Estimating farm scale greenhouse gas emission intensity of pig production in Norway

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ABSTRACT

To assess greenhouse gas (GHG) emission intensity and its variation in Norwegian pig production, we conducted an analysis of 15 farrow-to-finish pig farms to calculate farm scale emissions of GHGs, expressed as carbon dioxide equivalents (CO_2eq) per kg carcass weight (CW) sold. A model, HolosNor, was developed to estimate net GHG emissions, including soil C changes, from pig farms. Based on data from 2008 the estimated GHG intensity was 2.65 kg CO_2eq kg^{-1} CW (range: 1.24 to 4.03). The production of the feed consumed by the pigs contributed most to total GHG emissions; accounting for 2.14 kg CO_2eq kg^{-1} CW, or more than 80% of the total emissions. Our study estimated a large variation in GHG intensity among pig farms in Norway which indicates opportunity for incorporating mitigation practices. A valuable contribution of the current work is the framework of a farm-scale tool for assessing farm-specific mitigation options.

Keywords: Feed production, greenhouse gas emissions, gross margin, manure, pigs

Introduction

Pig production can have significant environmental impacts, including the emission of greenhouse gases (GHGs) (Dalgaard, 2007). As with other livestock systems, pig producing farms in future will need to reduce GHG emissions per unit of product. Norwegian pig farms are small scale operations, typically 75 sows (Ingris, 2012). Animal performance is high both in terms of reproduction (23.5 pigs reared per sow per year, 2.18 litters per sow per year, 13 pigs born alive per litter) and growth (daily average live weight gain in finishing pigs is 952 g per day, the feed conversion ratio is 2.58 kg feed per kg live weight, average lean meat percentage is 60.8, average slaughter weight is 80.3 kg). Norwegian agricultural policy aims to preserve the linkages between the natural resource base of the farms and the animal production systems. For pig production, this has been accomplished by implementing quotas for number of pigs, manure disposal requirements, and compulsory planning of manure use. The result is small-scale pig production closely linked to feed production. The high animal performance of pig production combined with farm scale linkage between animals and soil should ensure low GHG emissions per unit of product. Yet, there is variation among farms both in animal performance (Ingris, 2012) and feed production (Bonesmo et al., 2012) which may give opportunity for mitigation options. The development and use of simulation models or simpler calculators for estimation of GHG emissions at the farm level has been useful in detecting tactical mitigation options in dairy and beef production (i.e., options within a production season that do not require a change of the whole farm strategy) (Schils et al., 2007; Beauchemin et al., 2010; Bonesmo et al., 2013). Similar development and use of a whole farm model for estimating GHG emission for pig production intensities would be helpful in identifying suitable GHG mitigation options. Thus, our objectives were to: (1) develop a whole farm model for estimating GHG emission intensities of pig production that encompasses the farms' natural resource base and management; and (2) estimate the average level of and the variation among GHG emission intensities of pig production for Norwegian farms and thereby identify opportunities for mitigation.

Materials and methods

In the following section we first describe the model; thereafter, the farm specific operational and natural resource base data are described.

The system boundaries and the whole-farm model

A farm scale model, HolosNor, was developed to estimate net GHG emissions from pig production systems, including soil C changes. Based on the Canadian Holos model (Little et al., 2008), HolosNor is an empirical model with a yearly time-step. Its framework is based on the methodology of the Intergovernmental Panel on Climate Change (IPCC, 2006) with modifications that recognize the distinctness of Norwegian conditions. The following GHG sources are considered: enteric CH_4 and manure-derived CH_4 and N_2O; on-farm N_2O emissions from soils; off-farm N_2O emissions from N leaching, run-off and volatilization (indirect N_2O emissions); on-farm CO_2 emissions or C sequestration due to soil C changes; CO_2 emissions from energy used on-farm; and off-farm CO_2 and N_2O emissions from supply of inputs of mineral fertilizers, pesticides, feed, and fuel. All gas emissions are expressed as CO_2eq to account for the global warming potential of the respective gases given a time horizon of 100 years: CH_4 kg × 25 + N_2O kg × 298 + CO_2 kg × 1 (IPCC, 2007). The GHG emission intensities are reported as kg CO_2eq kg^{-1} carcass weight (CW) sold.

Yearly enteric CH_4 emissions ($CH_{4enteric}$) are calculated for each class of pigs (i = sows, starters, finishers) as:

$$CH_{4enteric\_i} = \frac{1.5}{365} \times pigs_i \times days_i$$

where 1.5 kg CH_4 year^{-1} is the yearly enteric emission rate (IPCC, 2006), *pigs* is the yearly average number of animal in each class of pigs, and *days* is the number of days by pig class (*days* for sows = 365, for starters = 33.9, finishers = 90.3).

Manure CH_4 emissions estimates (kg CH_4 year^{-1}) are calculated for each class of pigs based on volatile solids (*VS*) production, according to IPCC (2006), and assumed to be 10% of the daily feed intake (value simplified from Table A4-21 in Little et al, 2008). The VS production is multiplied by a maximum CH_4 producing capacity of the manure (B_o = 0.45 m³ CH_4 kg^{-1} *VS* for pigs of all classes, IPCC, 2006), a conversion factor from volume to mass (0.67 kg m^{-3}) and a CH_4 conversion factor specific to the manure management practice (*MCF*):

$$CH_{4manure\_i} = VS \times B_o \times MCF \times 0.67 \times pigs_i \times days_i$$

The MCF is calculated for each farm individually based on Mangino et al. (2001) and Vergé et al. (2006), assuming that a crust cover reduces CH_4 emissions by 40% as compared with no cover (IPCC, 2006) and the emptying of the VS by 2/3 in May and completely in September (Gundersen & Rognstad, 2001). Calculating MCF for individual farms gave a range of 0.12 - 0.14, with an average of 0.13.

The manure N is estimated by pig class from daily concentrate intake (*FI,* kg "as fed" head^{-1} day^{-1}), the crude protein content of the diet (diet *CP* for sows = 0.20, for starters = 0.22, for finishers = 0.18), and protein retention (*PR* =0.3; Little et al., 2008) by the animals based on IPCC (2006) and Little et al. (2008):

$$N_{manure\_i} = \frac{FI_i \times CP_i \times (1 - PR)}{6.25} \times pigs_i \times days_i$$

The IPCC (2006) calculates direct N_2O emissions from manure by multiplying the manure N content by an emission factor for the manure handling system. For stored pig manure as liquid slurry with natural crust cover, as is the case for the farms in this investigation, the emission factor is set to 0. Indirect N_2O emissions caused by leaching and volatilization are calculated as fractions of the total N excretion rate multiplied by specific emission factors (Little et al., 2008). For manure stored as liquid slurry with a natural crust cover, the leaching fraction is zero and the volatilization fraction is 0.48. The emission factor for volatilization is 0.0075 kg N_2O-N (kg N)$^{-1}$.

Estimates of direct soil N_2O emissions are based upon the IPCC (2006) emission factor of 0.01 kg N_2O-N kg^{-1}of total N input, defined as the sum of N fertilizer applied, crop residual N, and mineralized N. The residue N is calculated as the sum of above ground and below ground residue N (Janzen et al., 2003). The mineralised N is derived from an N:C ratio of soil organic matter of 0.1 (Little et al., 2008). The N_2O emission is strongly affected by soil moisture and temperature conditions (Watts and Hanks, 1978). Relative effects of percent water filled pore space of 25 cm top soil (WFPS) and of soil temperature at 30 cm depth (ts30 °C) are derived from Sozanska et al. (2002) as described by Bonesmo et al. (2012). The seasonal variation in direct soil N_2O emissions is taken into account by dividing the year into four seasons, spring (April-May), summer (June-August), fall (September-November), and winter (December-March), with their respective values of total N input, WFPS, and ts30. This approach allows for a simple description of the seasonal interaction between the fertilization rate and the current soil moisture and temperature conditions.

The indirect soil N_2O emissions due to leaching and runoff are calculated according to IPCC (2006); the leaching fraction is 0.3, and the emission factor for leaching and runoff is 0.0075 kg N_2O-N kg^{-1}. Emissions of N_2O due to volatilisation are calculated using the IPCC (2006) constants of 0.1 for the volatilisation fraction and 0.01 for the emission factor.

The estimates of soil C change are based upon the Introductory Carbon Balance Model (ICBM) of Andrén et al. (2004). The ICBM is a two-component model, comprising young and old soil C, input of total C from crop residues and manure, two decay constants, parameters of humification (humification coefficient for pig manure is set to 0.25 according to Wang et al., 2012, and for crop values cf. Bonesmo et al., 2012), a farm specific multiplicative index of the relative effects of soil moisture and soil temperature, and a soil cultivation factor. For the individual farm the multiplicative soil moisture and temperature index is estimated on a daily basis and averaged over the year (Bonesmo et al., 2012). The proportions of arable land in cereal production and of farms with arable crops have been continuously increasing in Norway during the last 60 years. Over time, the rate of soil C loss gradually declines in a continuously arable crop system when following a mixed farming system including perennial grass (Riley & Bakkegard, 2006). Thus, we used the ICBM's estimate of soil C change in the 30th year of continuous arable cropping.

Direct emissions from diesel fuel, electricity, and off-farm emissions of the manufacturing and production of farm inputs are estimated using appropriate emission factors for Norway or Northern Europe (for values cf. Bonesmo et al., 2012). Emissions related to purchased concentrates are estimated by first calculating the amount of energy and CP they supplied in order to estimate the amount of grain and soybean meal comprised by the concentrates. It is assumed that farm produced grain crops (barley and oats) replace the grain crops of the concentrate and that the soybean meal was imported from South America. The emissions for the purchased concentrates were then assessed as on-farm emissions from the individual farm's production of barley and oats (including soil N_2O, soil C change, and indirect and direct energy use), and off-farm emissions from the production of imported soybean meal (1.09 kg CO_2eq kg^{-1} dry matter; Dalgaard et al., 2008). If the amount of feed grains grown on the farm is insufficient, then the average emission for barley and oats grown in Norway is used (0.62 kg CO_2eq kg^{-1} dry matter; Bonesmo et al., 2012). Emissions from excess on-farm feed crop production (i.e., soil N_2O, soil C change, and indirect and direct energy) were not included in the total farm emissions related to pig production. Emissions from the farms' wheat production were not included in the total farm emissions because wheat is not grown specifically as feed for pig production in Norway, although in some years wheat is used as a feed if the quality requirements for bread production are not met (Norske Felleskjøp, 2012).

INSERT TABLE 1 HERE

Farm operational and natural resource base data

The effects of variation in farm management practices on GHG emissions was explored by running the model with data from 15 Norwegian farrow-to-finish pig farms for the year 2008. The data set was established by combining individual farm operational data from The Norwegian Farm Accountancy Survey (NILF, 2009) with farm level data on soil characteristics, provided by the Norwegian Forest and Landscape Institute, and farm level weather data for the year 2008 provided by the Norwegian Meteorological Institute.

Farm specific CW sold and numbers of pigs including sows, recruitment sows, starters, and finishers were obtained from the Norwegian Farm Accountancy Survey (NILF, 2009) (Table 1). The farm specific amount of concentrate fed was estimated on the basis of the farm's expenditures for concentrate (NILF, 2009) and current price of concentrate (BFJ, 2010). The on-farm use of concentrate was distributed among the pig classes based on the feeding recommendations for the various pig classes (Table 1); the relative amount of concentrate was: sows, 1.0; finishers, 0.13; and starters, 0.02. Based on these relative amounts, the number of pigs in each class and the typical concentrate types and their prices, the farm specific daily average amounts of concentrate fed to each pig class were estimated. The areas (ha) and yields (kg ha^{-1}) of barley, oats, spring and winter wheat were specified in the Norwegian Farm Accountancy Survey (NILF, 2009) (Table 1) and the farm specific application levels of N and the amount of pesticides applied to each type of field crop were estimated on the basis of NILF (2009) according to Bonesmo et al. (2012) The pesticide energy use (MJ ha^{-1}) was estimated according to Audsley et al. (2009). Farms that received regional payments for maintaining land under reduced tillage are specified in the accountancy survey (NILF, 2009), and from the payments received, the area with reduced tillage was estimated for each farm (Bonesmo et al., 2012). The farm expenditures for fuel and electricity (NILF, 2009) were distributed to crops according to their respective areas, and the energy use was calculated by dividing these amounts by the 2008 average consumer price of electricity (Statistics Norway, 2010) or the 2008 average on-farm price of fuel (BFJ, 2010) (Table 1).

Soil survey records for the 15 farms were provided by the Norwegian Forest and Landscape Institute for homogenous soil type mapping units down to 0.4 ha, each with specifications of top soil and subsoil layers. From these records soil moisture capacities were derived by using pedotransfer functions of Riley (1996). The 2008 daily weather data from the network of the Norwegian Meteorological Institute were interpolated to each farm's geographical midpoint and altitude (Tveito et al., 2005). From these data daily values and annual means of $r_w \times r_T$ for ICBM, seasonal values for WFPS and ts30 were calculated (Table 1). A detailed description of the processing of the farm's natural resource base data for field crops is given by Bonesmo et al. (2012).

The GHG emission intensities

The GHG emission intensities were calculated for individual farms by relating the estimated total farm GHG emissions (CO_2eq) to meat as kg CW and live animals sold from all pig classes. To explore causes of variation in the estimated GHG emission intensities among farms, simple linear regressions were calculated between (1) the farm specific estimated feed related emissions and the gross margin in crop production; and (2) the animal related emissions and the economic feeding efficiency.

Results

The average GHG intensity for the 15 farrow-to-finish pig farms was estimated as 2.65 kg CO_2eq kg^{-1} CW (Table 2). The production of the feed (on-farm and off-farm) consumed by the pigs contributed most to total GHG emissions; accounting for about 2.14 kg CO_2eq kg^{-1} CW or 80% of the total emissions. Animal related GHG emissions (enteric and manure storage CH_4, manure storage N_2O) accounted for about 0.51 kg CO_2eq kg^{-1} CW or 20% of the total emissions. The soil N_2O emissions were the largest single on-farm source accounting for 21% of the total emissions, and the soil C change the smallest accounting for 2% of the emissions. The on-farm emission from fuel use in feed crop production was on average 0.18 kg CO_2eq kg^{-1} CW or 7% of the total emissions. There was large variation in estimated GHG emission intensities among farms (Table 2). The maximum GHG emission per kg CW was more than three times higher than the minimum, a difference of 2.79 kg CO_2eq kg^{-1} CW. The variation in the estimated soil N_2O emissions was the source that contributed most to the total variation in GHG emissions among the farms. The difference between the minimum and the maximum levels for soil N_2O emissions was 1.56 kg CO_2eq kg^{-1} CW.

INSERT TABLE 2 HERE

In general, higher GHG emissions per kg CW could be explained by higher emissions from feed production (on and off farm) (regression slope 0.86, $r^2 = 0.99$); the animal related emissions were smaller (regression slope 0.14, $r^2 = 0.72$) (Fig 1). Consequently, the proportion of emissions related to animals was lower at farms with the higher GHG emissions per kg CW.

INSERT FIGURE 1 HERE

Examination of correlations between farm scale economic efficiencies, gross margin in crop production and economic feeding efficiency, and the estimated emission intensity per kg CW sold revealed no strong relationships (Fig. 2A). However, there was a decrease in GHG emission intensity per kg CW of feed related emissions with increased gross margin in crop production ($r^2 = 0.21$, p=0.086). A similar relationship was found for the estimated animal related emission intensities per kg CW and economic feed efficiency ($r^2=0.23$, p=0.070) (Fig. 2B).

INSERT FIGURE 2 HERE

Discussion

The estimated average GHG emission intensity of 2.65 kg CO_2eq kg^{-1} CW for Norwegian pig production was similar to the average of five Swedish studies as reported by Soneson et al. (2009); the average of Swedish pig production was 4.1 kg CO_2eq kg^{-1} bone free meat recalculated to 2.5 kg CO_2eq kg^{-1} CW. Our estimated GHG emission was also close to the average of 2.4 kg CO_2eq kg^{-1} CW reported for four German pig production systems (Hirschfeld et al., 2008). The ranges of the Swedish studies and the German production systems were 1.9 – 3.1 and 1.7 – 3.1 kg CO_2eq kg^{-1} CW, respectively. The range of variation found in our study of 15 farms was somewhat wider (1.24 – 4.03 kg CO_2eq kg^{-1} CW; Table 2), which is expected because our numbers are from actual farms rather than from constructed model farms as was the case in the Swedish as well as in the German studies. Other studies with estimates of 3.3 and 3.4 kg CO_2eq kg^{-1} CW for pig production in Denmark and UK, respectively (Dalgaard et al., 2007), and 3.0 kg CO_2eq kg^{-1} CW for pig production in France (Basset Mens & van der Werf, 2005) were somewhat higher, but still very close to the average of the Norwegian farms. This difference can mainly be attributed to lower animal husbandry related emissions estimated by our model. The lower estimates of animal related emissions can be explained by the high animal performance of Norwegian pig production. In 2008 the daily average live weight gain in finishing herds was 5% higher and the feed conversion ratio was 1% lower than for Danish finishing herds (calculations based on data from Ingris, 2010, and Groes Christiansen, 2011). Further it should be recognized that there are inevitable differences in quality of farm data, boundaries assumed, and emission factors applied in the different studies. However, the overall conclusion is that the GHG emissions related to pig production are relatively low. Using an emission factor of 3.0 kg CO_2eq litre^{-1} fuel for direct and indirect fuel use (cf. Bonesmo et al., 2012), the emissions from the production of 1 kg CW of pork would be comparable to the emissions of a 10 km drive in a typical family car. Moreover, the emission intensity of pig production is about one seventh of the intensity (19 kg CO_2eq kg^{-1} CW) reported for beef from dairy herds (Bonesmo et al., 2013) and only one tenth of the intensity (37 kg CO_2eq kg^{-1} CW) for beef from specialised beef cattle (Dalgaard et al., 2007). Substituting beef with pork might thus be a GHG emission abatement strategy. However, this is a simplified comparison as it does not credit the ruminant- production for the CO_2 storage in grassland; land use change is not considered in this abatement strategy. If the grass production and pasture land were converted to grain land for pig production substantial soil C losses would be expected.

Application of tactical mitigation options (i.e., options tailored to the specific farm's strategy) to lower GHG intensity of pork production assumes significant variation within the production system. Our study estimates large variation in GHG intensity among pig farms in Norway (1.24 – 4.03 kg CO_2eq kg^{-1} CW) which indicates a sensitivity of emissions to mitigation. The variation in GHG emissions is mainly caused by the variation in feed related emissions (Fig. 1), and thus mitigation measures should be applied to crop production. Agronomic measures at the tactical level are perhaps the most difficult mitigation practices to assess; reducing N fertilisation, the use of reduced tillage, catch crops (i.e., crops grown that remove N from the soil at the time leaching takes place), and crop rotation all impact yields and crop residues (cf. discussion of Bonesmo et al., 2012). Thus, a whole-farm analysis using farm level decision support tools would be helpful. Our results showed a decrease in estimated GHG emission intensities with both an increase in gross margin in crop production and an increase in economic feeding efficiency (Fig 2), suggesting that there are few negative economic impacts of reducing the GHG emissions in pig production.

Conclusion

The GHG emission intensity for 15 farrow- to- finish pig farms in Norway was on average 2.65 kg CO_2eq kg^{-1} CW, which is similar to emissions from pig production in other western European countries. There was a large variation in GHG emission intensity among farms in Norway (1.24 – 4.03 kg CO_2eq kg^{-1} CW) indicating a sensitivity of emissions levels to mitigation measures. The variation in GHG emissions was mainly caused by the variation in feed related emissions, and thus mitigation measures should be applied to crop production. There were few negative farm scale economic impacts of reducing the GHG emissions in pig production. The HolosNor model takes into account the interactions between the farm's soil and production of crops and animals. Thus, a valuable contribution of this study is the framework of an on-farm tool for assessing farm-specific mitigation options of Norwegian pig production.

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Table 1. Data for animals, fuel usage, crops, and natural resources for the 15 Norwegian farrow-to-finish pig farms included in the analyses.

Farm characteristics, units	n	Mean	Range [min, max]
Animals			
Sows including recruitments, number fed year^{-1}	15	58	[20, 96]
Starters, number fed year^{-1}	15	1105	[379, 1782]
Finishers, number fed year^{-1}	15	843	[345, 1473]
Carcass weigth, kg sold year^{-1}	15	77747	[29375, 130294]
Concentrate to sows, kg year^{-1}	15	93556	[32302, 138661]
Concentrate to starters, kg year^{-1}	15	24157	[8178, 39957]
Concentrate to finishers, kg year^{-1}	15	175908	[71074, 281539]
Energy, direct usage			
Fuel, litre year^{-1}	15	5495	[1685, 12980]
Electricity, kWh year^{-1}	15	45507	[19429, 84995]
Crops			
Barley area, ha	12	20	[8, 49]
Barley yield, kg DM ha^{-1}	12	4582	[2510, 5647]
Barley mineral fertilizers, kg N ha^{-1}	12	89	[0, 148]
Barley reduced tilllage, ratio	12	0,7	[0, 1]
Barley pesticides, MJ ha^{-1}	12	163	[0, 206]
Oats area, ha	6	18	[6, 36]
Oats yield, kg DM ha^{-1}	6	5126	[4386, 7267]
Oats mineral fertilizers, kg N ha^{-1}	6	107	[82, 134]
Oats reduced tillage, ratio	6	0,7	[0.4, 1.0]
Oats pesticides, MJ ha^{-1}	6	187	[91, 488]
Spring wheat area, ha	8	21	[8, 61]
Spring wheat yield, kg DM ha^{-1}	8	3760	[2460, 5620]
Spring wehat mineral fertilizers, kg N ha^{-1}	8	100	[20, 140]
Spring wheat reduced tillage, ratio	8	0,8	[0.4, 1.0]
Spring wheat pesticides, MJ ha^{-1}	8	244	[133, 537]
Winter wheat area, ha	4	12	[4, 23]
Winter wheat yield, kg DM ha^{-1}	4	7738	[3970, 6130]
Winter wheat mineral fertilizers, kg N ha^{-1}	4	125	[125, 125]
Winter wheat pesticides, MJ ha^{-1}	4	546	[330, 1079]
Soil weather			
Soil temperature at 30 cm depth[a], winter, °C	15	1,4	[0.9, 2.5]
Soil temperature at 30 cm depth, spring, °C	15	8,0	[6.4, 9.5]
Soil temperature at 30 cm depth, summer, °C	15	15,5	[13.9, 17.0]
Soil temperature at 30 cm depth, fall, °C	15	7,2	[6.5, 9.1]
Water filled pore space[b], winter, %	15	79	[70, 84]
Water filled pore space, spring, %	15	64	[52, 74]
Water filled pore space, summer, %	15	63	[33, 70]
Water filled pore space, fall, %	15	79	[49, 71]
$r_w \times r_T$ yearly[c], dimensionless	15	1,72	[1.46, 2.09]
Soil organic C, Mg ha^{-1}	15	78,5	[61.3, 102.5]

[a] Estimated according to Kätterer and Andrén (2009)

[b] Estimated according to Bonesmo et al. (2012)

[c] Estimated according to Andrén et al. (2004)

Table 2.

Mean, minimum, and maximum values of GHG emission intensities, expressed as kg CO_2eq kg^{-1} CW, for 15 Norwegian farrow-to-finish pig farms. Values less than 0 indicate removal from the atmosphere (i.e., soil C gain).

	GHG emissions, kg CO_2eq kg^{-1} CW sold		
	Mean	Range [min, max]	Proportion, %
Total GHGs	2.65	[1.24, 4.03]	
Enteric CH_4	0.14	[0.07, 0.18]	5.3
Manure CH_4 N_2O [a]	0.38	[0.18, 0.55]	14.3
Soil N_2O [a]	0.56	[0.11, 1.68]	21.1
Soil C change [a]	0.06	[-0.07, 0.49]	2.3
Off-farm barley	0.41	[0.00, 0.98]	15.5
Off-farm soya	0.71	[0.28, 1.22]	26.8
Indirect energy	0.21	[0.04, 0.65]	7.9
Direct energy	0.18	[0.07, 0.35]	6.8

[a] On-farm emissions only

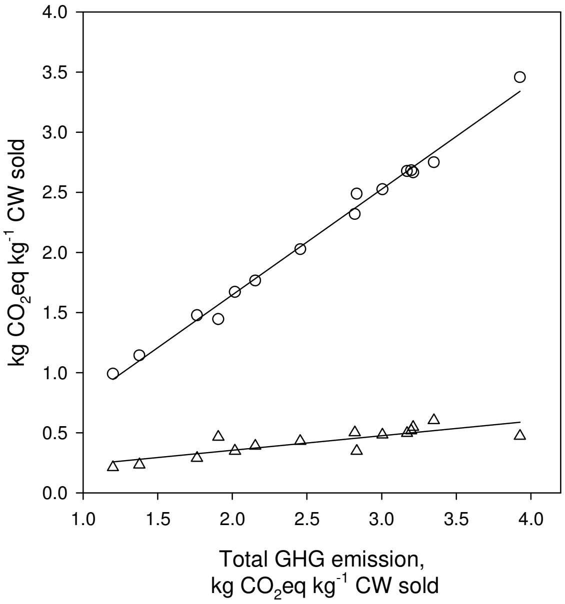

Figure 1. Relationships between estimated emissions from two groups of sources of GHG emission and total GHG emission both expressed as kg CO_2eq kg^{-1} CW sold, based on data for 15 farrow-to-finish pig farms; open circles are feed related emissions, open triangles are animal related emissions.

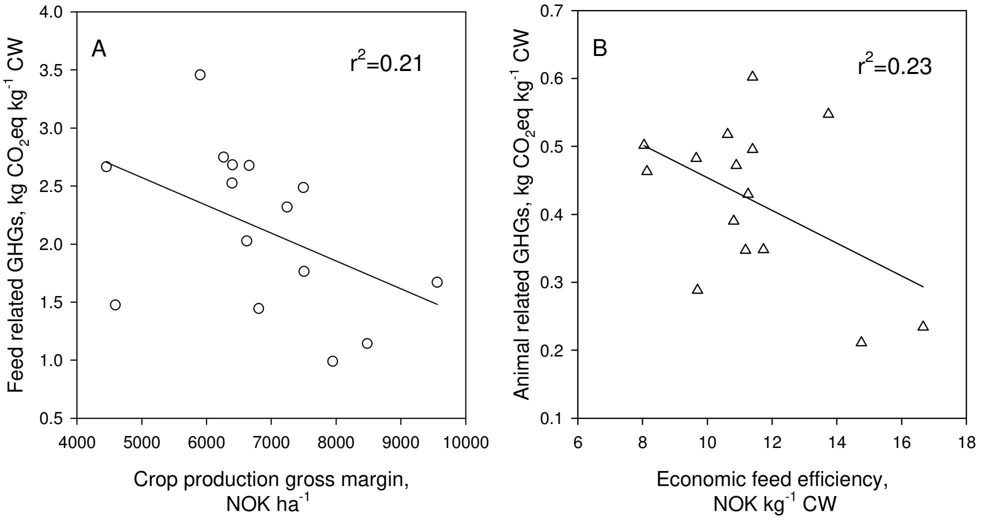

Figure 2. Relationships between estimated GHG emission intensities as: (A) feed related kg CO_2eq kg^{-1} CW and the crop production gross margin; and (B) animal related kg CO_2eq kg^{-1} CW and economic feed efficiency. Data for 15 farrow-to-finish pig farms, solid lines indicate trends.