nearly zero at the lowest value to 3.3 % of digested energy (DE). This is of similar magnitude as reported by Jentsch et al. (2007) for female calves (50-75 kg body weight) but much lower than reported for ruminants where the loss as fermentation of CH_4 can be as high as 9-13 % of digestible energy (DE) (Johnson & Johnson, 1995).

3.2.2 Diurnal variation in methane and carbon dioxide

Table 2 shows the average excretion of CH_4 and CO_2. However, close inspection of the results revealed large diurnal variation depending on feeding and physical activity, and the digestion and fermentation in the intestine. **Figure 3 and 4** show examples of diurnal variation in a growing pig and an adult sow, respectively, fed equal type of diet/fibre, respectively. In the Figures 2 and 3, effects of feeding either a low fibre diet (A) or a high fibre diet (B) are illustrated. The variation in CO_2 is mainly a reflection of feeding a meal and the subsequent activity (Le Goff et. Al. 2002; Schrama et al. 1998 and review by Pedersen et al. 2008). The animals here are fed twice daily at 08.00 and 15.00 h. The lowest CO_2 concentration is found during night-time from around 20.00 in the evening to 07.00 the next morning. This is the period with the lowest heat production during the day and can be defined as basal metabolic rate or maintenance. The sudden increase in CH_4 concentration shown occasionally is related to the activity where the animals stand up and release some intestinal gas (flatulence).

3.2.3 Correlation between variables

The correlation between dietary characteristic and production of CH_4 and CO_2 is presented in **Table 3**. As expected there was a negative correlation between CH_4 and dietary protein, dietary fat and dietary starch and positive correlations to the fibre fractions. The highest correlation to the daily CH_4 excretion is found for fermented fibre per kg DM intake (r=0.86) as illustrated in **Figure 5**.

There is a strong relationship between CO_2 production and DM intake (r=0.87) and between CO_2 production and body weight (r=0.83). This is a reflection of the growth of the animals as the metabolic pathways involved in maintenance and growth require energy, which will lead to CO_2 production (**Figure 6,** black circles from growing pigs at maintenance + retention). In a comprehensive review of the metabolic studies from the Oscar-Kellner Institute it was shown that increasing the daily weight gain of animals results in an overall lower CO_2 emission (Jentsch et al. 2009) as higher daily weight gain results in relatively less energy for maintenance. From **Figure** 6 it can also be seen that the CO_2 production from the adult sows (red squares) up to a DM intake of approximately 3.5 kg/day is higher because the sows at the low feed intake are fed at maintenance where all energy intake is either excreted or oxidised.

3.2.3 Influence of dietary fat on methane excretion

Dietary fat can potentially influence the CH_4 production, as have been shown in ruminants (Beaucemin & McBurn, 2006), due to biohydrogenation of unsaturated fatty acids and enhanced propionate production. Fat sources with medium chain fatty acids i.e. coconut oil and palm oil is also shown to depress CH_4 production in ruminants (Machmüller et al, 2003). In two of our studies growing pigs have been fed increasing amount of either rapeseed oil or fish oil, as shown in **Figure 7A&B**. The concentration of dietary fat varied from 3 to 21 % but had only a small and insignificant influence on the CH_4 production. However, neither of these experiments was specifically designed to investigate the effect on CH_4 production and all diets had a relatively low level of dietary fibre (12 – 18 % dietary fibre), which is the main substrate for fermentation. Pigs, as non-ruminants, digest the majority of various fat sources up to 90 %, (Jørgensen and Fernández, 2000; Jørgensen et al. 2003) and when feeding fish oil or coconut oil as high as 94 % of the fat is digested at the terminal ileum (Jørgensen et al. 1996; 2000). It is therefore only limited amount of the fatty acids that reach the large intestine with a potential for reducing the CH_4 production.

Feeding of lactating sows requires a diet with a higher energy density, i.e. diets with low fibre content. In order to obtain higher energy density addition of fat is therefore normal practice. In **Table 4** is shown lactating sows fed with low and high dietary fat. The total daily amount of produced CH_4 is 12 – 17 litre/day. However, because of relative low fibre content and high feed intake CH_4 energy expressed relative to gross energy (GE) is measured to 0.5 –0.7 % (Theil et al. 2004). In the experiment with the lactating sows the measurement was done on both sow and piglets. In another experiment where the piglets were fed with milk replacer, the piglets had a CH_4 production of approximately 0.12 % of the gross energy.

3.2.4 Influence on environmental temperature on methane excretion

In ruminants it is generally assumed that CH_4 production decreases with increasing passage rates associated with cold adaptation (McAllister et al. 1996). In order to evaluate if low ambient temperature decreases CH_4 production in pigs, results from three experiments where ambient temperature have varied in the range 12-29 °C were evaluated (**Figure 8A&B**). A tendency was seen for a reduced CH_4 production at the low temperature independent of whether CH_4 was corrected for differences in feed intake or not (A *vs* B).

3.2.5 Influence of body weight on methane production

The pigs' gastrointestinal tract develops with age (weight) towards increased capacity and ability to ferment the dietary fibre fraction of the diet. This is illustrated in **Figure 9A&B** for growing pigs. The results are from an experiment where equal types of diet are fed through several periods (i.e. Latin square design). The results show some variation from period to period, but the general trend is increasing CH_4 production (A) in response to increasing body weight. However, as the pigs grow daily feed intake increases as well and in order to test the influence of only body weight, the CH_4 production is corrected for differences in feed intake (DM intake) as shown in **Figure 9B**. Even with this correction there is a significant effect of body weight on CH_4 production, and the derived equations are shown below:

CH_4, L/day = 0.26 + 0.0437 x BW, kg, n = 55, R^2 = 0.71 [1]

CH_4, L/day per kg DM intake = 1.01 + 0.0107 x BW, kg, n = 55, R^2 = 0.71 [2]

3.2.6 Comparison between growing pigs and adult sows fed similar types of fibre

A comparison of the ability of growing pigs and sows to digest and utilise various fibre rich feedstuffs is shown in **Figure 10A&B**. The data in Figure 10 is limited to experiments where the animals are fed the same type of fibre. The results demonstrate that both growing pigs and sows produce equal amounts of CH_4 per g fermented fibre. However, the sows had a much greater fermentative capacity, i.e. they can ferment a much larger amount of fibre per day. In the actual experiments neither the sows nor the growing pigs were able to consume more of the most voluminous fibre feedstuffs. No significant difference between the slopes from the two classes of animals was found. Therefore, only one common equation is shown:

CH_4, L/day = -2.80 + 0.0248 x Fermented Fibre, g/day, n = 23, R^2 = 0.80 [3]

CH_4, L/day per kg DM intake = -7.57 + 0.0112 x Fermented Fibre, g/day, n = 23, R^2 = 0.71 [4]

3.2.7 Effect of feed intake in adult sows

Sows are normally feed restricted in the dry period and during pregnancy (approximately 2-2.5 Feed Units (FUp) per day) in order not to gain excessive weight because this may cause health problems around farrowing and lactation. In the last 3-4 weeks of the pregnancy period, the feeding level is in general increased to 3.5 FUp per day. **Figure 11** presents results from three experiments with pregnant sows fed either a standard diet or one of two fibre-rich diets supplemented with wheat bran or sugar beet pulp, respectively. The fibre from wheat bran is more resistant to fermentation than fibre from sugar beet pulp. As expected the amount of fibre fermented and consequently CH_4 production is higher when sows are fed sugar beet pulp rather than wheat bran. A higher feeding level increased the CH_4 production (**Figure 11 A**) but relative to dry matter intake the production was lower (**Figure 11B**). However, the slopes in the equations are not significantly different from zero; the P-value was 0.21 for equation [5] and 0.11 for equation [6]:

CH_4, L/day = 5.16 + 0.00156 x Fermented Fibre, g/day, n = 14, R^2 = 0.71   [5]

CH_4, L/day per kg DM = 5.98 - 0.000913 x Fermented Fibre, g/day, n = 14, R^2 = 0.65 [6]

3.2.8 Comparison between growing pigs and adult sows – data from the whole database

The whole database was used to compare the CH_4 production in growing pigs and adult sows (**Figure 12)**. The experiment shows great variation in the fermentability of the different fibres but it was also found that some animals had low CH_4 production independent of amount and fibre. When comparing the contribution of the different fibre rich feedstuffs to the CH_4 emission it should be kept in mind that the lower energy digestibility in fibre rich feedstuffs compared to concentrated feeds implies that the pigs must consume a larger quantity of feed to obtain the same production. When the CH_4 production was expressed as either L/day or L/day per kg DM intake, there was no significant difference between growing pigs and adult sows:

CH_4, L/day = 0.440 + 0.0206 x Fermented Fibre, g/day, n = 137, R^2 = 0.74   [7]

CH_4, L/day per kg DM intake = 0.626 + 0.00894 x Fermented Fibre, g/day, n = 137, R^2 = 0.64 [8]

However, when the CH_4 emission was expressed relative to either GE or DE (**Figure 13**) the slopes for growing pigs and sows were significant different and expressed as:

CH_4-energy, % GE = 0.0628 + 0.00277 (growing pigs) x Fermented Fibre, g/kg DM

CH_4-energy, % GE = 0.0628 + 0.00488 (adult sows) x Fermented Fibre, g/kg DM

n = 137, R^2 = 0.72   [9]

CH_4-energy, % DE = 0.0838 + 0.00376 (growing pigs) x Fermented Fibre, g/kg DM

CH_4-energy, % DE = 0.0838 + 0.00606 (adult sows) x Fermented Fibre, g/kg DM

n = 137, R^2 = 0.74   [10]

On average, energy from CH_4 relative to DE amounted to 0.68% (**Table 2**). However, energy loss of CH_4 in adult sows was approximately three times higher (1.31% of DE) than in growing pigs (0.47% of DE; **Figure 13**). The reason for the higher loss of CH_4 in proportion of DE per g of fermented fibre in sows than in growing pigs is, as discussed by Jørgensen (2007), the sow's relatively greater capacity for fermentation. A factor of importance is also that non-pregnant sows were fed relatively less relative to the body size. The values estimated in current compilation are comparable to results obtained by Scharma et al. (1998) for growing pigs and Kirchgessner et al.

(1991) and Le Goff et al. (2002) for adult sows. As indicated in Figure 12, the CH_4 production in sows could be as high as 3.25% of DE.

The average CH_4 production by growing pigs was estimated 0.39% of GE or 0.47% of DE, which is lower than the value for all classes of pigs (0.6% of GE) assumed in the report on emission of greenhouse gases from Danish agriculture (Mikkelsen et al., 2006). If the value of CH_4-energy (1.0% of GE or 1.3% of DE) is representative for diets for sows (lactating and non-lactating), then the value in the latter report is underestimated for this class of pigs.

3.2.9 Case study – methane production when feeding low and high fibre diets to growing pigs and adult sows

In **Table 5** are shown examples of the typical variations in diet composition that may influence the CH_4 emission from pigs (Sørensen and Fernandez, 2003). All the diets were formulated to satisfy the nutritive recommendations and they resemble diets used in practice.

Over the last two decades diets have been formulated closer to pigs' requirement with regard to amino acid composition to reduce N-pollution to the environment. This is illustrated with diet no. 5 and 6 (Table 5), where diet no. 6 is supplemented with free amino acids. Both diets having the same growth potential but diet no. 6 had reduced protein content and a reduced content of especially soybean meal. Because less fibre is fermented a lower CH_4 production can be expected. Sugar beet pulp was used to increase the concentration of dietary fibre in diet 7, which resulted in higher fermentation of fibre and, consequently, emission of CH_4 that was 60 % higher compared to diet 6 at the same daily gain.

Restricted feeding is generally used for dry and gestating sows to avoid overweight, which can lead to farrowing and locomotion problems. An undesired effect of that are animal welfare problems such as stereotypic behaviour, which, however, can be reduced by feeding high fibre diets. The consequences of increasing the fibre content are illustrated by diet no. 11 and 12 relative to diet 9. Diet no. 9 contains fibre with relative high content of insoluble fibre from barley straw, which illustrates a situation where the sows eat some of the bedding material, which is common. Insoluble fibre is more resistant to fermentation and subsequently the amount of fermented fibre is the lowest of the three diets and the calculated CH_4 emission is low too. In diets no. 11 and no. 12, the amount of fermentable fibre is increased by adding sugar beet pulp, which resulted in almost a tripling of the CH_4 emission when comparing diet no. 12 with diet 9.

4. Conclusion

The main dietary contributor to the CH_4 production at all live weight of pigs is the dietary concentration of fibre, whereas neither dietary fat nor protein had any significant impact on the CH_4 production. The lack of effect of dietary fat on the CH_4 production is possibly due to a very high digestibility of the fat in the small intestine.

Production of CH_4 by piglets is low and amounts to only 0.13 L/day or 0.1 % of GE. For growing pigs' feed, a low fibre diet or a standard diet, the CH_4 production can be estimated to 0.2 to 0.5 % of GE corresponding to 3.4 L/day for an average slaughter pig. When feeding diets with higher fibre content, the CH_4 production depends on type and might contribute up to 1 % of GE. Dry and gestating sows fed at maintenance have a CH_4 production varying from 0.6 to 2.7 % of GE depending on feeding level and fibre type, whereas the CH_4 production of lactating sows is estimated to be approximately 0.6 % of GE. In all the experiments the CH_4 production of sows has been found to exceed 0.6 % of GE.

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Table 1. Description of data

Experiment	Balances, n	Main purpose	LW, kg	LW range, kg	Diets/Treatments	CH_4, L/day	Reference
Piglets							
974-DLW piglets (2000)	12	Artificial reared	4.9	4 - 6	1 diet*3 periods	0.13	Theil et al. 2007
Growing pigs							
Clima–Fibre (1991)	24	Temperature*DietaryFibre	81	71 - 93	2 Temp*2 Diets	6.7	Jørgensen et al. 1996
Uwe-pigs (1991)	28	Adaptation to Fibre	67	61 - 76	4 diets	3.2	Bornholt et al. unpublish
SCFA-infusion (1992-94)	86	SCFA into caecum	92	60 - 120	2 diets	1.0	Jørgensen et al. 1997
73-RapeseedOil (1994)	48	Increasing RapeSeedOil - LW	52	28 - 77	4 diets*4 periods	3.2	Jørgensen et al. 1996
173-FiberSources (1995)	30	Increasing Potato / Soja fibre	60	58 - 62	9 diets	2.6	Jørgensen 1997
573-TemperaturProtein (1997)	24	Temperature*Dietary Protein	68	65 - 70	2 Temp*2 Protein	3.4	Jørgensen unpublish
673-Tagatose (1997)	24	Tagatose/Sucrose	65	45 - 85	3 diets	1.0	Jørgensen et al. unpublish
773-WholeChain (1997-98)	27	PotatoPulp WheatBran	63	61 - 67	3 diets	4.1	Jørgensen et al. 2001
873-ØkoPigs (1997)	48	Silage	64	45 - 79	4 diets	4.6	Carlson et al. 1999
274-HeatChallenge (1998)	42	4 breeds – Low/High Temperature	77	64 - 88	4 breeds*2 Temp	3.1	Theil et al. 2001
WangRice (1999)	48	Starch - Fibre	51	37 - 66	4 diets*4 periods	3.6	Wang et al. 2002
375-FishOil (2000)	30	Increasing FishOil	50	30 - 85	6 diets	1.4	Jørgensen unpublish
944-AllanGrow (2000)	56	Growth – 3 sex	83	25 - 152	Sex*periods	2.8	Jørgensen et al. unpublish
675-Foderstruktur (2001)	16	Processing – Grinding/Pelleting	77	75 - 79	1 diet*4 treatments	4.4	Jørgensen et al. unpublish
476-HealthPromoting (2003)	16	Dietary Fibre	90	87 - 92	4 diets	6.4	Jørgensen et al. unpublish
575-ByProducts (2003)	37	Fibre sources	61	53 - 69	7 diets	3.7	Serena et al. 2007

Sows							
473-FiberSows (1997)	16	Pregnant - 2 Fibre*2 Feed level	290	282 - 298	2 Fibre*2 Feed level	13.6	Olesen et al. 2001
773-WholeChain (1997-99)	36	Pregnant - Fibre*2 Feed level	230	219 - 248	3 diets*2 Feed level	7.5	Theil et al. 2004
773-Silage (1997)	9	Dry sows - Silage	231	207 - 248	3 diets	8.2	Jørgensen unpublish
774-StomachCannulae (1999)	24	Pregnant – Fibre	210	208 - 210	3 diets	5.7	Jørgensen et al. 2010
974-DLW (2000)	9	Pregnant - High/Low protein*Feed level	209	190 - 230	2 diets*2 Feed level	5.4	Theil et al. 2002
974-DLW (2000)	25	Lactating – High/Low fat	206	192-219+piglets	2 diets	14.4	Theil et al. 2004
575-WholeChain (2001)	18	Pregnant - Protein and Fibre	212	206 - 219	4 diets	9.9	Jørgensen unpublish
575-ByProducts (2003)	32	Dry sows – Fibre sources	214	200 - 220	7 diets	12.2	Serena et al. 2009

Table 2. Chemical composition of feeds, faeces and urine for growing pigs

Name	n	Mean	Range of values	Standard deviation	CV
Chemical composition					
Crude Protein, g/kg DM	140	177	98 - 239	27	15.5
Crude fat, g/kg DM	140	69	26 - 257	42	61.1
Starch, g/kg DM	140	435	92 - 706	117	26.9
Total sugars, g/kg DM	103	45	13 - 220	33	74.5
Crude fibre, g/kg DM	54	85	13 - 266	54	63.8
Total NSP, g/kg DM	86	176	5 - 438	106	60.2
Total dietary fibre, g/kg DM *	140	215	0 - 536	113	52.6
Main Results					
Live weight, kg	140	106	4 - 298	75	70.2
DM intake, kg/d	140	1.84	0.15 – 4.87	0.62	34.5
ME intake, MJ/d	140	27.58	3.05 – 75.84	9.19	34.3
CO_2, L/d	140	867	74 - 1837	299	34.5
CH_4, L/d	140	5.0	0.1 – 28.7	4.5	89.3
H_2, L/d	133	1.2	0 – 13.5	1.4	123.4
CH_4, g/d	140	3.6	0.1 – 20.5	3.2	89.3
CH_4, L/kg DM intake	140	2.6	0.2 – 12.4	2.1	80.9
CH_4-energy, % GE	140	0.54	0 – 2.7	0.5	84.0
CH_4-energy, % DE	140	0.68	0 – 3.3	0.6	86.9
Energy digestibility, %	140	83.9	49 - 99	7.9	9.6
Total fibre fermented, %	140	56.7	0 - 87	14.9	26.3

*The content of total fibre was calculated as the residual fraction after subtraction of the analysed content of sugars starch, crude protein, crude fat and ash from the dry matter content.

Table 3. Pearson correlations of chemical compositions (g/kg DM, g/d, %) of 140 diets/treatment

	Chemical composition of feeds							
	Protein	Fat	Starch	NSP	Total fibre	Total fibre, g/d	Total ferm. fibre, g/d	dc Energy
CH_4, L/day	-0.423	-0.230	-0.319	0.708	0.632	0.748	0.857	-0.288
CO_2, L/day	-0.609	-0.466	0.178	0.329	0.342	0.652	0.619	-0.238
CH_4, g/kg DM intake	-0.404	-0.190	-0.394	0.725	0.686	0.630	0.792	-0.271
n	140	140	140	86	140	140	140	140

Table 4. Methane production by lactating sows fed low and high dietary fat (Theil et al. 2004)

Diet - Dietary fat	**Dietary fibre, %**	**LW, kg**	**DM intake, kg/day**	**Ferm. fibre, g/kg DM**	**CH_4, l/day**	**CH_4 % DE**	**DC energy, %**	**CH_4% GE**
Low fat – 3.0 %	17.3	219	4.87	109	12.1	0.6	85	0.53
High fat – 11.3 %	15.1	192	4.76	98	16.9	0.9	82	0.71

LW, live weight; DE, digested energy; DC, digestibility coefficient; GE, gross energy.

Table 5. Examples on trend in diets for growing pigs and dry sows (Data from Sørensen & Fernandez, 2003).

Animal	Growing pigs			Dry sows		
Diet[1]	5	6	7	9	11	12
Composition of diet						
Wheat	33.3	40.1	22.0	45.2	-	40.7
Barley	25.1	33.9	30.4	38.5	81.2	4.6
Sunflower cake	-	-	-	5.7	-	-
Rapeseed cake	-	-	-	3.0	-	-
Barley straw	-	-	-	5.0	-	-
Soybean meal	15.4	10.0	19.5	0.5	3.7	-
Peas	11.6	4.3	-	-	-	-
Sweet lupine	10.0	6.6	10.9	-	0.5	10.1
Sugar beet pulp	2.0	2.0	15.0	-	12.5	42.8
DL-Methionine 40	0.14	0.20	0.13	-	0.05	0.13
L-Threonine 50	-	0.30	-	-	0.05	0.19
L-Lysine 50	-	0.70	-	-	-	-
Mineral + Vitamins	2.46	1.90	2.07	2.10	2.00	1.48
Chemical composition						
Dietary protein, % in DM	23.3	20.0	23.2	14.6	13.0	15.1
Dietary fibre, % in DM	22.5	21.0	29.8	22.6	27.9	41.5
DM-intake, kg/day	1.68	1.70	1.80	1.85	1.83	1.81
DC energy	83	82	78	82	83	84
Fermented fibre, g/kg DM	139	123	194	106	180	335
Expected[2] CH_4, l/day	5.3	4.7	7.6	4.4	7.2	12.7
CH_4-energy[3] % GE	0.44	0.41	0.60	0.58	0.94	1.70
CH_4-energy[3] % DE	0.61	0.54	0.81	0.73	1.18	2.11

[1] The diet number refers to the diet number in the paper of Sørensen & Fernandez (2003)
[2] Calculated from amount of fermented fibre (equations 7).
[3] Calculated from amount of fermented fibre (equations 9 and 10 for growing pigs and adult sows, respectively).
DC, digestibility coefficient; GE, gross energy; DE, Digested energy.

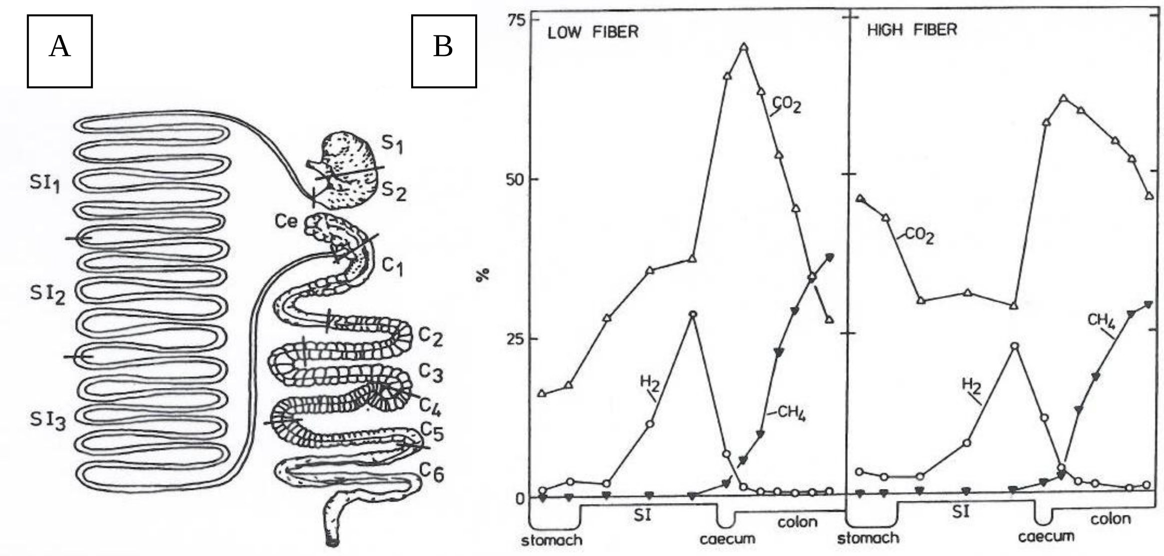
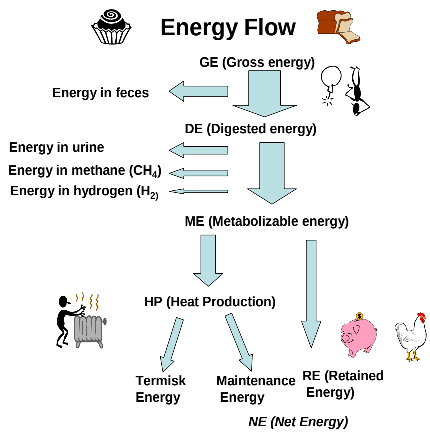


Figure 1. Sampling sites in the gastrointestinal tract. SI, small intestine; S, stomach, Ce, caecum; C, colon. (A). Composition of gases from various regions of the gastrointestinal tract of pigs fed the low- and high-fiber diets (B). Data from Jensen & Jørgensen (1994).



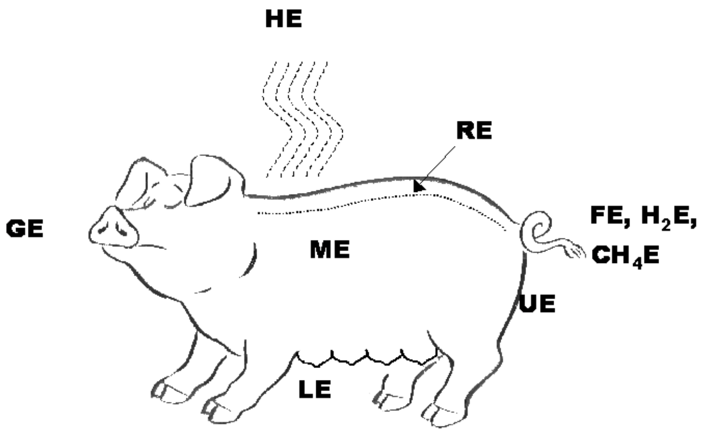
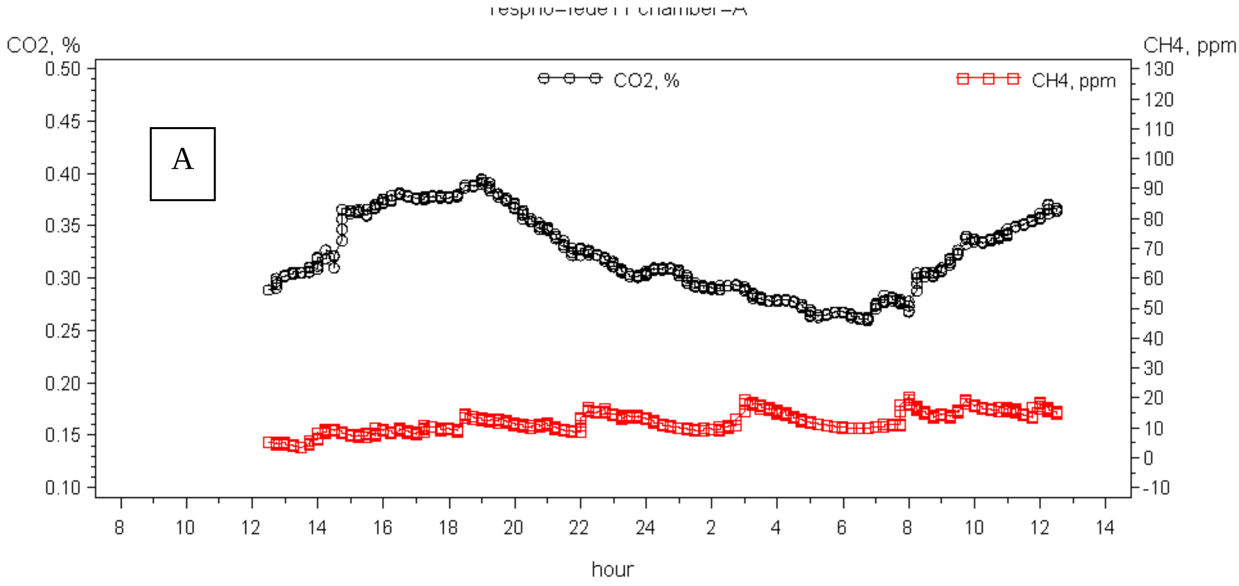


Figure 2. Illustration of energy flow in a pig: GE, total gross energy intake; ME, metabolizable energy (energy available for metabolisme); HE, heat energy; RE, retained energy, LE, lactation energy; UE, urine energy; FE, faecal energy; H_2E, hydrogen energy; CH_4E, CH_4 energy.



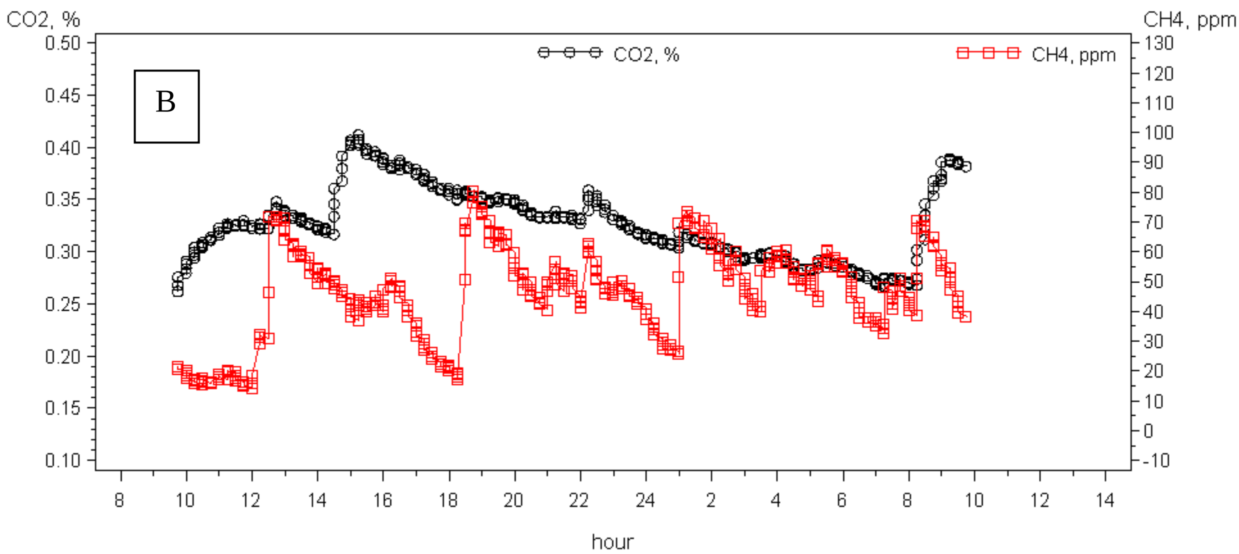


Figure 3. Diurnal variation in concentration of carbon dioxide (CO_2) and methane (CH_4) in the outgoing air from the respiration chambers of a growing pig fed either a control diet (A) or a diet containing sugar beet pulp (B). The gas from the respiration chambers are measured every 4 minutes.

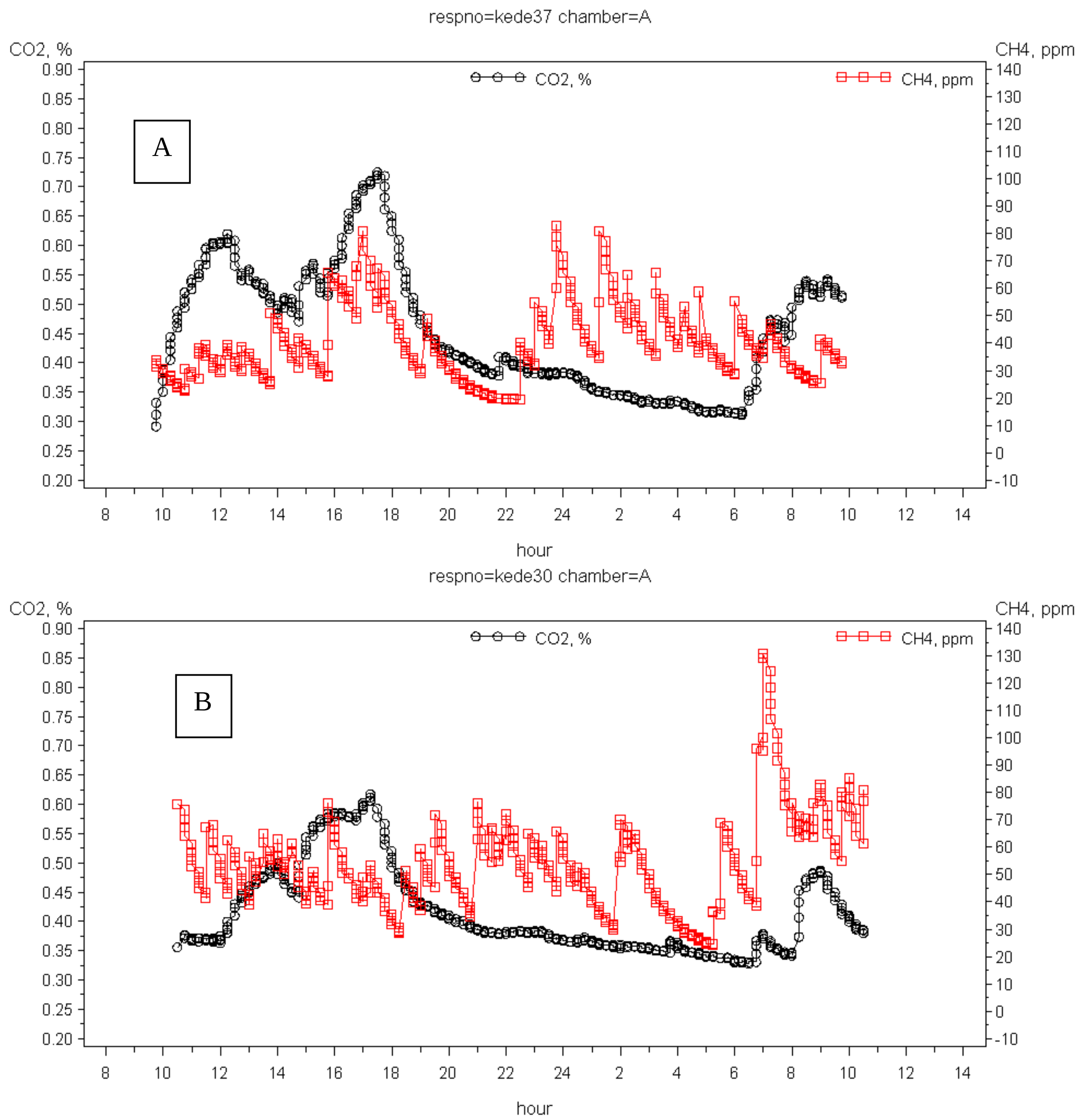


Figure 4. Diurnal variation in concentration of carbon dioxide (CO_2) and methane (CH_4) in the outgoing air from the respiration chambers of a adult sow fed either a control diet (A) or a diet containing sugar beet pulp (B). The gas from the respiration chambers are measured every 4 minutes.

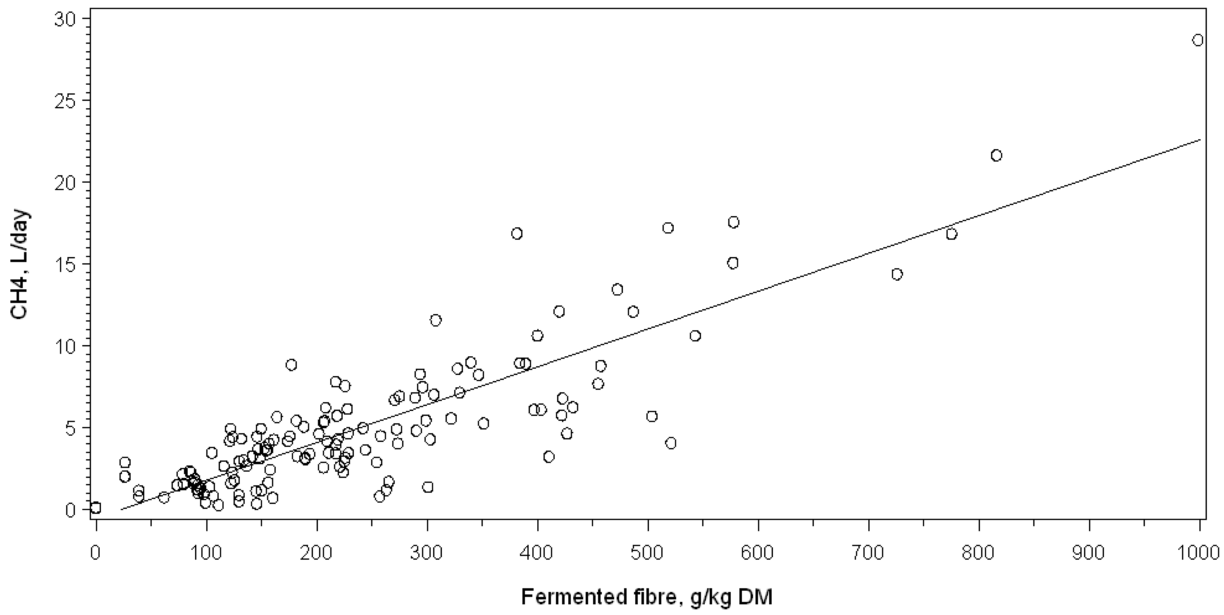


Figure 5. Plot of CH_4 excretion (L/day) against total fermented fibre (g/kg Dry Matter intake) on the total dataset (n=140).

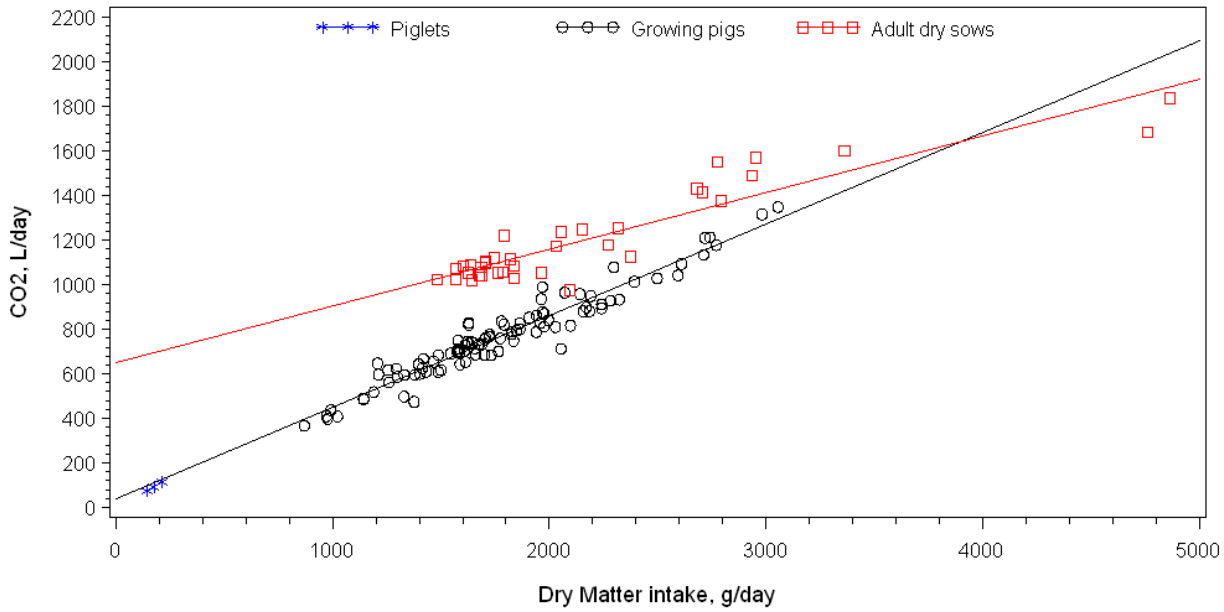
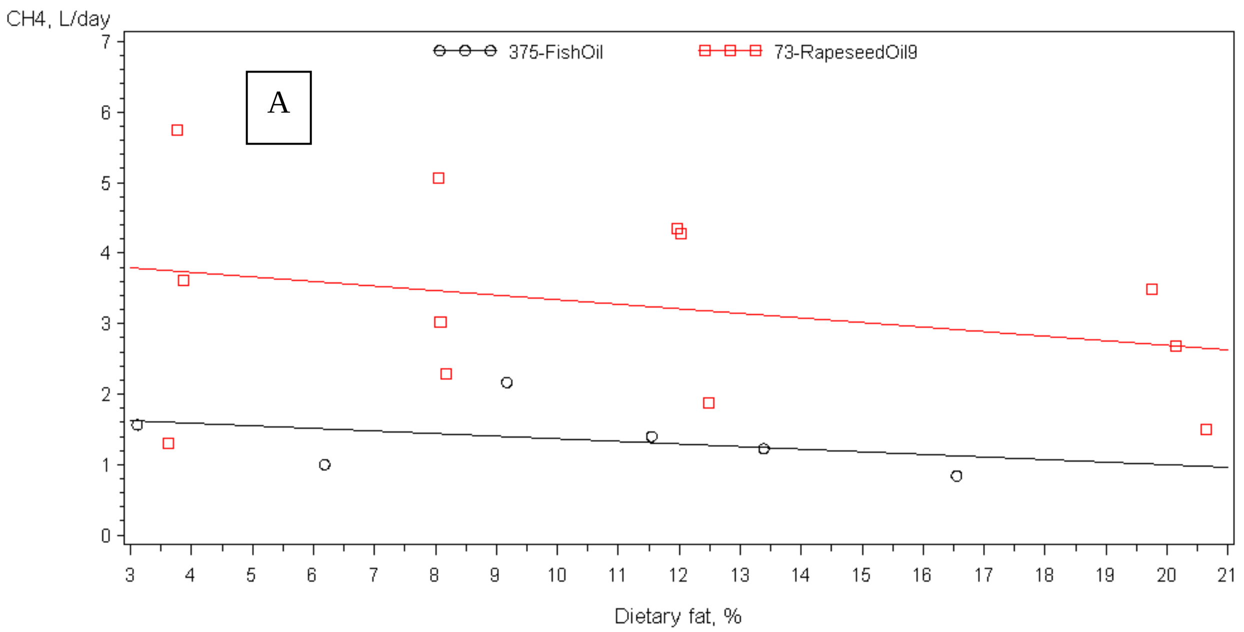


Figure 6. Plot of CO_2 excretion (L/day) against total dry matter intake (g/kg) on the total dataset (n=140).



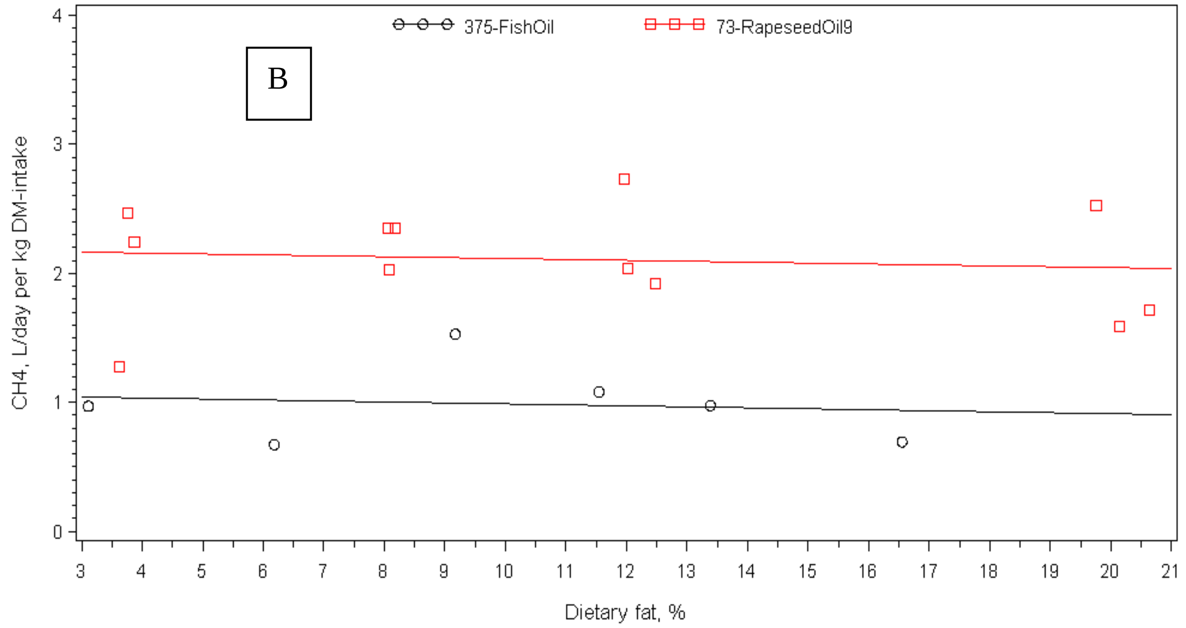


Figure 7. Influence of dietary fat on fermentation/excretion of CH_4. Results from two experiments were growing pigs were fed either increasing amount of dietary fat as fish oil or rapeseed oil. (A) Show CH_4 excretion in L/day and (B) when the excretion is corrected for feed intake (L/day per kg Dry matter intake).

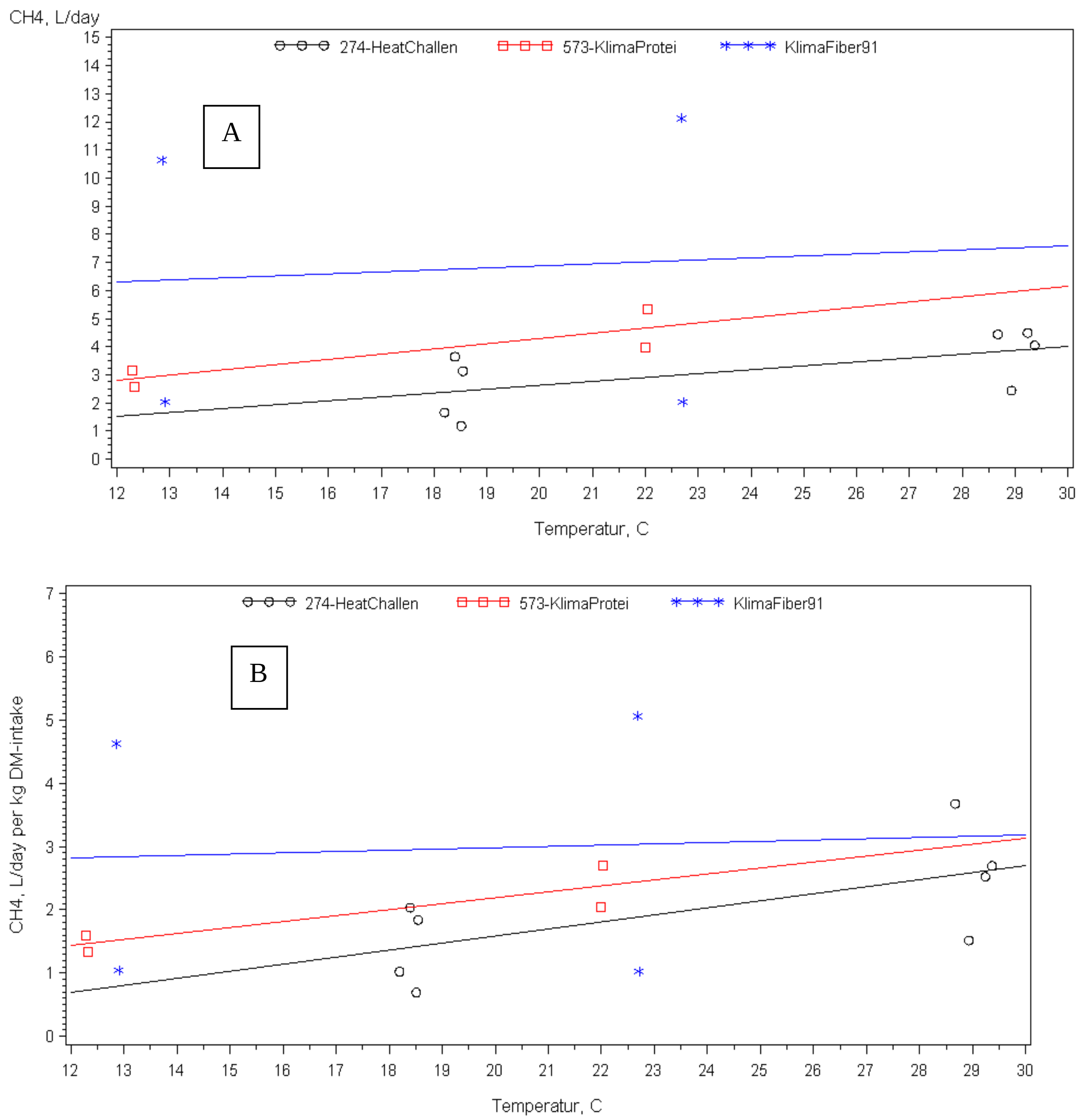


Figure 8. Influence of environmental temperature on fermentation/excretion of CH_4. Results from three experiments with environmental temperature varied from 12 – 29 °C. (A) Show CH_4 excretion in L/day and (B) when the excretion is corrected for feed intake (L/day per kg Dry matter intake).

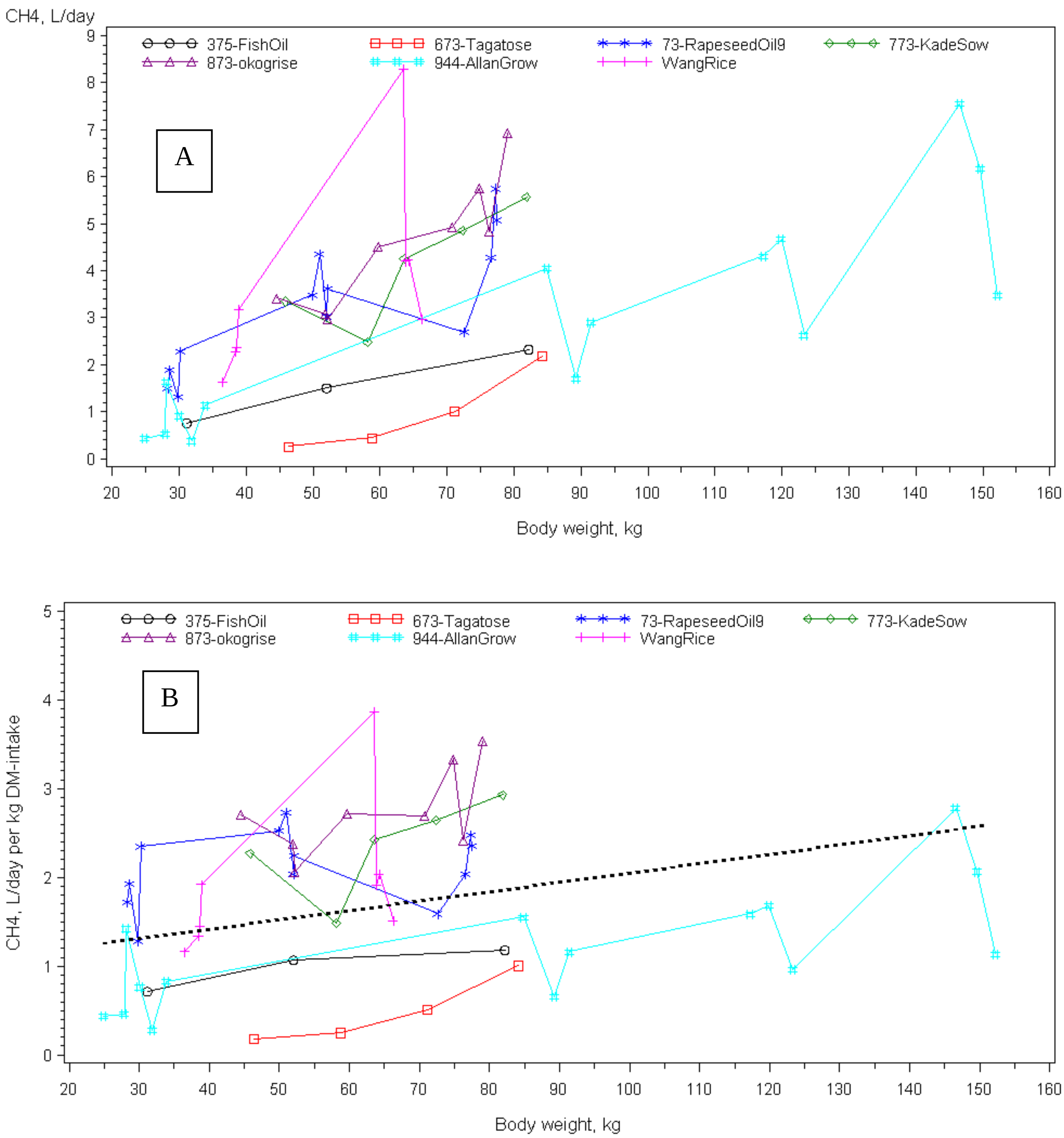


Figure 9. Influence of body weight on fermentation/excretion of CH_4. (A) Show CH_4 excretion in L/day and (B) when the excretion is corrected for feed intake (L/day per kg Dry matter intake).

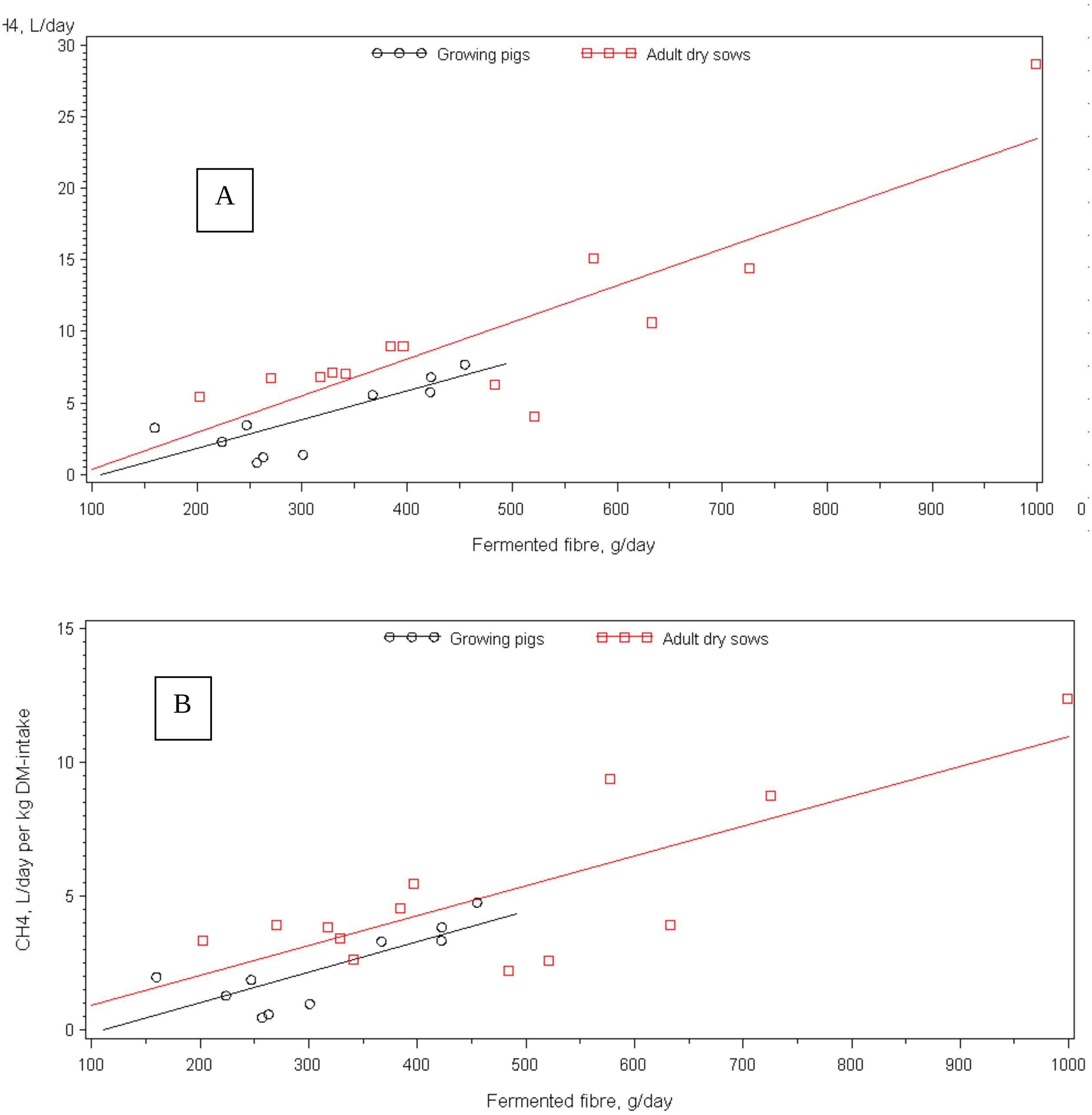


Figure 10. Influence of body weight (growing pigs *vs* adult sows) on fermentation/excretion of CH_4 in experiments where the animals are fed equal type of fibers. (A) Show CH_4 excretion in L/day and (B) when the excretion is corrected for feed intake (L/day per kg Dry matter intake).

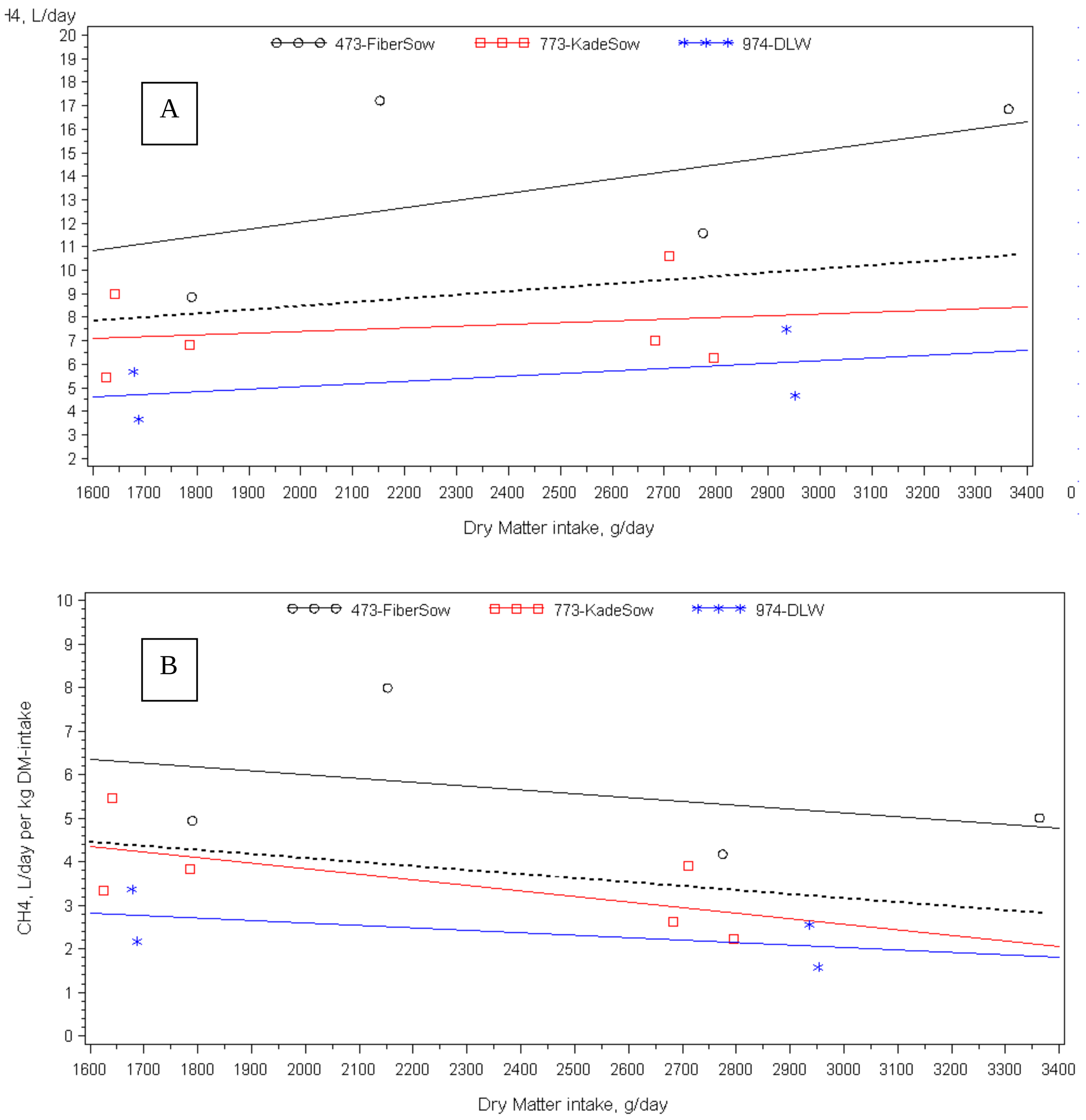


Figure 11. Influence of feeding level (pregnant sows) on fermentation/excretion of CH_4. (A) Show CH_4 excretion in L/day and (B) when the excretion is corrected for feed intake (L/day per kg Dry matter intake).

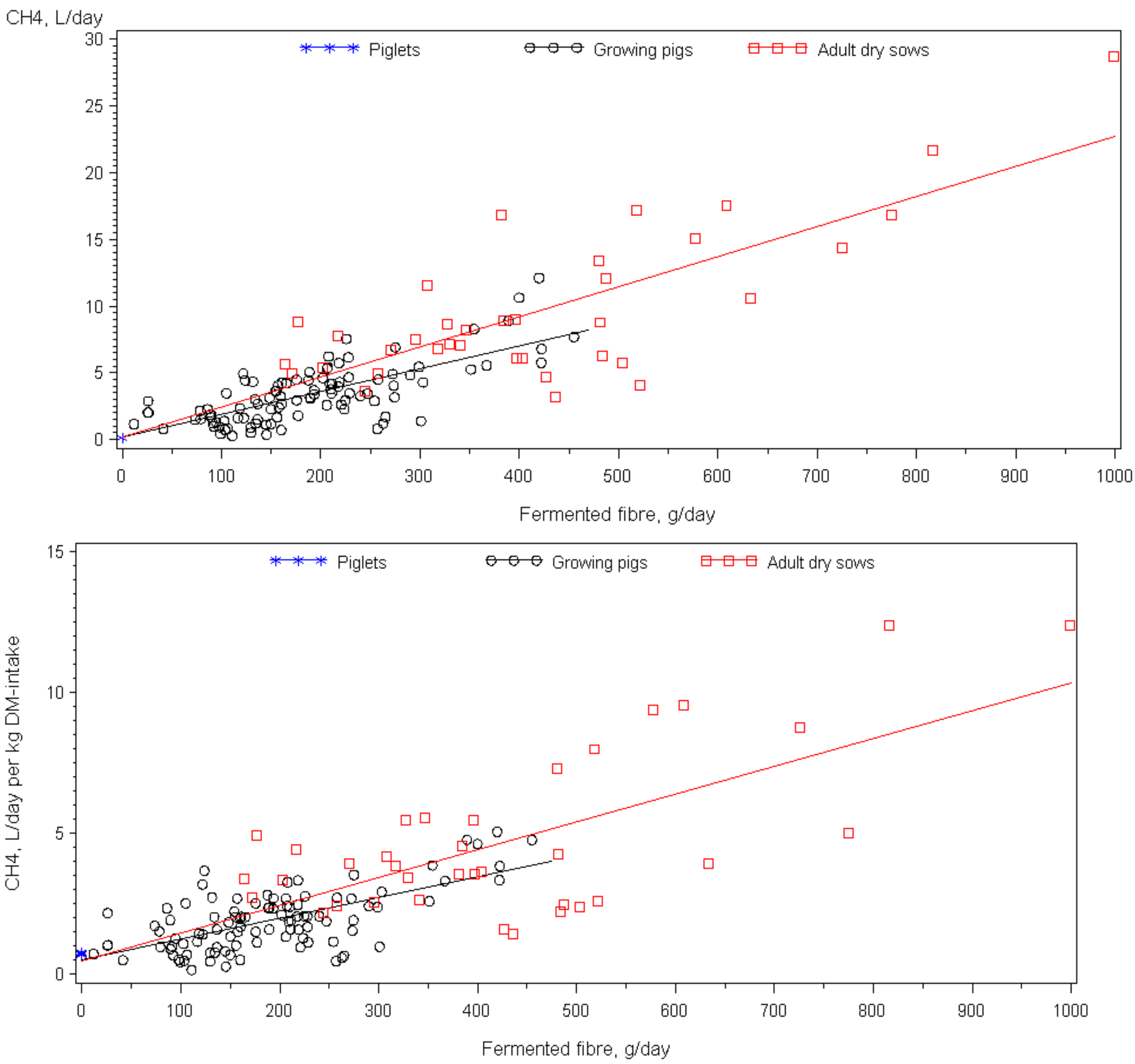


Figure 12. Influence of body weight (growing pigs, black circles *vs* adult sows, red squares) on fermentation/excretion of CH_4 when plotting the whole dataset. (A) Show CH_4 excretion in L/day and (B) when the excretion is corrected for feed intake (L/day per kg Dry matter intake).

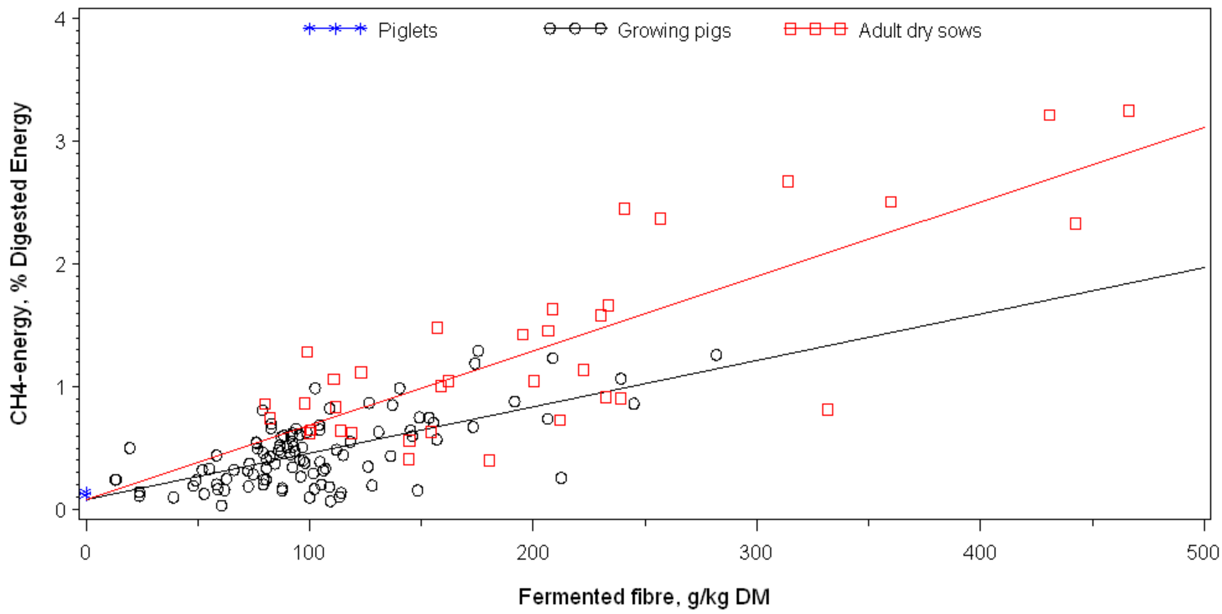


Figure 13. Production of methane-energy relative to digested energy (DE) in relation to amount of fermented dietary fiber in growing pigs (black circles) and adult sows (red squares). Data from piglets shown as blue stars.