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Greenhouse gas emissions and mitigation costs of selected mitigation measures in agricultural production

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1 Introduction

This report represents the final step in a series of MEACAP papers with respect to the evaluation of the greenhouse gas (GHG) mitigation potential and costs of reduction options within agricultural production. In the previous report (MEACAP report D7a), possible GHG mitigation measures were collected and described along with basic assumptions for the modelling of these measures. In this report, these selected measures have been modelled and the results discussed.

The analysis of potential mitigation measures for greenhouse gas (GHG) emissions in agricultural production is based on a literature review, data from existing studies and on the expert knowledge of the MEACAP partners and external experts.

As a first step of WP3, possible mitigation measures for both animal husbandry and crop production were collected and described (D7a). For the selection of technical and management-based mitigation measures within the agricultural sector the following evaluation criteria were used for D7a: 1) GHG mitigation potential, 2) technical feasibility, 3) environmental added value and 4) cost effectiveness as well as the additional criteria for D10a: 5) social acceptance, 6) animal health and welfare / ethical acceptance, 7) state of technology knowledge (of farmers and science) and 8) availability of emission factors. In addition, all the possible technical measures to be evaluated were arranged within the general categories: 1) N efficiency, 2) animal production efficiency and livestock density, 3) manure, 4) carbon sequestration, 5) biomass and 6) agricultural energy use.

In order to select the measures with greatest GHG mitigation and policy potential, all measures were listed and judged according to these criteria with the results arranged in different combined evaluation tables to derive a ranking of the most promising measures (appendix 1 of D10a). All measures were given a score with respect to the above mentioned evaluation criteria (5 = best to 1 = worst score, 0 = killing assumption). A "killing assumption" meant that these measures had at least one negative impact (e.g. negative social acceptance or that no emissions factors are available for modelling) so that such measures were automatically ruled out from the evaluation process. For all measures a total score over all criteria was calculated, which allowed a ranking of all measures (appendix 1 of D10a). Additionally, the measures were given weighting factors with regard to the most important criteria 'GHG mitigation potential' (3), 'technical feasibility' (2) and 'cost-effectiveness' (2) to select particularly those measures with the highest potential concerning the respective question. During a workshop with the MEACAP partners (of WP3/6/7) and based on the described evaluation tables, potential mitigation options were selected with additional consideration given to the feasibility of the policy measures concerning administrative costs of implementation, control, monitoring and enforcement. These mitigation measures cover the whole production chain of an agricultural system. Furthermore, organic farming as a management-based measure was included in the modelling process.

Within this evaluation process the following set of possible measures for the comparison of different mitigation techniques or management systems were selected for modelling:

- Livestock feeding strategies
- Comparison of straw-based and slurry-based livestock housing systems
- Frequency of manure removal from animal housing
- Improved outdoor manure storage techniques
- Improved manure application techniques
- Use of slow and controlled-release fertilisers and fertilisers with urease or nitrification inhibitors
- Increase in livestock grazing in comparison to more permanent housing

- Anaerobic digestion
- Organic farming

The selection of the mitigation measures and associated modelling GHG abatement options in agricultural production points to the potential importance of reductions in emissions from nitrogen (N_2O, NH_3) achieved by an improvement of the nutrient cycle and N efficiency. In general, the nitrogen cycle and nitrogen efficiency are influenced by various activities in agricultural production chains referring to livestock and manure management, as well as crop production and fertilisation, and therefore provide several starting points for GHG mitigation measures. Hence, all mitigation measures addressing the N-cycle were modelled for their impact on N_2O, NH_3 but also on CH_4 and CO_2 emissions.

In a final step (in D15a), a cost-benefit analysis was carried out to assess the GHG reduction costs for all selected mitigation measures. In addition, the respective mitigation measures were evaluated with respect to their environmental side-effects (e.g. changes in acidification, eutrophication and biodiversity).

In Chapter 2 the main characteristics of the defined model farms and the farm model and data used for the analysis of the selected potential mitigation measures are described. Chapter 3 summarises the model calculation results with respect to the global warming, acidification and eutrophication potential of the defined reference model farms. In the separate sub-chapters of Chapter 4, the changes with respect to GHG emissions and costs for the implementation of the nine selected mitigation measures are defined and the modelling results in relation to the GHG mitigation potential and mitigation costs are shown and discussed. In addition, in terms of the implementation of the different mitigation measures the expected environmental side-effects (for example, acidification, eutrophication) are discussed. In Chapter 5 the findings are summarised and the GHG mitigation costs of the selected mitigation measures are compared.

2 Material and Methods

It was the aim of this study to model the effect of the mitigation measures for representative farms in Germany to feed into a broader European analysis. Therefore, for the definition of representative model farms a cluster analysis of existing farms in North-West Germany (North Rhine-Westphalia, Lower Saxony, Schleswig-Holstein, Bremen, Hamburg), based on the Farm Accountancy Data Network (FADN, Data 2003), was conducted by FAL and reported in Appendix 2 of deliverable report D10a. On the one hand, the cluster analysis was carried out for three farm types (dairy farms, bull and pig fattening farms) - representing the most important European livestock production systems - with the intention of classifying farms by different production intensity levels (livestock density, farm feed and fertiliser import, N use per ha, amount of market products etc.). On the other hand, it was the aim of the cluster analysis not to devise an average farm but to select three "typical" dairy farms (DF1, DF2, DF3), two bull fattening farms (BF1, BF2) and two pig fattening farms (PF1, PF2). Based on the results of this cluster analysis, representative model farms were defined with respect to stocking rate, crop rotations, milk, meat and crop yields etc. to model the impact of the implementation of the selected measures on greenhouse gas (GHG) emissions.

The analysis of the GHG mitigation potential and cost-efficiency of the different selected technical and management-based measures in the seven defined model farms was carried out with the whole-farm model "ModelFarm" (Michel et al., 2006). This process-orientated farm production model was primarily developed to allow quantification of relevant environmental and all economic effects of agricultural systems with and without biogas utilisation. In the model, all internal flows and C and N budgets (between the sections of the farms e.g. arable land and grassland, animal housing, manure storage, biogas plant) and external flows (import of resources such as seed, feedstuffs, fertilisers and energy; export of crops, milk and meat) are calculated. For the internal flows, all direct and indirect gaseous emissions (CO_2, CH_4, N_2O, NH_3) were estimated for all farm sections by the use of emission factors and equations based on various studies and reports, such as IPCC (1997, 2000), MIDAIR (the FarmGHG model, Olesen et al., 2004) or ALFAM (Søgaard et al., 2002). The energy used for production of machinery and buildings is additionally considered in the model and was mainly based on data by KTBL (2004, 2006). The environmental effects from the prechains were estimated using the results of the Ecoinvent Data 1.1 (Ecoinvent Centre, 2004). Financial data and labour expenses mainly based on KTBL (2002, 2004, 2006), Mittelfränkische Landwirtschaftsverwaltung (2004), Bioland (2005) and ZMP (2005). The model ModelFarm is described in detail in Michel et al. (2006).

Finally, for the cost-benefit analysis of nine selected GHG mitigation measures all costs of the farms (except any premiums) were calculated in comparison to the standard model farms to determine the mitigation costs per reduced tonne of CO_2 equivalents.

Deliverable report D10a contains the detailed descriptions with respect to the modelling of the nine selected technical and management-based GHG mitigation measures including the used emission factors / equations and costs to model the GHG abatement efficiency and cost-effectiveness of the selected mitigation measures.

3 Standard model farms

The analysis of the effect of the implementation of the nine selected potential agricultural mitigation measures on greenhouse gas (GHG) emissions and on environmental side-effects (e.g. acidification and eutrophication) was carried out for seven representative model farms (three dairy farms, two bull and two pig fattening farms). Since they were intended to serve as reference systems for the evaluation of mitigation efficiency, the standard model farms were defined in detail with respect to crop rotations, yields, animal numbers etc. in German conditions and then modelled to calculate all relevant emissions and costs.

The main characteristics of the dairy farms (DF1, DF2, DF3), bull fattening farms (BF1, BF2) and pig fattening farms (PF1, PF2) are listed in Table 1. The feeding plans of the standard model farms are documented in the report appendix (Table A 1 - Table A 7).

Livestock densities on the mode of dairy farms range between 1.69 (DF2) and 1.98 LU ha^{-1} (DF1). Farm milk production is between 266,356 (DF2) and 436,735 kg milk $farm^{-1}$ a^{-1} (DF3) caused by the respective number of dairy cows and the average milk yield of 6,026 (DF2), 6,818 (DF1) and 7,267 kg milk cow^{-1} a^{-1} (DF3). The share of grassland in the total agricultural farm area is 65 % for DF2 and DF3 and 37 % for DF1 (having the highest livestock density) but DF1 has approximately a 5 ha greater area of rotational grass-clover production.

BF1 and BF2 mainly differ in their share of grassland (BF1 39 % and BF2 13 % of total agricultural area) and their livestock density (BF1 1.15 and BF2 1.78 LU ha^{-1}). The reduced amount of BF2 grassland for fodder production is mainly compensated by an 8 ha higher share for maize silage production. In total, BF2 produces one third more meat than BF1.

The pig fattening farms show the highest (PF1 2.19 LU ha^{-1}) and lowest stocking rate (PF1 0.81 LU ha^{-1}) of all model farms. PF1 sells about 255,000 kg meat a^{-1} whereas PF2 brings only 137,000 kg meat a^{-1} on the market. But PF1 imports about 460 t DM of feed per year and exports almost 100 t DM of plant products whereas PF2 imports only 100 t DM but exports about 200 t DM of market crops. By contrast, PF2 buys 78 kg more N fertiliser per hectare than PF1.

Since the total agricultural area is different for all model farms (53.8-76.1 ha), the potential to reduce GHG emissions was calculated per hectare and year to compare the effect of mitigation measures for the different sized model farms that supply different types of product (milk, cattle meat, pig meat, rape seed, wheat, barley etc.).

Table 2 shows the modelled reference GHG emissions caused by different farm compartments of plant and livestock production of the respective farming systems. The results clearly reflect the relationship between livestock density and the amount of GHG emissions. BF1, with the second lowest livestock density of 1.15 LU ha^{-1}, has the lowest GHG emissions per hectare (5.66 t CO_2-eq. ha^{-1} a^{-1}). In comparison, PF2, with the highest stocking rate, also shows the highest GHG emissions per hectare (15.2 t CO_2-eq. ha^{-1} a^{-1}). These emissions are mainly caused by the supply of huge amounts of farm imported feed concentrates (Table 1).

With respect to the most important environmental side-effects of agricultural production, Table 3 reflects the effect of the model farms on acidification and Table 4 on eutrophication. Since emissions of agricultural systems influencing acidification and eutrophication are mainly caused by ammonia and nitrogen oxide, both the acidification potential, expressed in SO_2 equivalents, and the PO_4^{3-} emissions, which are a relevant indicator of eutrophication, show similar results. Hence, the effect of model farms on acidification and eutrophication is directly linked to livestock density and particularly to NH_3 emissions from animal production ($r^2 = 0.98$). Thus, BF1 with lowest livestock density shows the lowest potential for acidification and eutrophication (66 kg SO_2-eq. ha^{-1} a^{-1}, 11.9 kg PO_4^{3-}-eq. ha^{-1} a^{-1}), whereas PF1 shows the highest emission factors (186 kg SO_2-eq. ha^{-1} a^{-1}, 32.8 kg PO_4^{3-}-eq. ha^{-1} a^{-1}).

Table 1: Main characteristics of the seven defined dairy (DF1, DF2), bull fattening (BF1, BF2) and pig fattening (PF1, PF2) standard model farms (German conditions).

	DF1	DF2	DF3	BF1	BF2	PF1	PF2
Total agricultural area [ha]	66.5	68.4	75.4	65.3	56.1	53.8	76.1
Grassland [ha]	24.7	44.6	48.9	25.7	7.4	—	—
Arable land [ha]	39.3	21.9	24.7	36.6	47.1	49.3	70.9
Set-aside land [ha]	2.5	1.9	1.8	3.0	1.6	4.5	5.2
Calves (0-6 months) [number]	19.8	17.6	18.4	14.5	36.4	—	—
Heifers (6-27 months) [number]	49.3	43.5	50.9	12.3	3.3	—	—
Dairy cows [number]	49.3	44.2	60.1	—	—	—	—
Milk production [kg milk farm^{-1} a^{-1}]	336,109	266,356	436,735	—	—	—	—
Milk production [kg milk cow^{-1} a^{-1}]	6,818	6,026	7,267	—	—	—	—
Bulls [number]	24.0	20.7	17.8	73.7	109.2	—	—
Piglets (10-25 kg) [number]	—	—	—	—	—	29	20
Runners (25-50 kg) [number]	—	—	—	—	—	301	153
Fattening pigs (50-115 kg) [number]	—	—	—	—	—	528	284
Livestock density [LU ha^{-1}]	1.98	1.69	1.86	1.15	1.78	2.19	0.81

	DF1		DF2		DF3		BF1		BF2		PF1		PF2	
Plant production	[ha]	[t DM]	[ha]	[t DM]	[ha]	[t DM]	[ha]	[t DM]	[ha]	[t DM]	[ha]	[t DM]	[ha]	[t DM]
Grassland	24.7	207.6	44.6	334.4	48.9	335.0	25.7	127.2	7.4	62.2	—	—	—	—
Grass-clover (rotational)	7.4	56.2	2.2	16.1	2.6	17.6	1.4	10.5	1.0	6.8	—	—	—	—
Maize (silage)	13.6	200.9	7.7	113.2	12.4	188.8	8.8	131.1	16.7	258.9	—	—	—	—
Maize (grain maize)	—	—	—	—	—	—	1.5	13.2	6.2	51.5	—	—	—	—
Maize (CCM)	—	—	—	—	—	—	—	—	—	—	11.1	69.3	3.9	24.2
Wheat	6.8	42.0	4.2	22.7	3.4	20.1	9.8	62.2	6.6	44.8	13.7	90.6	27.5	181.4
Barley	5.5	30.1	3.3	16.1	2.6	12.9	6.3	35.6	6.2	33.7	10.0	59.1	13.8	79.4
Rye	3.7	19.0	2.8	12.4	2.8	14.6	5.7	24.8	5.2	24.4	7.5	42.0	7.5	43.9
Sugar beets	—	—	—	—	—	—	—	—	1.5	21.7	1.5	20.6	4.0	50.0
Potatoes	—	—	—	—	—	—	—	—	2.7	21.0	1.2	9.5	3.3	30.0
Rape seed	2.3	7.9	1.7	4.3	0.9	4.0	3.1	9.7	1.0	3.6	4.3	14.4	10.9	37.5
Rape seed (set-aside)	2.5	8.6	1.9	4.9	1.8	7.9	3.0	9.4	1.6	5.7	4.5	15.1	5.2	17.9

Table 2: Global warming potential of the seven defined dairy (DF1, DF2), bull fattening (BF1, BF2) and pig fattening (PF1, PF2) standard model farms.

CO_2 emissions (global warming potential)		DF1	DF2	DF3	BF1	BF2	PF1	PF2
Farm area	[ha]	66.5	68.4	75.4	65.3	56.1	53.8	76.1
Resources plant production	[t CO_2-eq. a^{-1}]	52.5	56.1	57.2	55.0	57.3	35.7	102.3
Direct emissions plant production	[t CO_2-eq. a^{-1}]	122.7	115.9	132.9	108.0	125.8	132.3	180.0
Total emissions plant production	[t CO_2-eq. a^{-1}]	175.2	172.0	190.1	163.0	183.1	167.9	282.3
Resources livestock farming	[t CO_2-eq. a^{-1}]	80.5	50.5	41.9	38.1	95.5	450.2	154.8
Direct emissions livestock farming	[t CO_2-eq. a^{-1}]	335.6	298.0	367.8	168.5	226.7	197.3	105.3
Total emissions livestock farming	[t CO_2-eq. a^{-1}]	416.1	348.6	409.7	206.6	322.2	647.5	260.2
Total emissions per farm	[t CO_2-eq. a^{-1}]	591.3	520.5	599.9	369.6	505.3	815.5	542.5
Total emissions per hectare	[t CO_2-eq. ha^{-1} a^{-1}]	8.89	7.61	7.96	5.66	9.01	15.16	7.13

Table 3: Acidification potential of the seven defined dairy (DF1, DF2), bull fattening (BF1, BF2) and pig fattening (PF1, PF2) standard model farms.

SO_2 emissions (acidification potential)		DF1	DF2	DF3	BF1	BF2	PF1	PF2
Farm area	[ha]	66.5	68.4	75.4	65.3	56.1	53.8	76.1
Resources plant production	[kg SO_2-eq. a^{-1}]	335.6	348.6	363.0	341.7	354.8	257.6	574.2
Direct emissions plant production	[kg SO_2-eq. a^{-1}]	3,927.3	3,985.6	4,739.5	2,539.9	2,893.3	2,961.0	1,891.3
Total emissions plant production	[kg SO_2-eq. a^{-1}]	4,262.9	4,334.2	5,102.4	2,881.6	3,248.2	3,218.6	2,465.5
Resources livestock farming	[kg SO_2-eq. a^{-1}]	500.1	303.5	344.9	248.0	631.1	3,219.7	999.1
Direct emissions livestock farming	[kg SO_2-eq. a^{-1}]	1,682.4	1,489.0	1,781.3	1,174.6	1,588.0	3,573.9	1,906.3
Total emissions livestock farming	[kg SO_2-eq. a^{-1}]	2,182.5	1,792.4	2,126.2	1,422.6	2,219.1	6,793.6	2,905.4
Total emissions per farm	[kg SO_2-eq. a^{-1}]	6,445.4	6,126.6	7,228.7	4,304.2	5,467.3	10,012.2	5,370.9
Total emissions per hectare	[kg SO_2-eq. ha^{-1} a^{-1}]	96.92	89.57	95.87	65.91	97.46	186.10	70.58

Table 4: Eutrophication potential of the seven defined dairy (DF1, DF2), bull fattening (BF1, BF2) and pig fattening (PF1, PF2) standard model farms.

PO_4^{3-} emissions (eutrophication potential)		DF1	DF2	DF3	BF1	BF2	PF1	PF2
Farm area	[ha]	66.5	68.4	75.4	65.3	56.1	53.8	76.1
Resources plant production	[kg PO_4^{3-}-eq. a^{-1}]	51.2	53.0	55.6	51.6	54.8	40.4	88.8
Direct emissions plant production	[kg PO_4^{3-}-eq. a^{-1}]	731.2	742.0	882.4	472.9	538.7	551.3	352.1
Total emissions plant production	[kg PO_4^{3-}-eq. a^{-1}]	782.4	795.0	938.0	524.5	593.4	591.6	440.9
Resources livestock farming	[kg PO_4^{3-}-eq. a^{-1}]	72.3	43.8	57.1	36.1	91.8	504.7	151.2
Direct emissions livestock farming	[kg PO_4^{3-}-eq. a^{-1}]	313.2	277.2	331.6	218.7	295.6	665.4	354.9
Total emissions livestock farming	[kg PO_4^{3-}-eq. a^{-1}]	385.6	321.0	388.7	254.8	387.4	1,170.1	506.1
Total emissions per farm	[kg PO_4^{3-}-eq. a^{-1}]	1,167.9	1,116.0	1,326.7	779.3	980.9	1,761.7	947.0
Total emissions per hectare	[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]	17.56	16.32	17.60	11.93	17.48	32.75	12.44

4 Mitigation measures

4.1 Livestock feeding strategies

In general, the nutrition and performance of animals considerably influences the N excretion amount and, accordingly, the farm's GHG emissions. Therefore, adjusting the feed composition to decrease the amount of nitrogen excreted could be a very efficient measure to reduce GHG emissions. At the farm level, the total GHG emission balance not only depends closely on the nutrition of animals and the feed efficiency but must also be seen in connection with the different expenses (and GHG emissions) for feed production and feed concentrate supply. Thus, for the dairy model farms DF1, DF2 and DF3 as well as for the pig fattening model farms PF1 and PF2 different feeding strategies were implemented to reduce the N surplus by increasing the feed efficiency and were then modelled on the whole farm level.

Dairy farms

For cattle mainly fed on roughage (e.g. grass, grass silage), a certain protein surplus is often inevitable (particularly during summer) due to an imbalance between energy and protein in the feed. The protein surplus can be reduced by adding components such as maize silage with lower protein content to the ration. Additionally, or as an alternative the proportion of concentrates in the ration must be adapted.

Thus, for all dairy farms one of the mitigation measures examined was an extensification of grassland on the farm so as to bring about a 15 % reduction of the grass yield. Hence, a reduced N input according to the grass demand being modelled. Due to the reduced grass yield, only three rather than four harvestings were operated per year. For model farm DF1, two scenarios with a 50 % (DF1-FS-50 % RG) and 100 % reduction (DF1-FS-100 % RG) and for both DF2 (DF2-FS) and DF3 (DF3-FS), a 100 % reduction of the grass-clover area was implemented to use the additional area for maize silage production. The feeding plans (especially of dairy cows) were adapted to increase the share of maize silage instead of grass silage. If needed, the amount of feed concentrates was also increased or the composition of the concentrates adapted. In addition, feed urea was added to compensate the ruminal N deficiency. Finally, the N excretion amount was reduced by 10 % (StMLF, 2003).

The adapted feeding plans of calves, heifers, cows and bulls of DF1 are listed in Table A 8 for a 50 % reduction of the rotational grass-clover production (3.7 ha) and in Table A 9 for the total use of the grass-clover area (7.4 ha) for maize silage production. For the model farms DF2 and DF3, the total grass-clover area was displaced by maize silage (DF2 2.2 ha, DF3 2.6 ha). The adapted feeding plans are documented in Table A 10 (DF2) and Table A 11 (DF3) of the report appendix.

Pig fattening farms

For fattening pigs the most promising strategy to decrease N losses and subsequently to reduce GHG emissions is to match the supply of available nutrients to animals' requirements as closely as possible. Since overfeeding nutrients relative to the animals' requirements will increase the N output, animals will simply excrete all of the nutrients they are unable to use for maintenance and growth. One of the reasons for possible high N losses from pig production arises from the fact that the protein demand of the animals changes considerably during the course of fattening pig production, while the protein content of the feed is often kept constant at the level of maximum requirement. This mainly produces a protein surplus along the whole production chain (see Figure 2 of deliverable report D10a). Therefore, the food composition with regards to the protein content and the decline in protein requirement should be adapted more accurately to the actual pig demand several times during the fattening period. This can be done using several types of feed with different protein content by phase feeding.

In general, all standard model farms were assumed to be a mixture of a typical and best managed production having a 2-phase feeding system (PF1/PF2-FS-2P). However, as in some countries, such as Germany, only 50 % of fattening pigs are fed by an N-adapted feeding plan (usually a 2-phase feeding system; Osterburg, 2002) an additional reference model farm with one universal diet (1-phase feeding system, one feed for piglets and one feed composition for all age levels of fattening pigs, PF1/PF2-FS-1P) was modelled. As a mitigation measure, improved feeding plans for fattening pigs were defined with a 3-phase feeding system (PF1/PF2-FS-3P) and a 3-phase feeding system including the addition of (synthetic) amino acids (PF1/PF2-FS-3P+AA) to better meet the animals' needs for the most limiting amino acids.

Finally, the N excretion was increased for FS-1P by 10 % and reduced by 6.5 % for FS-3P (Heber et al., 1996; Spiekers & Pfeffer, 1990; UBA, 2005; Baidoo, 2001) and by 34 % for FS-3P+AA (Spiekers & Pfeffer, 1990; Heber et al., 1996; Kirchgessner et al., 1994) compared to the standard model farms with a 2-phase feeding system due to the improved feeding (see chapter 3.1.1 of deliverable report D10a).

The feeding plans for a universal diet are documented in Table A 12 (PF1-FS-1P) and Table A 15 (PF2-FS-1P), for the 3-phase feeding of fattening pig in Table A 13 (PF1-FS-3P) and Table A 16 (PF2-FS-3P) and for the 3-phase feeding systems with the addition of amino acids in Table A 14 (PF1-FS-3P+AA) and Table A 17 (PF2-FS-3P+AA).

Further details (cost changes etc.) to both feeding strategies for dairy and pig fattening model farms are described in deliverable report D10a.

4.1.1 GHG emissions and mitigation costs

Dairy farms

Table 5 shows the modelling results for the implementation of the feeding strategy for the dairy farms DF1, DF2 and DF3. The results confirm that the standard model farm (SMF) with respect to feeding and feed supply (feed production and farm import) already operate very close to the farms' GHG optimum. Furthermore, the feeding strategy shows for all scenarios that the farm income can be increased considerably (up to 15,500 € a^{-1} for FS-DF3) if an improved feeding strategy including the connected feed production and supply system is implemented.

The feeding strategy scenario of DF1 with a 50 % reduction of the rotational grass-clover area for maize silage production (FS-50 % RG) resulted in a total farm GHG emission reduction of 2.6 % (–15.4 t CO_2-eq. $farm^{-1}$ a^{-1}, –0.23 t CO_2-eq. ha^{-1} a^{-1}). Due to a higher farm income caused by lower costs for plant production (–4,100 € a^{-1}) and livestock farming (–400 € a^{-1}), the mitigation costs are negative and increased the income by 296 € relative to one tonne reduced CO_2 equivalents (Table 5). If the total grass-clover area of DF1 is used for maize silage production (7.4 ha) the farm income additionally increased up to 6,050 € $farm^{-1}$ a^{-1}. However, due to the additional fertiliser use for maize silage production (instead of the N fixation by grass-clover) and further feed imports (soya and feed urea) the total farm GHG emissions exceeded the emissions of the standard model farms by 0.75 %.

The feeding strategy for DF2 shows modelling outcomes similar to DF1-FS-50 % RG. The farm balance resulted in a GHG emission reduction by 4.2 % (21.8 t CO_2-eq. a^{-1}) and also showed an income increase so that the mitigation costs are negative (–254 € t^{-1} CO_2-eq.).

Although the farm structure of DF2 and DF3 looks similar with respect to the grassland to arable land ratio, different feeding plans were defined, caused by different maize silage and cereal production amounts. Therefore, the feeding plans of DF2 were based on higher concentrate intake consisting of wheat and rape seed extraction grist whereas dairy cows of DF2 were fed on lower concentrate and soy extraction grist amounts. Thus, the feeding strategy of DF3 resulted in a decrease of diesel and mineral fertiliser use and rape seed extraction grist imports reducing farm GHG emissions considerably. However, due to a noticeable increase of wheat imports as feed concentrate (causing high prechain emissions) farm GHG emissions exceeded the emissions of the standard model farm by 1 %. Nevertheless, the farm income increased considerably (15,500 € a^{-1}) if the defined feeding strategy was implemented.

The modelling results show that for cattle farming a universal applicable feeding strategy for GHG mitigation is difficult to define. For individual cases, however, a change in the feeding strategy has a respectable potential to reduce GHG emissions without causing additional costs.

Table 5: GHG emissions and mitigation costs of the feeding strategy in dairy farms DF1, DF2 and DF3 in comparison to standard model farms (SMF).

		DF1			DF2		DF3	
		SMF	FS-50 % RG [a]	FS-100 % RG [b]	SMF	FS	SMF	FS
Farm area	[ha]	**66.5**	**66.5**	**66.5**	**68.4**	**68.4**	**75.4**	**75.4**
Operating income	[€ ha^{-1}]	**-24**	**44**	**67**	**-229**	**-149**	**-55**	**150**
Resources plant production	[t CO_2-eq. a^{-1}]	52.5	52.4	59.5	56.1	45.3	57.2	47.8
Direct emissions plant production	[t CO_2-eq. a^{-1}]	122.7	121.7	129.5	115.9	106.1	132.9	124.2
Total emissions plant production	[t CO_2-eq. a^{-1}]	175.2	174.0	189.0	172.0	151.4	190.1	172.0
Resources livestock farming	[t CO_2-eq. a^{-1}]	80.5	66.6	71.5	50.5	49.7	41.9	66.7
Direct emissions livestock farming	[t CO_2-eq. a^{-1}]	335.6	335.3	335.3	298.0	297.7	367.8	367.4
Total emissions livestock farming	[t CO_2-eq. a^{-1}]	416.1	401.8	406.7	348.6	347.3	409.7	434.1
Total emissions per farm	[t CO_2-eq. a^{-1}]	591.3	575.9	595.7	520.5	498.7	599.9	606.1
Total emissions per hectare	[t CO_2-eq. ha^{-1} a^{-1}]	8.89	8.66	8.96	7.61	7.29	7.96	8.04
Mitigation costs	[€ t^{-1} CO_2-eq.]		**-295.5**	**—**		**-253.6**		**—**

a) 50 % reduction of rotational grass-clover area for maize silage production
b) 100 % reduction of rotational grass-clover area for maize silage production

Pig fattening farms

The feeding strategies with a 2-phase and 3-phase feeding system of PF1 and PF2 in comparison to the universal diet of fattening pigs resulted in comparable GHG emission reductions. The 2-phase feeding reduced the GHG emissions by 2 % (PF1) and 4.5 % (PF2) whereas the 3-phase feeding system decreased emissions by 5.5 % (PF1) and 5.4 % (PF2). The total GHG emission reduction derived from reduced N_2O and NH_3 emissions due to the reduced N excretion and subsequently reduced manure-N application, although the application amounts of mineral fertiliser increased. In addition, the changed feeding systems reduced the farm import of wheat and soya but increased the farm import of barley as feed concentrate. The overall results of the farm modelling of the 2- and 3-phase feeding system show that in consequence of the implemented changes, the farm GHG emissions were reduced and additionally the farm income increased, caused by lower costs for feed concentrates. Thus, the mitigation costs are negative.

For the 3-phase feeding system, including the addition of amino acids, the pig fattening model farms show converse results with respect to the GHG mitigation effect. On the one hand, the emissions of PF1 were additionally reduced by 8.9 % in total compared to the reference system with a universal diet. On the other hand, the addition of amino acids influenced the whole PF2 farm in such a way that the GHG emissions increased by 0.1 % in comparison to the reference farm. These different impacts on the farm GHG balance were mainly affected by the contrary livestock densities (PF1 2.2 LU ha^{-1}, PF2 0.8 LU ha^{-1}) so that the changed system of PF2 only had a minor GHG mitigation effect on N_2O and NH_3 emissions from crop production compared to PF1 with approximately double the amount of manure nitrogen being applied. These different effects of the different pig fattening systems are also confirmed by the fact that the additional farm income of PF1 is with 159 € ha^{-1} (8,550 € $farm^{-1}$ a^{-1}) considerably higher than for PF2 (55 € ha^{-1}, 4,190 € $farm^{-1}$ a^{-1}).

Table 6: GHG emissions and mitigation costs of the feeding strategies 2-phase feeding (FS-2P), 3-phase feeding (FS-3P) and 3-phase feeding with the addition of amino acids (FS-3P+AA) of the pig fattening farms PF1 and PF2 in comparison to an universal diet feeding system (FS-1P).

		PF1				PF2			
		FS-1P	FS-2P	FS-3P	FS-3P+AA	FS-1P	FS-2P	FS-3P	FS-3P+AA
Farm area	[ha]	**53.8**	**53.8**	**53.8**	**53.8**	**76.1**	**76.1**	**76.1**	**76.1**
Operating income	[€ ha^{-1}]	**681**	**705**	**765**	**840**	**446**	**447**	**468**	**501**
Resources plant production	[t CO_2-eq. a^{-1}]	30.2	35.7	37.3	52.5	99.3	102.3	104.8	114.8
Direct emissions plant production	[t CO_2-eq. a^{-1}]	134.8	132.3	128.4	122.3	181.2	180.0	179.8	178.8
Total emissions plant production	[t CO_2-eq. a^{-1}]	164.9	167.9	165.7	174.8	280.5	282.3	284.5	293.5
Resources livestock farming	[t CO_2-eq. a^{-1}]	468.7	450.2	424.0	389.9	181.8	154.8	148.1	172.2
Direct emissions livestock farming	[t CO_2-eq. a^{-1}]	198.5	197.3	196.5	193.3	106.0	105.3	105.0	103.2
Total emissions livestock farming	[t CO_2-eq. a^{-1}]	667.2	647.5	620.5	583.1	287.8	260.2	253.1	275.4
Total emissions per farm	[t CO_2-eq. a^{-1}]	832.1	815.5	786.2	758.0	568.2	542.5	537.6	568.9
Total emissions per hectare	[t CO_2-eq. ha^{-1} a^{-1}]	15.47	15.16	14.61	14.09	7.47	7.13	7.06	7.48
Mitigation costs	**[€ t^{-1} CO_2-eq.]**		**-79.1**	**-98.4**	**-115.9**		**-2.9**	**-55.5**	**—**

Table 7 summarises the effect of the 3-phase feeding system with and without the addition of amino acids in comparison to the real standard model farm with a 2-phase feeding system. As the 2-phase feeding already represents an improved feeding system compared to the universal diet of fattening pigs, the GHG mitigation effect in this comparison is, as a logical consequence, lower (PF1: FS-3P –3.6 %, FS-3P+AA –7.1 %; PF2: FS-3P –0.9 %, FS-3P+AA +4.9 %).

The negative mitigation costs increased as the additional income remained constant, whereas the reduced GHG emissions were reduced. Thus, the negative mitigation costs per reduced tonne CO_2 equivalents increased.

Table 7: GHG emissions and mitigation costs of the feeding strategies 3-phase feeding (FS-3P) and 3-phase feeding with the addition of amino acids (FS-3P+AA) of the pig fattening farms PF1 and PF2 in comparison to the 2-phase feeding (FS-2P) system of the standard model farms.

		PF1			PF2		
		FS-2P	FS-3P	FS-3P+AA	FS-2P	FS-3P	FS-3P+AA
Farm area	[ha]	**53.8**	**53.8**	**53.8**	**76.1**	**76.1**	**76.1**
Operating income	[€ ha^{-1}]	**705**	**765**	**840**	**447**	**468**	**501**
Resources plant production	[t CO_2-eq. a^{-1}]	35.7	37.3	52.5	102.3	104.8	114.8
Direct emissions plant production	[t CO_2-eq. a^{-1}]	132.3	128.4	122.3	180.0	179.8	178.8
Total emissions plant production	[t CO_2-eq. a^{-1}]	167.9	165.7	174.8	282.3	284.5	293.5
Resources livestock farming	[t CO_2-eq. a^{-1}]	450.2	424.0	389.9	154.8	148.1	172.2
Direct emissions livestock farming	[t CO_2-eq. a^{-1}]	197.3	196.5	193.3	105.3	105.0	103.2
Total emissions livestock farming	[t CO_2-eq. a^{-1}]	647.5	620.5	583.1	260.2	253.1	275.4
Total emissions per farm	[t CO_2-eq. a^{-1}]	815.5	786.2	758.0	542.5	537.6	568.9
Total emissions per hectare	[t CO_2-eq. ha^{-1} a^{-1}]	15.16	14.61	14.09	7.13	7.06	7.48
Mitigation costs	**[€ t^{-1} CO_2-eq.]**		**-109.3**	**-126.5**		**-333.6**	**—**

The modelling results show that changing from a one feed system to multiple phases more precisely meet the N needs of fattening pigs within the growing period has a high potential to reduce GHG emissions at the farm level. Since this mitigation measure can be implemented easily in all comparable farms without additional costs, the implementation of an improved feeding strategy also has a high potential for the entire European pig production.

4.1.2 Environmental side-effects

With respect to environmental side-effects for the implementation of the feeding strategy in dairy production systems, the modelling results regarding the acidification (Table 8) and eutrophication (Table 9) reduction potential show that beside the influence on greenhouse gases, emissions with an acidification and eutrophication effect can also be reduced. The acidification reduction potential ranges between 0.5 and 6.2 % (ø 2.6 %) and, for the eutrophication potential, was reduced by an average 3.5 % (0.5-5.9 %).

The effect of this measure on further environmental side-effects, for instance on biodiversity, are difficult to evaluate as the production of different concentrate types and amounts also have to be judged. On the one hand, for the model farm, a less intensive grass-clover production is displaced by a high intensive maize silage production with all the known negative impacts (higher pesticide use, increase in erosion and nitrate leaching, reduced biodiversity etc.).

Table 8: Acidification emissions and mitigation costs for the implementation of a feeding strategy in dairy farms (DF1, DF2, DF3) in comparison to standard model farms (SMF).

		DF1			DF2		DF3	
		SMF	FS-50 % RG [a]	FS-100 % RG [b]	SMF	FS	SMF	FS
Farm area	[ha]	**66.5**	**66.5**	**66.5**	**68.4**	**68.4**	**75.4**	**75.4**
Resources plant production	[kg SO_2-eq. a^{-1}]	335.6	321.0	347.8	348.6	282.9	363.0	362.3
Direct emissions plant production	[kg SO_2-eq. a^{-1}]	3,927.3	3,916.0	4,019.4	3,985.6	3,714.9	4,739.5	4,743.2
Total emissions plant production	[kg SO_2-eq. a^{-1}]	4,262.9	4,237.1	4,367.3	4,334.2	3,997.8	5,102.4	5,105.6
Resources livestock farming	[kg SO_2-eq. a^{-1}]	500.1	406.3	425.9	303.5	328.6	344.9	344.9
Direct emissions livestock farming	[kg SO_2-eq. a^{-1}]	1,682.4	1,605.9	1,605.9	1,489.0	1,420.3	1,781.3	1,738.2
Total emissions livestock farming	[kg SO_2-eq. a^{-1}]	2,182.5	2,012.2	2,031.8	1,792.4	1,749.0	2,126.2	2,083.2
Total emissions per farm	[kg SO_2-eq. a^{-1}]	6,445.4	6,249.2	6,399.1	6,126.6	5,746.8	7,228.7	7,188.8
Total emissions per hectare	[kg SO_2-eq. ha^{-1} a^{-1}]	96.9	94.0	96.2	89.6	84.0	95.9	95.3
Mitigation costs	**[€ kg^{-1} SO_2-eq.]**		**-23**	**-131**		**-15**		**-388**

a) 50 % reduction of rotational grass-clover area for maize silage production
b) 100 % reduction of rotational grass-clover area for maize silage production

Table 9: Eutrophication emissions and mitigation costs for the implementation of a feeding strategy in dairy farms (DF1, DF2, DF3) in comparison to standard model farms (SMF).

		DF1			DF2		DF3	
		SMF	FS-50 % RG [a]	FS-100 % RG [b]	SMF	FS	SMF	FS
Farm area	[ha]	**66.5**	**66.5**	**66.5**	**68.4**	**68.4**	**75.4**	**75.4**
Resources plant production	[kg PO_4^{3-}-eq. a^{-1}]	51.2	49.6	53.7	53.0	43.9	55.6	47.0
Direct emissions plant production	[kg PO_4^{3-}-eq. a^{-1}]	731.2	729.1	748.3	742.0	691.6	882.4	815.9
Total emissions plant production	[kg PO_4^{3-}-eq. a^{-1}]	782.4	778.7	802.0	795.0	735.5	938.0	862.9
Resources livestock farming	[kg PO_4^{3-}-eq. a^{-1}]	72.3	59.2	61.3	43.8	50.3	57.1	84.8
Direct emissions livestock farming	[kg PO_4^{3-}-eq. a^{-1}]	313.2	299.0	299.0	277.2	264.4	331.6	314.2
Total emissions livestock farming	[kg PO_4^{3-}-eq. a^{-1}]	385.6	358.2	360.2	321.0	314.7	388.7	399.0
Total emissions per farm	[kg PO_4^{3-}-eq. a^{-1}]	1,167.9	1,136.8	1,162.2	1,116.0	1,050.2	1,326.7	1,261.9
Total emissions per hectare	[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]	17.6	17.1	17.5	16.3	15.4	17.6	16.7
Mitigation costs	**[€ kg^{-1} PO_4^{3-}-eq.]**		**-146**	**-1,068**		**-84**		**-239**

a) 50 % reduction of rotational grass-clover area for maize silage production
b) 100 % reduction of rotational grass-clover area for maize silage production

On the other hand, the grassland fertilisation is reduced by 15 %. Here, it is also possible to use one part as intensive grassland (85 % of grassland area) and to focus the extensification on the remaining part of the grassland (15 % without fertiliser use) with higher nature value potential. Hence, this measure can also have a potential to increase biodiversity on farm level.

The different feeding strategies for fattening pigs may also have a positive impact on acidification and eutrophication as a result of the reduced N excretion and subsequently reduced NH_3 emissions. In comparison to the universal diet system the acidification potential decreased for the 2-phase feeding system by 4.1 % (PF1) and 5.8 % (PF2), for the 3-phase feeding system by 8.0 % (PF1) and 8.5 % (PF2) and for the 3-phase feeding system with addition of amino acids by 20.8 % (PF1) and 15.1 % (PF2). Due to the fact that the impact on the eutrophication potential is also based on changes of NH_3 emissions, the results are to a very large extent identical to the acidification reduction potential (FS-2P: PF1 –4.0 %, PF2 –5.5 %; FS-3P: PF1 –7.7 %, PF2 –8.1 %; FS-3P+AA: PF1 –20.6 %, PF2 –15.3 %).

Moreover, the feeding strategies for fattening pigs do not seem to have any direct influence on biodiversity. As NH_3 emissions can be reduced, less deposition to N-limited areas may also indirectly favourably influence biodiversity.

4.2 Comparison of straw- and slurry-based livestock housing systems

Animal housing systems can be differentiated in tied and loose housing systems as well as divided into slurry- and straw-based systems whereas loose straw-based stalls can be constructed as cubicle houses with bedding or the animals are kept in deep litter stalls on a thick layer of a mixture of manure and absorbent material (straw, sawdust or wood shavings).

In general, straw- and slurry-based housing systems differ considerably in their impact on the emissions of the greenhouse gases NH_3, N_2O and CH_4 due to the different predominating aerobic or anaerobic storage conditions. On the one hand, bedding material may absorb urine which can effectively reduce NH_3 emissions during storage. On the other hand, the bedding material also increases the surface area of the manure exposed to the air (depending on the amount and texture of the material used for bedding) which can influence the microbial material and activity in farmyard manure (FYM). These different storage conditions mainly affect NH_3 emissions but also influence N_2O and CH_4 emissions of FYM, slurry and liquid manure during storage in animal houses and manure stores. N_2O emissions of straw-based systems tend to be higher during storage than in slurry-based systems (due to better aerobic microbial conditions for nitrification and potentially subsequently for denitrification) whereas CH_4 emissions of slurry-based systems are higher compared to straw-based systems (due to the anaerobic conditions in the pits or manure stores that increase methane production).

For the dairy production system DF1, the standard model farm (SMF) using a slurry-based loose housing system was compared with a deep litter system (DL) as well as with tied stalls as slurry-based (TS slu) and straw-based (separate) systems (TS sep). The standard pig fattening model farm PF1 was compared with a deep litter housing system as the only reasonable applicatory alternative to slurry-based animal housing.

Details of the different defined straw- and slurry-based housing systems, their impact on the relevant direct and indirect GHG emissions and the estimated costs of the housing systems are described in detail in deliverable report D10a (chapter 3.2).

4.2.1 GHG emissions and mitigation costs

The results with respect to the comparison of straw- and slurry-based animal housing systems depend, besides NH_3 and N_2O emissions, on the methane emission factor used for the modelling of slurry and liquid manure storage. In the year 1997, IPCC published a methane conversion factor (k_{MCF}) of 0.1 (10 %) and in the year 2001 of 0.39 (39 %). For the updated IPCC report of 2007, a methane conversion factor of 0.1 is already signalled as appropriate for the "cool" region. Thus, for the modelling in WP3 of the MEACAP project the comparison of straw- and slurry-based systems was calculated for both methane conversion factors 0.1 (Table 10) and 0.39 (Table 11).

The modelling results confirm that only the standard model farms as slurry systems (TS slu) and the FYM system (TS sep) with a minor amount of liquid manure show a reduction in GHG emissions when the emission factor 0.1 instead of 0.39 is used. In contrast, the GHG balance of the deep litter systems remains at a fairly constant level. The exchange of CH_4 emission factors reduces GHG emissions of the standard model farms DF1 by 21.6 % and PF1 by 14.5 % but TS sep only by 1.8 %.

If a methane emission factor of 0.39 (IPCC, 2001) is used for modelling, the GHG emissions of the deep litter systems were reduced by 8.4 (DF1) and 5.9 % (PF1) causing mitigation costs of 437 (DF1) and 244 € t^{-1} CO_2-eq. (PF1) (Table 10). The straw-based tied system reduces GHG emission by 13.6 % with lowest mitigation costs of 132 € t^{-1} CO_2-eq. The tied stalls as slurry-based system show a little GHG reduction (–0.6 %) for the use of both methane conversion factors. However, this system results in the highest mitigation costs of

1,763 € t^{-1} CO_2-eq. and hence is, for financial as well as animal health and welfare reasons, not recommended.

If the lower methane emission factor of 0.1 (IPCC, 2001) is used for modelling, all straw-based housing systems give higher GHG emissions than the slurry-based stalls (Table 11). In addition, deep litter systems cause considerably higher emissions on farm level (for DF1 DL about twice the amount of TS sep) than typical FYM systems (DF1 DL +16.7 %, DF1 TS sep +8.2 %; PF1 DL +10.1 %). This increase in emissions mainly originates from higher NH_3 and N_2O emissions of straw and especially of deep litter systems during FYM storage.

As the origin of the higher methane emission factor is still not clarified, and as a lower emission factor is anticipated for the new IPCC report in 2007, the results of Table 11 seem to be more realistic. Hence, with respect to the aim of reducing GHG emissions, changing from slurry- to straw-based systems is not recommended. Thus, a conflict between GHG mitigation and an increase in animal health and welfare exists.

Table 10: Comparison of the impact of straw- and slurry-based livestock housing systems on GHG emissions and mitigation costs if a methane conversion factor of 0.39 is assumed (SMF = standard model farm, DL = deep litter, TS slu = tied stall as slurry-based system, TS sep = tied stall as straw-based (separate) system).

		DF1				PF1	
		SMF	DL	TS slu	TS sep	SMF	DL
Farm area	**[ha]**	**66.5**	**66.5**	**66.5**	**66.5**	**53.8**	**53.8**
Operating income	**[€ ha^{-1}]**	**-24**	**-352**	**-109**	**-183**	**705**	**486**
Resources plant production	**[t CO_2-eq. a^{-1}]**	52.5	58.1	50.2	60.4	35.7	54.3
Direct emissions plant production	**[t CO_2-eq. a^{-1}]**	122.7	123.9	123.0	124.0	132.3	131.4
Total emissions plant production	**[t CO_2-eq. a^{-1}]**	175.2	182.0	173.2	184.4	167.9	185.7
Resources livestock farming	**[t CO_2-eq. a^{-1}]**	80.5	107.4	80.5	85.0	450.2	463.4
Direct emissions livestock farming	**[t CO_2-eq. a^{-1}]**	335.6	252.0	334.5	241.8	197.3	118.2
Total emissions livestock farming	**[t CO_2-eq. a^{-1}]**	416.1	359.4	414.9	326.8	647.5	581.6
Total emissions per farm	**[t CO_2-eq. a^{-1}]**	591.3	541.4	588.1	511.2	815.5	767.3
Total emissions per hectare	**[t CO_2-eq. ha^{-1} a^{-1}]**	8.89	8.14	8.84	7.69	15.16	14.26
Mitigation costs	**[€ t^{-1} CO_2-eq.]**		**437.0**	**1,763**	**132.1**		**244.3**

Table 11: Comparison of the impact of straw- and slurry-based livestock housing systems on GHG emissions and mitigation costs if a methane conversion factor of 0.1 is assumed (SMF = standard model farm, DL = deep litter, TS slu = tied stall as slurry-based system, TS sep = tied stall as straw-based (separate) system).

		DF1				PF1	
		SMF	DL	TS slu	TS sep	SMF	DL
Farm area	**[ha]**	**66.5**	**66.5**	**66.5**	**66.5**	**53.8**	**53.8**
Operating income	**[€ ha^{-1}]**	**-24**	**-352**	**-109**	**-183**	**705**	**486**
Resources plant production	**[t CO_2-eq. a^{-1}]**	52.5	58.1	50.2	60.4	35.7	54.3
Direct emissions plant production	**[t CO_2-eq. a^{-1}]**	122.7	123.9	123.0	124.0	132.3	131.4
Total emissions plant production	**[t CO_2-eq. a^{-1}]**	175.2	182.0	173.2	184.4	167.9	185.7
Resources livestock farming	**[t CO_2-eq. a^{-1}]**	80.5	107.4	80.5	85.0	450.2	463.4
Direct emissions livestock farming	**[t CO_2-eq. a^{-1}]**	208.2	252.0	207.0	232.6	78.8	118.2
Total emissions livestock farming	**[t CO_2-eq. a^{-1}]**	288.6	359.4	287.5	317.6	529.0	581.6
Total emissions per farm	**[t CO_2-eq. a^{-1}]**	463.8	541.4	460.6	502.0	696.9	767.3
Total emissions per hectare	**[t CO_2-eq. ha^{-1} a^{-1}]**	6.97	8.14	6.93	7.55	12.95	14.26
Mitigation costs	**[€ t^{-1} CO_2-eq.]**		**—**	**1,763**	**—**		**—**

4.2.2 Environmental side-effects

The modelling of the acidification (Table 12) and eutrophication (Table 13) potential of straw- and slurry-based systems shows that these respective emissions can only be reduced by a slurry-based system with tied cows (–9.0 %). This is in contrast to the straw-based system with tied stall were the acidification and eutrophication potential is increased by 0.9 %. The deep litter systems of the pig fattening farm and especially of the dairy farm caused a considerable increase of the acidification and the eutrophication potential (PF1: SO_2-eq. +12.0 %, PO_4^{3-}-eq. +12.4 %; DF1: SO_2-eq. +31.2 %, PO_4^{3-}-eq. +31.5 %). These clear negative impacts of straw-based animal housings on these important environmental side-effects are additional arguments against the implementation of straw-based systems.

Impacts of the different animal housing systems on further environmental side-effects such as biodiversity are not explored further.

Table 12: Acidification emissions and mitigation costs for the implementation of straw- and slurry-based livestock animal housing systems of the dairy farm DF1 and the pig fattening farm PF1 (SMF = standard model farm, DL = deep litter, TS slu = tied stall as slurry-based system, TS sep = tied stall as straw-based (separate) system).

		DF1				PF1	
		SMF	DL	TS slu	TS sep	SMF	DL
Farm area	[ha]	**66.5**	**66.5**	**66.5**	**66.5**	**53.8**	**53.8**
Resources plant production	[kg SO_2-eq. a^{-1}]	335.6	365.2	327.1	377.8	257.6	337.9
Direct emissions plant production	[kg SO_2-eq. a^{-1}]	3,927.3	1,588.6	3,963.0	2,735.4	2,961.0	1,972.1
Total emissions plant production	[kg SO_2-eq. a^{-1}]	4,262.9	1,953.8	4,290.1	3,113.2	3,218.6	2,310.0
Resources livestock farming	[kg SO_2-eq. a^{-1}]	500.1	738.7	500.1	540.4	3,219.7	3,336.4
Direct emissions livestock farming	[kg SO_2-eq. a^{-1}]	1,682.4	5,762.2	1,077.6	2,848.2	3,573.9	5,562.9
Total emissions livestock farming	[kg SO_2-eq. a^{-1}]	2,182.5	6,500.9	1,577.7	3,388.6	6,793.6	8,899.3
Total emissions per farm	[kg SO_2-eq. a^{-1}]	6,445	8,455	5,868	6,502	10,012	11,209
Total emissions per hectare	[kg SO_2-eq. ha^{-1} a^{-1}]	96.9	127.1	88.2	97.8	186.1	208.4
Mitigation costs	**[€ t^{-1} SO_2-eq.]**		**—**	**9.7**	**—**		**—**

Table 13: Eutrophication emissions and mitigation costs for the implementation of straw- and slurry-based livestock animal housing systems of the dairy farm DF1 and the pig fattening farm PF1 (SMF = standard model farm, DL = deep litter, TS slu = tied stall as slurry-based system, TS sep = tied stall as straw-based (separate) system).

		DF1				PF1	
		SMF	DL	TS slu	TS sep	SMF	DL
Farm area	[ha]	**66.5**	**66.5**	**66.5**	**66.5**	**53.8**	**53.8**
Resources plant production	[kg PO_4^{3-}-eq. a^{-1}]	51.2	56.2	49.9	57.0	40.4	52.9
Direct emissions plant production	[kg PO_4^{3-}-eq. a^{-1}]	731.2	295.8	737.8	509.3	551.3	367.2
Total emissions plant production	[kg PO_4^{3-}-eq. a^{-1}]	782.4	351.9	787.7	566.2	591.6	420.1
Resources livestock farming	[kg PO_4^{3-}-eq. a^{-1}]	72.3	111.0	72.3	78.9	504.7	523.6
Direct emissions livestock farming	[kg PO_4^{3-}-eq. a^{-1}]	313.2	1,072.8	200.6	530.3	665.4	1,035.7
Total emissions livestock farming	[kg PO_4^{3-}-eq. a^{-1}]	385.6	1,183.7	273.0	609.1	1,170.1	1,559.3
Total emissions per farm	[kg PO_4^{3-}-eq. a^{-1}]	1,168	1,536	1,061	1,175	1,762	1,979
Total emissions per hectare	[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]	17.6	23.1	15.9	17.7	32.7	36.8
Mitigation costs	**[€ t^{-1} PO_4^{3-}-eq.]**		**—**	**52.3**	**—**		**—**

4.3 Frequency of manure removal from animal housing

Dependent on the livestock feeding regime, an extensive amount of the ingested nitrogen is excreted by animals in urine and manure. If these excrements are not removed immediately from fouled animal housing surfaces and manure pits into closed manure stores, ammonia and methane can be emitted from housing systems with the exhaust air into the atmosphere.

A reduction of these NH_3 and CH_4 emissions can be achieved if either the surface area of manure exposed to the air is reduced through regular (weekly, daily or several times per day) washing or scraping the floor, or if the slurry is frequently pumped out of the channels and transferred into covered, outside storages. Scraping systems, especially with toothed scrapers, have a significant (50 %) potential to reduce NH_3 emissions from different animal housing systems (Poulsen et al., 2001; Swierstra et al., 2001). Therefore, this system with a high mitigation potential was modelled for the dairy production systems DF1 and DF3, the bull fattening farms BF1 and BF2 and the pig fattening farms PF1 and PF2.

In addition, a change in the frequency of manure removal from animal housing pits into the outdoor manure store reduces NH_3 volatilisation but in particular CH_4 emissions. Methane emissions from slurry-based manure management systems strongly depend on the temperature of the slurry so that a higher storage temperature in animal houses increases these emissions considerably. This especially affects animal houses for pig fattening that are, in contrast to cattle houses, for animal welfare reasons heated to enhance growth rates. Thus, the effect of a more frequent removal of manure from slurry channels on the reduction of methane emissions is expected to be higher for pig fattening farms due to the temperature difference between manure storage in animal houses and covered manure stores outside of the building.

The emission factors and equations used, along with the assessed costs for the use of the removal techniques are documented in detail in chapter 3.3 of deliverable report D10a.

4.3.1 GHG emissions and mitigation costs

The effect of the implemented techniques to increase the manure removal frequency on farm GHG emissions and their mitigation costs are presented in Table 14 for dairy farms, in Table 15 for bull fattening farms and in Table 16 for pig fattening farms.

In dairy farms (Table 14), the implementation of a more frequent removal of manure by a scraping system effectively reduced NH_3 emissions from manure storage in animal houses by 34 % (DF1, DF2). This also reduced the subsequent use of mineral fertilisers in plant production by 7.8 % (DF1) and 7.1 % (DF3) due to the reduction of N losses from manure. Because of the significantly higher NH_4^+ concentration in manure, NH_3 emissions from crop production increased slightly by 0.9 % (DF1) and 1.0 % (DF3). However in total, these savings of overall biogenic emissions were completely compensated by the emissions caused by the electricity use of the manure removal system. In addition, the saved expenses for the decreased mineral fertiliser use were insufficient to cover the higher costs for the electricity use meaning that the implementation of this potential mitigation measure actually resulted in higher farm costs.

The same technologies on bull fattening farms show a similar impact on the farm GHG balance to the dairy farms (Table 15). The NH_3 emissions from animal housing were reduced by 35.5 % (BF1) and 35.8 % (BF2) which, due to the lower livestock densities and manure amounts, only resulted in a reduction of mineral fertiliser use of –2.9 % (BF1) and –0.5 % (BF2). In conjunction with the increase of emissions from the additional electricity use for the scraping system (BF1 +64 % and BF2 +60 % of livestock production electricity use), total farm GHG emissions increased by 0.4 % (BF1) and 0.8 % (BF2). Since the costs of the manure removal system also exceeded the cost savings from the reduced fertiliser use, both bull fattening farms resulted in an increase in GHG emissions as well as in higher production costs.

Table 14: GHG emissions and mitigation costs for the implementation of an increased manure removal frequency (MRF) in comparison to the standard model farms (SMF) of the dairy production systems DF1 and DF2.

		DF1		DF3	
		SMF	MRF	SMF	MRF
Farm area	[ha]	**66.5**	**66.5**	**75.4**	**75.4**
Operating income	[€ ha^{-1}]	**-24**	**-83**	**22**	**-33**
Resources plant production	[t CO_2-eq. a^{-1}]	52.5	50.3	57.2	55.0
Direct emissions plant production	[t CO_2-eq. a^{-1}]	122.7	122.9	132.9	133.1
Total emissions plant production	[t CO_2-eq. a^{-1}]	175.2	173.2	190.1	188.2
Resources livestock farming	[t CO_2-eq. a^{-1}]	80.5	83.6	41.9	45.2
Direct emissions livestock farming	[t CO_2-eq. a^{-1}]	335.6	334.5	367.8	366.7
Total emissions livestock farming	[t CO_2-eq. a^{-1}]	416.1	418.2	409.7	411.9
Total emissions per farm	[t CO_2-eq. a^{-1}]	591.3	591.4	599.9	600.1
Total emissions per hectare	[t CO_2-eq. ha^{-1} a^{-1}]	8.89	8.89	7.96	7.96
Mitigation costs	[€ t^{-1} CO_2-eq.]		—		—

Table 15: GHG emissions and mitigation costs for the implementation of an increased manure removal frequency (MRF) in comparison to the standard model farms (SMF) of the bull fattening farms BF1 and BF2.

		BF1		BF2	
		SMF	MRF	SMF	MRF
Farm area	[ha]	**65.3**	**65.3**	**56.1**	**56.1**
Operating income	[€ ha^{-1}]	**-405**	**-448**	**-430**	**-497**
Resources plant production	[t CO_2-eq. a^{-1}]	55.0	54.1	57.3	57.1
Direct emissions plant production	[t CO_2-eq. a^{-1}]	108.0	109.0	125.8	128.2
Total emissions plant production	[t CO_2-eq. a^{-1}]	163.0	163.1	183.1	185.4
Resources livestock farming	[t CO_2-eq. a^{-1}]	38.1	40.3	95.5	98.4
Direct emissions livestock farming	[t CO_2-eq. a^{-1}]	168.5	167.7	226.7	225.6
Total emissions livestock farming	[t CO_2-eq. a^{-1}]	206.6	208.1	322.2	324.0
Total emissions per farm	[t CO_2-eq. a^{-1}]	369.6	371.2	505.3	509.4
Total emissions per hectare	[t CO_2-eq. ha^{-1} a^{-1}]	5.66	5.68	9.01	9.08
Mitigation costs	[€ t^{-1} CO_2-eq.]		—		—

Table 16 shows a reduction of GHG emissions from pig fattening animal housing of 4.0 % (PF1) and 5.4 % (PF2). This GHG mitigation originates mainly from a 14.7 % reduction of biogenic emissions from the entire animal house and manure storage systems caused by the implementation of a scraping system and a more frequent transfer of manure out of animal housing. These measures reduced the NH_3 emissions of both pig fattening farms consistently by 24 % and the CH_4 emissions by 14.8 %, due to the temperature differences of manure storage in animal houses and outside stores. Preventing the losses of ammonia from housing and storage also resulted in a decreased use of mineral fertiliser of –19.6 % for PF1 with a livestock density of 2.19 LU ha^{-1} and a manure amount of 2060 t a^{-1} whereas the use of fertilisers of PF2 with a livestock density of 0.81 LU ha^{-1} and a manure amount of 1100 t a^{-1} was only reduced by 2.5 %.

Hence, the modelling results show that a more frequent manure pumping process in pig fattening farms is connected with an additional mitigation of CH_4 emissions so that at the farm level the GHG emissions were reduced by 3.4 % (PF1) and 2.9 % (PF2). However, this measure causes very high mitigation costs of 472 (PF2) to 492 € t^{-1} CO_2-eq. (PF1) due to the additional investment for the scraping system and the electricity expenses.

In comparison to studies that only include the reduction of emissions in animal housing, the model results show that mitigation options with an apparent emission reduction potential may result in emission increases in other parts of the system, so that the overall effect is an increase in GHG emissions. It is thus essential to evaluate the mitigation measures at the system level.

According to the modelling results, the implementation of this GHG mitigation measure is only recommended for farms where temperature differences between the animal houses and the outside manure stores exist so that, as well as the reduction of NH_3 emissions that is mainly compensated within the whole production chain, an additional extensive reduction of methane emissions is possible.

Table 16: GHG emissions and mitigation costs for the implementation of an increased manure removal frequency (MRF) in comparison to the standard model farms (SMF) of the pig fattening farms PF1 and PF2.

		PF1		PF2	
		SMF	MRF	SMF	MRF
Farm area	**[ha]**	**53.8**	**53.8**	**76.1**	**76.1**
Operating income	**[€ ha^{-1}]**	**705**	**449**	**447**	**350**
Resources plant production	**[t CO_2-eq. a^{-1}]**	35.7	32.9	102.3	100.5
Direct emissions plant production	**[t CO_2-eq. a^{-1}]**	132.3	133.3	180.0	180.1
Total emissions plant production	**[t CO_2-eq. a^{-1}]**	167.9	166.1	282.3	280.6
Resources livestock farming	**[t CO_2-eq. a^{-1}]**	450.2	453.0	154.8	156.3
Direct emissions livestock farming	**[t CO_2-eq. a^{-1}]**	197.3	168.3	105.3	89.9
Total emissions livestock farming	**[t CO_2-eq. a^{-1}]**	647.5	621.3	260.2	246.2
Total emissions per farm	**[t CO_2-eq. a^{-1}]**	815.5	787.5	542.5	526.8
Total emissions per hectare	**[t CO_2-eq. ha^{-1} a^{-1}]**	15.16	14.64	7.13	6.92
Mitigation costs	**[€ t^{-1} CO_2-eq.]**		**492.1**		**471.9**

4.3.2 Environmental side-effects

The results of the model calculations on the acidification (Table 17) and eutrophication potential (Table 18) show that the reductions of NH_3 emissions arising from the implementation of a more frequent manure removal may also reduce the impact on acidification and eutrophication considerably. Emissions with an effect on acidification decreased by 7.8 % (DF3) up to 9.7 % (BF1) with an average reduction of 8.8 %. The eutrophication potential was reduced comparatively by 7.9 % (DF3) up to 10 % (BF1) (ø 9.2 %). The mitigation costs range for acidification between –0.1 to 15.8 € kg SO_2-eq. and for eutrophication between –0.4 and 85.1 € kg^{-1} PO_4^{3-}-eq.

The more frequent transfer of manure into a closed vessel or tank has some further positive side-effects for animal production. The improvement of air quality in animal houses by the reduction of ammonia also increases animal health and welfare and therefore the animal production performance. Odours may be reduced additionally and nutrients and organic matter conserved.

In addition, the reduction of ammonia emissions may avoid deterioration of cement, thus increasing the durability of animal houses and saving additional emissions from earlier reconstructions.

It is also important to consider that preventing losses of ammonia from housing and storage results in a higher NH_4^+ concentration in the remaining manure than if this measure were not applied. Hence, the emissions of NH_3 during application at field level will increase if no preventative measures (manure storage covers, improved application techniques) are added (Klaassen, 1994).

Table 17: Acidification emissions and mitigation costs for the implementation of an increased manure removal frequency (MRF) in comparison to the standard model farms (SMF) of the dairy farms DF1 and DF3, the bull fattening farms BF1 and BF2 and the pig fattening farms PF1 and PF2.

		DF1		DF3		BF1		BF2		PF1		PF2	
		SMF	MRF	SMF	MRF	SMF	MRF	SMF	MRF	SMF	MRF	SMF	MRF
Farm area	[ha]	**66.5**	**66.5**	**75.4**	**75.4**	**65.3**	**65.3**	**56.1**	**56.1**	**53.8**	**53.8**	**76.1**	**76.1**
Resources plant production	[kg SO_2-eq. a^{-1}]	335.6	327.5	363.0	354.6	341.7	338.3	354.8	354.2	257.6	246.9	574.2	567.2
Direct emissions plant production	[kg SO_2-eq. a^{-1}]	3,927	3,961	4,739	4,786	2,540	2,542	2,893	2,948	2,961	2,905	1,891	1,888
Total emissions plant production	[kg SO_2-eq. a^{-1}]	4,263	4,289	5,102	5,141	2,882	2,880	3,248	3,302	3,219	3,152	2,465	2,455
Resources livestock farming	[kg SO_2-eq. a^{-1}]	500.1	504.8	344.9	349.9	248.0	251.3	631.1	635.5	3,220	3,224	999.1	1,001
Direct emissions livestock farming	[kg SO_2-eq. a^{-1}]	1,682	1,109	1,781	1,177	1,175	758	1,588	1,021	3,574	2,715	1,906	1,448
Total emissions livestock farming	[kg SO_2-eq. a^{-1}]	2,182	1,614	2,126	1,526	1,423	1,009	2,219	1,657	6,794	5,939	2,905	2,449
Total emissions per farm	[kg SO_2-eq. a^{-1}]	6,445	5,903	7,229	6,668	4,304	3,889	5,467	4,959	10,012	9,090	5,371	4,904
Total emissions per hectare	[kg SO_2-eq. ha^{-1} a^{-1}]	96.92	88.76	95.87	88.43	65.91	59.56	97.46	88.39	186.10	168.96	70.58	64.44
Mitigation costs	**[€ kg^{-1} SO_2-eq.]**		**-0.1**		**7.4**		**6.7**		**7.3**		**14.9**		**15.8**

Table 18: Eutrophication emissions and mitigation costs for the implementation of an increased manure removal frequency (MRF) in comparison to the standard model farms (SMF) of the dairy farms DF1 and DF3, the bull fattening farms BF1 and BF2 and the pig fattening farms PF1 and PF2.

		DF1		DF3		BF1		BF2		PF1		PF2	
		SMF	MRF	SMF	MRF	SMF	MRF	SMF	MRF	SMF	MRF	SMF	MRF
Farm area	[ha]	**66.5**	**66.5**	**75.4**	**75.4**	**65.3**	**65.3**	**56.1**	**56.1**	**53.8**	**53.8**	**76.1**	**76.1**
Resources plant production	[kg PO_4^{3-}-eq. a^{-1}]	51.2	50.0	55.6	54.3	51.6	51.1	54.8	54.7	40.4	38.7	88.8	87.8
Direct emissions plant production	[kg PO_4^{3-}-eq. a^{-1}]	731.2	737.5	882.4	891.1	472.9	473.2	538.7	548.8	551.3	540.8	352.1	351.4
Total emissions plant production	[kg PO_4^{3-}-eq. a^{-1}]	782.4	787.4	938.0	945.4	524.5	524.3	593.4	603.5	591.6	579.5	440.9	439.2
Resources livestock farming	[kg PO_4^{3-}-eq. a^{-1}]	72.3	72.7	57.1	57.5	36.1	36.4	91.8	92.2	505	505	151.2	151.4
Direct emissions livestock farming	[kg PO_4^{3-}-eq. a^{-1}]	313.2	206.5	331.6	219.0	218.7	141.1	295.6	190.2	665.4	505.4	354.9	269.6
Total emissions livestock farming	[kg PO_4^{3-}-eq. a^{-1}]	385.6	279.2	388.7	276.5	254.8	177.4	387.4	282.3	1,170	1,010	506.1	421.0
Total emissions per farm	[kg PO_4^{3-}-eq. a^{-1}]	1,168	1,067	1,327	1,222	779.3	701.7	980.9	885.8	1,762	1,590	947.0	860.1
Total emissions per hectare	[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]	17.56	16.04	17.60	16.21	11.93	10.75	17.48	15.79	32.75	29.55	12.44	11.30
Mitigation costs	**[€ kg^{-1} PO_4^{3-}-eq.]**		**-0.4**		**39.4**		**36.0**		**39.2**		**80.2**		**85.1**

4.4 Improved outdoor manure storage techniques

Apart from a surface reduction per unit volume of manure storages (e.g. by the replacement of lagoons by tanks), the most practical technique to reduce GHG emissions from stored slurry is to cover slurry tanks either with low technology covering such as straw, peat, bark, granulates or floating oil, or to use flexible plastic covers or permanent rigid covers such as a solid lid, roof or tent structure.

These techniques have a high potential to reduce NH_3 emissions and, dependent on the cover technique and the respective formation and texture of the manure surface, to also influence CH_4 and N_2O emissions. Methane emissions can be decreased by the oxidation of CH_4 due to the aerobic conditions of the manure surface. But the balance of CH_4 emissions and CH_4 oxidation is currently still vague since both processes depend on the manure type, the conditions in the storage and the cover technique used or amount of the cover material used (such as straw). The addition of cover material (e.g. straw) may also result in higher CH_4 emissions due to the input of additional carbon into the system (Hüther, 1999). Also the potential to decrease N_2O emissions is less certain on account of a great number of competing effects that need to be considered. According to Sommer & Petersen (2002), a natural crust may partly cause a substantial increase of N_2O emissions from nitrification processes in the crust. Covers with straw, peat and bark may additionally change the redox status of the slurry surface like in a natural crust. The cover material may be colonised by aerobic micro-organisms that use ambient air as an oxygen source for nitrification of the slurry borne ammonia. A substantial increase in N_2O emissions has been demonstrated in lab experiments by Hüther & Schuchardt (1998) and Roß et al. (1998) but these results are in contrast to other studies that reported a reduction of N_2O and also CH_4 emissions for practice slurry tanks with, for instance, straw covers (Wanka & Hörnig, 1997; Wanka et al., 1998). The extent of N_2O emissions for the different manure storage covers is therefore still not certain.

The impact of manure storages with and without the formation of a natural surface crust (NC) and the effect of the implementation of the different cover techniques straw (S), granulates (G), plastic sheeting (PS) and rigid covers (RC) on farm level GHG mitigation was modelled for the two dairy model farms DF1 and DF3, the bull fattening farms BF1 and BF2 and the pig fattening model farms PF1 and PF2. Because of the different feeding systems for cattle and pigs the reference storage system for cattle manure is an uncovered storage with a natural surface crust whereas for fattening pigs no surface crust is anticipated. The average ammonia emission reduction factors for the different cover techniques were taken from Döhler et al. (2002). Nitrous oxide and methane emissions were excluded from the model since consistent emission factors for the various cover techniques are currently not available.

The interaction processes of the different greenhouse gases depending on the cover techniques used and the corresponding emission factors and cover costs used for modelling are described in detail in chapter 3.4 of deliverable report D10a.

4.4.1 GHG emissions and mitigation costs

The model results on the implementation of the different cover techniques on GHG emissions have to be separated for cattle (dairy and bull fattening farms) and pig fattening farms since the reference situation for cattle standard model farms with an already existing natural surface crust and for standard pig fattening farms without a surface crust is completely different.

The dairy model farms DF1 and DF3 showed to a large extent an identical effect of the cover techniques on the GHG balance of the farms (Table 19). The manure storage covers directly reduced the NH_3 emissions of total manure management by 9.2-9.3 % (S), 13.7-13.9 % (G, PS) and 18.3-18.5 % (RC) in relation to the entire NH_3 emissions from animal production. Due to these achieved nitrogen savings during manure storage the subsequent use of mineral fertiliser was reduced by 1.5-1.6 % (S), 2.3-2.5 % (G, PS) and 3.0-3.3 % (RC). These minor reductions related to the total GHG balance of the model farms DF1 and DF3 resulted in a mitigation potential of a maximum of –0.23 % (reduction for DF1 and DF3: 0.11-0.12 % (S), 0.17-0.18 % (G, PS) and 0.22-0.23 % (RC)). Therefore, these marginal GHG reductions give rise to high mitigation costs that range between 150 and 580 € t^{-1} CO_2-eq. depending on the reduction potential and the respective cover costs (Table 19).

With respect to the bull fattening farms, the implementation of the cover techniques shows for BF1, in comparison to the dairy farms, a negligible low GHG mitigation potential (–0.03 % (S), –0.06 % (G, PS) and –0.07 % (RC)) so that the mitigation costs range between 560 and 1,650 € t^{-1} CO_2-eq. (Table 20). For BF2, the already lower GHG emission reductions were completely compensated for all cover techniques by the increased NH_3 emissions and the direct and indirect (caused by an increase in nitrate leaching) N_2O emissions after manure application (+0.04 % (S), +0.06 % (G, PS) and +0.09 % (RC)).

Table 19: GHG emissions and mitigation costs for the implementation of the manure storage cover techniques straw (S), granulates (G), plastic sheeting (PS) and rigid cover (RC) in comparison to the uncovered manure stores with a natural crust of the standard model farms (SMF) DF1 and DF3.

		DF1					DF3				
		SMF	S	G	PS	RC	SMF	S	G	PS	RC
Farm area	[ha]	**66.5**	**66.5**	**66.5**	**66.5**	**66.5**	**75.4**	**75.4**	**75.4**	**75.4**	**75.4**
Operating income	[€ ha^{-1}]	**-24**	**-26**	**-27**	**-29**	**-35**	**22**	**20**	**18**	**17**	**11**
Resources plant production	[t CO_2-eq. a^{-1}]	52.5	52.0	51.8	51.8	51.5	57.2	56.8	56.5	56.5	56.3
Direct emissions plant production	[t CO_2-eq. a^{-1}]	122.7	122.8	122.9	122.9	122.9	132.9	133.0	133.0	133.0	133.1
Total emissions plant production	[t CO_2-eq. a^{-1}]	175.2	174.8	174.6	174.6	174.4	190.1	189.7	189.6	189.6	189.4
Resources livestock farming	[t CO_2-eq. a^{-1}]	80.5	80.5	80.5	80.5	80.5	41.9	41.9	41.9	41.9	41.9
Direct emissions livestock farming	[t CO_2-eq. a^{-1}]	335.6	335.3	335.2	335.2	335.0	367.8	367.5	367.3	367.3	367.2
Total emissions livestock farming	[t CO_2-eq. a^{-1}]	416.1	415.8	415.6	415.6	415.5	409.7	409.4	409.2	409.2	409.1
Total emissions per farm	[t CO_2-eq. a^{-1}]	591.3	590.6	590.3	590.3	589.9	599.9	599.1	598.8	598.8	598.5
Total emissions per hectare	[t CO_2-eq. ha^{-1} a^{-1}]	8.89	8.88	8.88	8.88	8.87	7.96	7.95	7.94	7.94	7.94
Mitigation costs	[€ t^{-1} CO_2-eq.]		**153.9**	**220.9**	**355.3**	**555.0**		**156.2**	**226.4**	**362.1**	**582.8**

Table 20: GHG emissions and mitigation costs for the implementation of the manure storage cover techniques straw (S), granulates (G), plastic sheeting (PS) and rigid cover (RC) in comparison to the uncovered manure stores with a natural crust of the standard model farms (SMF) BF1 and BF2.

		BF1					BF2				
		SMF	S	G	PS	RC	SMF	S	G	PS	RC
Farm area	[ha]	**65.3**	**65.3**	**65.3**	**65.3**	**65.3**	**56.1**	**56.1**	**56.1**	**56.1**	**56.1**
Operating income	[€ ha^{-1}]	**-405**	**-406**	**-407**	**-409**	**-412**	**-430**	**-432**	**-434**	**-436**	**-442**
Resources plant production	[t CO_2-eq. a^{-1}]	55.0	54.8	54.7	54.7	54.6	57.3	57.3	57.3	57.3	57.3
Direct emissions plant production	[t CO_2-eq. a^{-1}]	108.0	108.2	108.3	108.3	108.4	125.8	126.3	126.5	126.5	126.7
Total emissions plant production	[t CO_2-eq. a^{-1}]	163.0	163.1	163.0	163.0	163.1	183.1	183.6	183.8	183.8	184.0
Resources livestock farming	[t CO_2-eq. a^{-1}]	38.1	38.1	38.1	38.1	38.1	95.5	95.5	95.5	95.5	95.5
Direct emissions livestock farming	[t CO_2-eq. a^{-1}]	168.5	168.3	168.2	168.2	168.2	226.7	226.5	226.3	226.3	226.2
Total emissions livestock farming	[t CO_2-eq. a^{-1}]	206.6	206.4	206.3	206.3	206.3	322.2	321.9	321.8	321.8	321.7
Total emissions per farm	[t CO_2-eq. a^{-1}]	369.6	369.5	369.4	369.4	369.3	505.3	505.5	505.6	505.6	505.7
Total emissions per hectare	[t CO_2-eq. ha^{-1} a^{-1}]	5.66	5.66	5.66	5.66	5.66	9.007	9.011	9.013	9.013	9.015
Mitigation costs	[€ t^{-1} CO_2-eq.]		**561.0**	**619.0**	**965.4**	**1,650**		**—**	**—**	**—**	**—**

For pig fattening farms, the GHG mitigation effect was higher than for the cattle model farms due to the fact that the standard model farms PF1 and PF2 were defined to have no natural surface crust. Hence, an improved manure storage resulted in a higher GHG reduction so that for PF1 (Table 21) and PF2 (Table 22) the entire farm emissions were reduced: for the formation of a natural crust by 0.15 and 0.27 %, for the implementation of the cover techniques straw by 0.48 and 0.71 %, for granulates and plastic sheeting by 0.53 and 0.76 %, and for a rigid cover by 0.59 and 0.81 %. These emission reductions were caused by a decrease in NH_3 emissions from livestock production of 15 % (NC), 40 % (S), 42.5 % (G, PS) and 45 % (RC). Because of the different livestock densities of the pig fattening farms and corresponding different amounts of manure and saved N amounts that may substitute mineral fertiliser, the substitution for PF1 ranged between 8.2 and 28.2 % and was only reduced by 1.3-4.2 % for PF2. The reduced use of mineral fertilisers, the implementation of low technology covering and the use of plastic sheets for PF2 resulted in negative GHG mitigation costs (Table 21, Table 22). The mitigation costs for the use of plastic sheets in PF1 were 23 € t^{-1} CO_2-eq. and for the use of rigid covers 39 (PF2) and 90 € t^{-1} CO_2-eq. (PF1).

In conclusion, for cattle farms, an existing surface crust already represents a useful means of reducing NH_3 emissions such that it must be considered and recommended that filling and emptying liquid manure storage tanks should only take place from below the surface of the stored manure to conserve the slurry surface crust (underslat flushing). Additional cover techniques have only marginal additional reduction effects and cause high mitigation costs.

For the storage of pig slurry, the GHG reduction potential is higher since no natural crust normally exists and the NH_4^+ concentration in pig slurry is higher than in cattle manure. Hence, the mitigation costs for the implementation of cover techniques are negative or comparatively low for pig fattening model farms.

For the implementation of this mitigation measure it must be considered that apart from a reduction of NH_3 emissions, rigid covers also reduce manure storage volumes by excluding rain water from the store. This additionally reduces GHG emissions from energy use and costs for transport and application since smaller quantities of manure are then involved (these factors were not considered in modelling). Furthermore, additional CH_4 and N_2O emission reductions are possible that could further increase the reduction potential and thus may also reduce mitigation costs.

Table 21: GHG emissions and mitigation costs for the development of a natural crust (NC) and for the implementation of the manure storage cover techniques straw (S), granulates (G), plastic sheeting (PS) and rigid cover (RC) in comparison to the uncovered manure stores without natural surface crust of the standard model farm (SMF) PF1.

		PF1					
		SMF	NC	S	G	PS	RC
Farm area	**[ha]**	**53.8**	**53.8**	**53.8**	**53.8**	**53.8**	**53.8**
Operating income	**[€ ha^{-1}]**	**705**	**707**	**707**	**706**	**703**	**697**
Resources plant production	**[t CO_2-eq. a^{-1}]**	35.7	34.5	32.3	32.0	32.0	31.6
Direct emissions plant production	**[t CO_2-eq. a^{-1}]**	132.3	133.2	134.5	134.5	134.5	134.6
Total emissions plant production	**[t CO_2-eq. a^{-1}]**	167.9	167.7	166.7	166.5	166.5	166.2
Resources livestock farming	**[t CO_2-eq. a^{-1}]**	450.2	450.2	450.2	450.2	450.2	450.2
Direct emissions livestock farming	**[t CO_2-eq. a^{-1}]**	197.3	196.3	194.5	194.4	194.4	194.2
Total emissions livestock farming	**[t CO_2-eq. a^{-1}]**	647.5	646.5	644.8	644.6	644.6	644.5
Total emissions per farm	**[t CO_2-eq. a^{-1}]**	815.5	814.2	811.5	811.1	811.1	810.7
Total emissions per hectare	**[t CO_2-eq. ha^{-1} a^{-1}]**	15.16	15.13	15.08	15.08	15.08	15.07
Mitigation costs	**[€ t^{-1} CO_2-eq.]**		**-64.34**	**-29.53**	**-4.36**	**22.91**	**90.02**

Table 22: GHG emissions and mitigation costs for the development of a natural crust (NC) and for the implementation of the manure storage cover techniques straw (S), granulates (G), plastic sheeting (PS) and rigid cover (RC) in comparison to the uncovered manure stores without natural surface crust of the standard model farm (SMF) PF2.

		PF2					
		SMF	NC	S	G	PS	RC
Farm area	**[ha]**	**76.1**	**76.1**	**76.1**	**76.1**	**76.1**	**76.1**
Operating income	**[€ ha^{-1}]**	**447**	**448**	**448**	**448**	**447**	**445**
Resources plant production	**[t CO_2-eq. a^{-1}]**	102.3	101.4	99.7	99.5	99.5	99.3
Direct emissions plant production	**[t CO_2-eq. a^{-1}]**	180.0	180.0	180.2	180.2	180.2	180.2
Total emissions plant production	**[t CO_2-eq. a^{-1}]**	282.3	281.4	279.9	279.7	279.7	279.5
Resources livestock farming	**[t CO_2-eq. a^{-1}]**	154.8	154.8	154.8	154.8	154.8	154.8
Direct emissions livestock farming	**[t CO_2-eq. a^{-1}]**	105.3	104.8	103.9	103.8	103.8	103.7
Total emissions livestock farming	**[t CO_2-eq. a^{-1}]**	260.2	259.6	258.7	258.6	258.6	258.5
Total emissions per farm	**[t CO_2-eq. a^{-1}]**	542.5	541.0	538.6	538.3	538.3	538.1
Total emissions per hectare	**[t CO_2-eq. ha^{-1} a^{-1}]**	7.13	7.11	7.08	7.07	7.07	7.07
Mitigation costs	**[€ t^{-1} CO_2-eq.]**		**-47.16**	**-30.97**	**-16.48**	**-1.21**	**39.15**

4.4.2 Environmental side-effects

Since the manure storage cover techniques influence the farms' ammonia emissions, this mitigation measure also directly affects the acidification and eutrophication potential of agricultural production. For the cattle model farms DF1, DF3, BF1 and BF2, the acidification potential was decreased by 1.8-3.8 % with very low mitigation costs (0.8-3.2 € kg^{-1} SO_2-eq.; Table 23) and an almost identical reduction in eutrophication potential of 1.9-3.9 % with mitigation costs of 4.3-17.3 € kg^{-1} PO_4^{3-}-eq. (Table 24).

For the pig fattening model farms, the entire acidification potential was reduced considerably by 5.4-16.7 % and the eutrophication potential by 5.7-17.7 %. The mitigation costs for both the acidification and eutrophication potential depend on the reduction efficiency and the cover costs much range around zero Euro (acidification: –0.2 to +0.3 € kg^{-1} SO_2-eq.; eutrophication: –1.3 to +1.4 € kg^{-1} PO_4^{3-}-eq.). The results can be seen in Table 23 and Table 24.

Apart from an additional reduction of odours, no significant further environmental side-effects are expected.

Table 23: Acidification emissions and mitigation costs for the implementation of a natural crust (NC) and the manure storage covers straw (S), granulates (G), plastic sheeting (PS) and rigid covers (RC) of the dairy farms DF1 and DF3, the bull fattening farms BF1 and BF2 and the pig fattening farms PF1 and PF2.

		DF1		DF1 S	DF1 G	DF1 PS	DF1 RC
Total emissions per farm	**[kg SO_2-eq. a^{-1}]**	6445		6316	6251	6251	6186
Total emissions per hectare	**[kg SO_2-eq. ha^{-1} a^{-1}]**	96.92		94.98	94.00	94.00	93.03
Mitigation costs	**[€ kg^{-1} SO_2-eq.]**			**0.79**	**1.13**	**1.82**	**2.85**
		DF3		**DF3 S**	**DF3 G**	**DF3 PS**	**DF3 RC**
Total emissions per farm	**[kg SO_2-eq. a^{-1}]**	7229		7096	7029	7029	6963
Total emissions per hectare	**[kg SO_2-eq. ha^{-1} a^{-1}]**	95.87		94.10	93.22	93.22	92.34
Mitigation costs	**[€ kg^{-1} SO_2-eq.]**			**0.84**	**1.19**	**1.91**	**2.99**
		BF1		**BF1 S**	**BF1 G**	**BF1 PS**	**BF1 RC**
Total emissions per farm	**[kg SO_2-eq. a^{-1}]**	4304		4222	4180	4180	4139
Total emissions per hectare	**[kg SO_2-eq. ha^{-1} a^{-1}]**	65.91		64.65	64.02	64.02	63.39
Mitigation costs	**[€ kg^{-1} SO_2-eq.]**			**0.84**	**1.15**	**1.80**	**2.77**
		BF2		**BF2 S**	**BF2 G**	**BF2 PS**	**BF2 RC**
Total emissions per farm	**[kg SO_2-eq. a^{-1}]**	5467		5368	5317	5317	5267
Total emissions per hectare	**[kg SO_2-eq. ha^{-1} a^{-1}]**	97.46		95.69	94.78	94.78	93.89
Mitigation costs	**[€ kg^{-1} SO_2-eq.]**			**1.08**	**1.43**	**2.15**	**3.23**
		PF1	**PF1 NC**	**PF1 S**	**PF1 G**	**PF1 PS**	**PF1 RC**
Total emissions per farm	**[kg SO_2-eq. a^{-1}]**	10012	9463	8523	8432	8432	8335
Total emissions per hectare	**[kg SO_2-eq. ha^{-1} a^{-1}]**	186.10	175.88	158.43	156.73	156.73	154.92
Mitigation costs	**[€ kg^{-1} SO_2-eq.]**		**-0.15**	**-0.08**	**-0.01**	**0.06**	**0.26**
		PF2	**PF2 NC**	**PF2 S**	**PF2 G**	**PF2 PS**	**PF2 RC**
Total emissions per farm	**[kg SO_2-eq. a^{-1}]**	5371	5083	4596	4546	4546	4496
Total emissions per hectare	**[kg SO_2-eq. ha^{-1} a^{-1}]**	70.58	66.79	60.40	59.74	59.74	59.08
Mitigation costs	**[€ kg^{-1} SO_2-eq.]**		**-0.24**	**-0.15**	**-0.08**	**-0.01**	**0.20**

Table 24: Eutrophication emissions and mitigation costs for the implementation of a natural crust (NC) and the manure storage covers straw (S), granulates (G), plastic sheeting (PS) and rigid covers (RC) of the dairy farms DF1 and DF3, the bull fattening farms BF1 and BF2 and the pig fattening farms PF1 and PF2.

		DF1		DF1 S	DF1 G	DF1 PS	DF1 RC
Total emissions per farm	**[kg PO_4^{3-}-eq. a^{-1}]**	1168		1144	1132	1132	1120
Total emissions per hectare	**[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]**	17.56		17.20	17.02	17.02	16.84
Mitigation costs	**€ kg^{-1} PO_4^{3-}-eq.]**			**4.25**	**6.10**	**9.81**	**15.34**
		DF3		**DF3 S**	**DF3 G**	**DF3 PS**	**DF3 RC**
Total emissions per farm	**[kg PO_4^{3-}-eq. a^{-1}]**	1327		1302	1290	1290	1277
Total emissions per hectare	**[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]**	17.60		17.27	17.10	17.10	16.94
Mitigation costs	**€ kg^{-1} PO_4^{3-}-eq.]**			**4.50**	**6.43**	**10.29**	**16.08**
		BF1		**BF1 S**	**BF1 G**	**BF1 PS**	**BF1 RC**
Total emissions per farm	**[kg PO_4^{3-}-eq. a^{-1}]**	779		764	756	756	749
Total emissions per hectare	**[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]**	11.93		11.70	11.58	11.58	11.46
Mitigation costs	**€ kg^{-1} PO_4^{3-}-eq.]**			**4.49**	**6.21**	**9.68**	**14.88**
		BF2		**BF2 S**	**BF2 G**	**BF2 PS**	**BF2 RC**
Total emissions per farm	**[kg PO_4^{3-}-eq. a^{-1}]**	981		962	953	953	944
Total emissions per hectare	**[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]**	17.48		17.15	16.99	16.99	16.82
Mitigation costs	**€ kg^{-1} PO_4^{3-}-eq.]**			**5.79**	**7.70**	**11.57**	**17.33**
		PF1	**PF1 NC**	**PF1 S**	**PF1 G**	**PF1 PS**	**PF1 RC**
Total emissions per farm	**[kg PO_4^{3-}-eq. a^{-1}]**	1762	1660	1485	1468	1468	1450
Total emissions per hectare	**[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]**	32.75	30.85	27.60	27.29	27.29	26.95
Mitigation costs	**€ kg^{-1} PO_4^{3-}-eq.]**		**-0.79**	**-0.42**	**-0.06**	**0.34**	**1.39**
		PF2	**PF2 NC**	**PF2 S**	**PF2 G**	**PF2 PS**	**PF2 RC**
Total emissions per farm	**[kg PO_4^{3-}-eq. a^{-1}]**	947	894	803	794	794	785
Total emissions per hectare	**[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]**	12.44	11.74	10.55	10.43	10.43	10.31
Mitigation costs	**€ kg^{-1} PO_4^{3-}-eq.]**		**-1.27**	**-0.83**	**-0.45**	**-0.03**	**1.06**

4.5 Improved manure application techniques

The reduction of GHG emissions (in particular of NH_3 emissions) arising after application of slurries or liquid and solid manures is particularly important, because these account for a large proportion of total manure emissions and the application process represents the last step in manure handling. Hence, without abatement, measures addressing manure handling at the end-of-pipe stage, much of the benefit of other mitigation measures during animal housing and manure storage may be lost. Moreover, it is essential to minimise losses at this stage because any nitrogen saved during manure handling will also be lost as a nutrient for crop production if emissions are not controlled by appropriate field application techniques. Reducing nitrogen losses from slurries or solid and liquid manures means more plant-available N is potentially available for grass and crop uptake and thus in principle a substantially reduced amount of mineral fertilisers is needed on the farm. This reduction of mineral fertiliser use will in turn decrease GHG emissions in respect of the high energy use required for inorganic fertiliser production.

Techniques to mitigate these emissions include burying slurry or liquid and solid manures through direct incorporation into the soil (dependent on the time between manure application and incorporation) and using machinery (i.e. improved application techniques) to decrease the surface area of slurries. The effectiveness of improved application techniques relies on reducing the surface area of slurry exposed to the air, increasing the rate of infiltration into the soil so that ammonium-N adsorbs to clay particles, or reducing air flow over the slurry surface by placement beneath a crop or grass canopy. Hence, in the framework of this analysis different improved slurry application techniques were investigated with a focus on the mitigation of ammonia emissions after manure application. The use of improved application techniques may also influence N_2O emissions which were modelled on the one hand by the reduced NH_3 emissions and subsequently higher direct N_2O emissions from nitrification and denitrification. On the other hand, the decreased NH_3 deposition reduces indirectly N_2O emissions which were also considered in model calculations. In contrast to the results for N losses and as confirmed by a number of studies CH_4 emissions after slurry application can be neglected (Clemens et al., 1997; Velthof et al., 1997; Weslien et al., 1998; Chadwick et al., 2000; Wulf et al., 2001). Thus, differences in CH_4 emissions for the different application techniques were not considered during modelling.

The approach was to model the impact on GHG mitigation of the improved manure application techniques, for example trail hose, trail shoe and injection, compared to broadcasting taken as the standard application technique. Changes in ammonia volatilisation and fertiliser replacement values were calculated by the ModelFarm model (based on results and calculations from ALFAM, 2002; MIDAIR, 2004 and KTBL, 2004) for two dairy model farms DF1 and DF3, both bull fattening farms BF1 and BF2 and both pig fattening model farms PF1 and PF1. Details of the calculation of GHG emissions and the costs of using the different application techniques were reported in chapter 3.5 of deliverable report D10a.

4.5.1 GHG emissions and mitigation costs

Table 26 shows the effect of the different modelled manure application techniques trailing hose (TH), trailing shoe (TS) and injection (INJ) on GHG emissions of the dairy model farms DF1 and DF3. Since improved manure application has an impact mainly on ammonia volatilisation and N_2O emissions from cultivated fields and grassland, the fertiliser replacement values of the manure applied and the use of energy for the different application techniques, only the GHG emissions of plant production but not of livestock farming were influenced.

The highest GHG mitigation potential was calculated to arise from use of the trailing hose application system (DF1 –1.36 %, DF3 –1.62 %), followed by the trailing shoe technique (DF1 –1.08 %, DF3 –1.28 %) and manure application by injection (DF1 –0.98 %, DF3 –1.12 %). The different application techniques directly reduced NH_3 emissions after manure application by approximately 41 % (TH), 33 % (TS) and 45 % (INJ) which also decreased the use of mineral fertilisers (TH: DF1 –20 %, DF3 –22.5 %; TS: DF1 –16 %, DF3 –18 %; INJ: DF1 –21.5 %, DF3 –24.5 %). However, this mitigation effect was decreased dependent on the additional energy needed for the operation of the different application techniques. Diesel use for crop production increased for both the trail hose and trail shoe application by 1.7 % (DF1) and 2.6 % (DF3) respectively. This is in contrast to the application by injection which significantly increased the total diesel use for crop production by 15 % (DF1) and 19.5 % (DF3). In addition, for manure tank filling operations an electricity need of 193 kWh (DF1) and 207 kWh (DF3) was calculated for injection. These additional energy uses considerably reduced the GHG mitigation effect and increased the costs of this measure.

The mitigation costs were modelled to be relatively low for the trail hose application (DF1 93 € t^{-1} CO_2-eq., DF3 97 € t^{-1} CO_2-eq.), increased significantly for the trail shoe application (DF1 460 € t^{-1} CO_2-eq., DF3 437 € t^{-1} CO_2-eq.) and were highest for manure application by injection (DF1 565 € t^{-1} CO_2-eq., DF3 760 € t^{-1} CO_2-eq.) (Table 25).

Table 25: GHG emissions and mitigation costs for the implementation of the improved manure application techniques trailing hose (TH), trailing shoe (TS) and injection (INJ) of the dairy farms DF1 and DF3.

		DF1				DF3			
		SMF	TH	TS	INJ	SMF	TH	TS	INJ
Farm area	[ha]	**66.5**	**66.5**	**66.5**	**66.5**	**75.4**	**75.4**	**75.4**	**75.4**
Operating income	[€ ha^{-1}]	**-24**	**-35**	**-68**	**-73**	**22**	**9**	**-23**	**-46**
Resources plant production	[t CO_2-eq. a^{-1}]	52.5	47.3	48.3	49.7	57.2	51.0	52.4	54.4
Direct emissions plant production	[t CO_2-eq. a^{-1}]	122.7	119.9	120.4	119.7	132.9	129.3	130.0	129.0
Total emissions plant production	[t CO_2-eq. a^{-1}]	175.2	167.1	168.8	169.4	190.1	180.4	182.5	183.4
Resources livestock farming	[t CO_2-eq. a^{-1}]	80.5	80.5	80.5	80.5	41.9	41.9	41.9	41.9
Direct emissions livestock farming	[t CO_2-eq. a^{-1}]	335.6	335.6	335.6	335.6	367.8	367.8	367.8	367.8
Total emissions livestock farming	[t CO_2-eq. a^{-1}]	416.1	416.1	416.1	416.1	409.7	409.7	409.7	409.7
Total emissions per farm	[t CO_2-eq. a^{-1}]	591.3	583.2	584.9	585.5	599.9	590.1	592.2	593.1
Total emissions per hectare	[t CO_2-eq. ha^{-1} a^{-1}]	8.89	8.77	8.80	8.80	7.96	7.83	7.85	7.87
Mitigation costs per hectare	[€ t^{-1} CO_2-eq.]		**93.0**	**460.3**	**565.1**		**97.3**	**437.2**	**759.5**

The total impact of the implementation of the different manure application techniques on GHG mitigation on the bull fattening farms (Table 26) and pig fattening farms (Table 27) was considerably lower. This arises both from the different livestock densities and to some degree from the lower amounts of manure applied. The diverse manure types that differed, for instance, in their dry matter and NH_4^+ content were also an influencing factor. Manure application by trail hose reduced the GHG emissions by on average 0.33 % (BF1 –0.22 %, BF2 –0.55 %, PF1 –0.17 %, PF2 –0.38 %) and for trail shoe by 0.25 % (BF1 –0.15 %, BF2 –0.44 %, PF1 –0.13 %, PF2 –0.28 %). The application by injection resulted, for model farm BF2, in only a marginal GHG reduction (–0.07 %) whereas the higher energy use of this mitigation measure completely exceeded the direct (NH_3) and indirect (N_2O, mineral fertiliser) GHG reduction effect for the model farms BF1, PF1 and PF2. The application by the different techniques resulted, for all model farms, in the same percentage reduction of NH_3 emissions and also showed a similar increase in the consumption of diesel. However, because of the different manure amounts and manure types the effect on the replacement of mineral fertilisers was different. With the application techniques achieving lower reductions for the bull and pig fattening farms, the mitigation costs also increased (Table 26, Table 27).

Finally, according to these modelling results in German conditions, the manure application by trailing hose seems the best approach to mitigating emissions. This technique resulted in the highest GHG mitigation potential with lowest mitigation costs, whereas the higher energy use of the trailing shoe system and of injection compensated for or partly exceeded the achieved emission reductions. For the dairy model farms, the mitigation costs of trail hose have a wide margin of fluctuation dependent on the different agricultural production systems assumed, but are at moderate level, compared to other mitigation measures. These calculated mitigation costs for trail hose application of on average 413 € t^{-1} CO_2-eq. (93-1072 € t^{-1} CO_2-eq.) are in line with modelling results by Weiske et al. (2006) who calculated mitigation costs to average 391 € t^{-1} CO_2-eq. (174-831 € t^{-1} CO_2-eq.) for dairy production model farms in different European regions.

Table 26: GHG emissions and mitigation costs for the implementation of the improved manure application techniques trailing hose (TH), trailing shoe (TS) and injection (INJ) of the bull fattening farms BF1 and BF2.

		BF1				BF2			
		SMF	TH	TS	INJ	SMF	TH	TS	INJ
Farm area	[ha]	**65.3**	**65.3**	**65.3**	**65.3**	**56.1**	**56.1**	**56.1**	**56.1**
Operating income	[€ ha^{-1}]	**-405**	**-419**	**-439**	**-478**	**-430**	**-445**	**-476**	**-491**
Resources plant production	[t CO_2-eq. a^{-1}]	55.0	53.9	54.2	56.8	57.3	55.1	55.6	57.5
Direct emissions plant production	[t CO_2-eq. a^{-1}]	108.0	108.3	108.3	108.3	125.8	125.3	125.4	125.3
Total emissions plant production	[t CO_2-eq. a^{-1}]	163.0	162.2	162.5	165.1	183.1	180.3	180.9	182.8
Resources livestock farming	[t CO_2-eq. a^{-1}]	38.1	38.1	38.1	38.1	95.5	95.5	95.5	95.5
Direct emissions livestock farming	[t CO_2-eq. a^{-1}]	168.5	168.5	168.5	168.5	226.7	226.7	226.7	226.7
Total emissions livestock farming	[t CO_2-eq. a^{-1}]	206.6	206.6	206.6	206.6	322.2	322.2	322.2	322.2
Total emissions per farm	[t CO_2-eq. a^{-1}]	369.6	368.8	369.1	371.7	505.3	502.5	503.1	504.9
Total emissions per hectare	[t CO_2-eq. ha^{-1} a^{-1}]	5.660	5.647	5.652	5.692	9.007	8.957	8.968	9.001
Mitigation costs per hectare	**[€ t^{-1} CO_2-eq.]**		**1,072**	**4,115**	**—**		**290.9**	**1,161**	**9,416**

Table 27: GHG emissions and mitigation costs for the implementation of the improved manure application techniques trailing hose (TH), trailing shoe (TS) and injection (INJ) of the pig fattening farms PF1 and PF2.

		PF1				PF2			
		SMF	TH	TS	INJ	SMF	TH	TS	INJ
Farm area	[ha]	**53.8**	**53.8**	**53.8**	**53.8**	**76.1**	**76.1**	**76.1**	**76.1**
Operating income	[€ ha^{-1}]	**705**	**690**	**655**	**656**	**447**	**437**	**423**	**393**
Resources plant production	[t CO_2-eq. a^{-1}]	35.7	34.0	34.4	36.1	102.3	101.0	101.4	103.5
Direct emissions plant production	[t CO_2-eq. a^{-1}]	132.3	132.6	132.6	132.6	180.0	179.2	179.4	179.2
Total emissions plant production	[t CO_2-eq. a^{-1}]	167.9	166.6	166.9	168.8	282.3	280.3	280.8	282.7
Resources livestock farming	[t CO_2-eq. a^{-1}]	450.2	450.2	450.2	450.2	154.8	154.8	154.8	154.8
Direct emissions livestock farming	[t CO_2-eq. a^{-1}]	197.3	197.3	197.3	197.3	105.3	105.3	105.3	105.3
Total emissions livestock farming	[t CO_2-eq. a^{-1}]	647.5	647.5	647.5	647.5	260.2	260.2	260.2	260.2
Total emissions per farm	[t CO_2-eq. a^{-1}]	815.5	814.1	814.5	816.3	542.5	540.4	541.0	542.8
Total emissions per hectare	[t CO_2-eq. ha^{-1} a^{-1}]	15.158	15.132	15.139	15.173	7.129	7.102	7.109	7.133
Mitigation costs per hectare	**[€ t^{-1} CO_2-eq.]**		**584.2**	**2,605**	**—**		**344.8**	**1,162**	**—**

4.5.2 Environmental side-effects

The model calculations with respect to the implementation of improved manure application techniques showed that the substantial reductions of NH_3 emissions also had a significant influence on farms' acidification (Table 28) and eutrophication potential (Table 29).

The acidification potential was reduced for the cattle model farms DF1, DF3, BF1 and BF2 by averages of 24.5 % (TH), 19.5 % (TS) and 26 % (INJ) and for the pig fattening model farms by averages of 12.2 % (TH), 9.7 % (TS) and 12.9 % (INJ). The mitigation costs of emissions with an effect on acidification for the application by trail hose were on average 0.7 € kg^{-1} SO_2-eq. (0.5-1.1 € kg^{-1} SO_2-eq.), for trailing shoe application 2.7 € kg^{-1} SO_2-eq. (2.1-3.5 € kg^{-1} SO_2-eq.) and for injection 3.3 € kg^{-1} SO_2-eq. (1.9-6.0 € kg^{-1} SO_2-eq.).

The reduction of the eutrophication potential was on average 25.1 % (TH), 20.0 % (TS) and 26.7 % (INJ) for the cattle farms (DF1, DF3, BF1, BF2) and 12.9 % (TH), 10.3 % (TS) and 13.7 % (INJ) for the pig fattening farms (PF1, PF2). The mitigation costs ranged for trail hose application between 2.5 and 5.9 € kg^{-1} PO_4^{3-}-eq. (ø 3.8 € kg^{-1} PO_4^{3-}-eq.), for trail shoe application between 11.4 and 18.6 € kg^{-1} PO_4^{3-}-eq. (ø 14.5 € kg^{-1} PO_4^{3-}-eq.) and for injection between 10 and 32 € kg^{-1} PO_4^{3-}-eq. (ø 3.8 € kg^{-1} PO_4^{3-}-eq.).

Thus, the model results showed that an improved manure application technique may also lead to a positive reduction of a farms acidification and eutrophication potential as well as low mitigation costs.

In addition, an optimised application of slurries by trail hose, trail shoe or injection may reduce odour emissions, besides reducing ammonia volatilisation. Moreover, a more efficient application technique leads to less coverage of the crop with manure and lower forage contamination and therefore to an improved growth and quality of crops.

However, the applicability of trail hose and shoe or injection is limited by site conditions, such as the size, shape and slope of the field by the presence of stones on the soil surface. Injection techniques are also not applicable on very shallow or compacted soils, where it is impossible to achieve uniform penetration of the knives or disc coulters to the required working depth. In addition, trail hose and injection techniques are not usable on steeply sloping fields or if the straw content of the slurry is too high. On most European farms however, at least the trail hose application technique can be implemented very easily.

Apart from the indirect impact of the reduced acidification and eutrophication potential on biodiversity, other direct influences on biodiversity are not expected.

Table 28: Acidification emissions and mitigation costs for the implementation of the improved manure application techniques trailing hose (TH), trailing shoe (TS) and injection (INJ) of the dairy farms DF1 and DF3, the bull fattening farms BF1 and BF2 and the pig fattening farms PF1 and PF2.

		DF1	DF1 TH	DF1 TS	DF1 INJ
Total emissions per farm	[kg SO_2-eq. a^{-1}]	6,445	4,800	5,137	4,693
Total emissions per hectare	[kg SO_2-eq. ha^{-1} a^{-1}]	96.92	72.18	77.24	70.58
Mitigation costs	[€ kg^{-1} SO_2-eq.]		**0.46**	**2.25**	**1.87**
		DF3	**DF3 TH**	**DF3 TS**	**DF3 INJ**
Total emissions per farm	[kg SO_2-eq. a^{-1}]	7,229	5,238	5,646	5,113
Total emissions per hectare	[kg SO_2-eq. ha^{-1} a^{-1}]	95.87	69.48	74.88	67.82
Mitigation costs	[€ kg^{-1} SO_2-eq.]		**0.48**	**2.12**	**2.41**
		BF1	**BF1 TH**	**BF1 TS**	**BF1 INJ**
Total emissions per farm	[kg SO_2-eq. a^{-1}]	4,304	3,291	3,499	3,237
Total emissions per hectare	[kg SO_2-eq. ha^{-1} a^{-1}]	65.91	50.40	53.58	49.58
Mitigation costs	[€ kg^{-1} SO_2-eq.]		**0.88**	**2.77**	**4.44**
		BF2	**BF2 TH**	**BF2 TS**	**BF2 INJ**
Total emissions per farm	[kg SO_2-eq. a^{-1}]	5,467	4,300	4,540	4,230
Total emissions per hectare	[kg SO_2-eq. ha^{-1} a^{-1}]	97.46	76.66	80.92	75.40
Mitigation costs	[€ kg^{-1} SO_2-eq.]		**0.70**	**2.78**	**2.77**
		PF1	**PF1 TH**	**PF1 TS**	**PF1 INJ**
Total emissions per farm	[kg SO_2-eq. a^{-1}]	10,012	8,778	9,031	8,698
Total emissions per hectare	[kg SO_2-eq. ha^{-1} a^{-1}]	186.1	163.2	167.9	161.7
Mitigation costs	[€ kg^{-1} SO_2-eq.]		**0.66**	**2.77**	**2.04**
		PF2	**PF2 TH**	**PF2 TS**	**PF2 INJ**
Total emissions per farm	[kg SO_2-eq. a^{-1}]	5,371	4,719	4,853	4,691
Total emissions per hectare	[kg SO_2-eq. ha^{-1} a^{-1}]	70.58	62.01	63.77	61.64
Mitigation costs	[€ kg^{-1} SO_2-eq.]		**1.10**	**3.45**	**5.99**

Table 29: Eutrophication emissions and mitigation costs for the implementation of the improved manure application techniques trailing hose (TH), trailing shoe (TS) and injection (INJ) of the dairy farms DF1 and DF3, the bull fattening farms BF1 and BF2 and the pig fattening farms PF1 and PF2.

		DF1	DF1 TH	DF1 TS	DF1 INJ
Total emissions per farm	[kg PO_4^{3-}-eq. a^{-1}]	1,168	862.1	924.7	841.5
Total emissions per hectare	[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]	17.56	12.96	13.90	12.65
Mitigation costs	€ kg^{-1} PO_4^{3-}-eq.]		**2.45**	**12.12**	**10.05**
		DF3	**DF3 TH**	**DF3 TS**	**DF3 INJ**
Total emissions per farm	[kg PO_4^{3-}-eq. a^{-1}]	1,327	956.8	1,033	932.5
Total emissions per hectare	[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]	17.60	12.69	13.69	12.37
Mitigation costs	€ kg^{-1} PO_4^{3-}-eq.]		**2.56**	**11.38**	**12.91**
		BF1	**BF1 TH**	**BF1 TS**	**BF1 INJ**
Total emissions per farm	[kg PO_4^{3-}-eq. a^{-1}]	779.3	590.7	629.4	579.8
Total emissions per hectare	[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]	11.93	9.05	9.64	8.88
Mitigation costs	€ kg^{-1} PO_4^{3-}-eq.]		**4.72**	**14.87**	**23.75**
		BF2	**BF2 TH**	**BF2 TS**	**BF2 INJ**
Total emissions per farm	[kg PO_4^{3-}-eq. a^{-1}]	980.9	763.8	808.3	750.0
Total emissions per hectare	[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]	17.48	13.62	14.41	13.37
Mitigation costs	€ kg^{-1} PO_4^{3-}-eq.]		**3.74**	**14.92**	**14.84**
		PF1	**PF1 TH**	**PF1 TS**	**PF1 INJ**
Total emissions per farm	[kg PO_4^{3-}-eq. a^{-1}]	1,762	1,532	1,579	1,517
Total emissions per hectare	[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]	32.75	28.48	29.35	28.19
Mitigation costs	€ kg^{-1} PO_4^{3-}-eq.]		**3.54**	**14.90**	**10.91**
		PF2	**PF2 TH**	**PF2 TS**	**PF2 INJ**
Total emissions per farm	[kg PO_4^{3-}-eq. a^{-1}]	947.0	825.8	850.7	819.7
Total emissions per hectare	[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]	12.44	10.85	11.18	10.77
Mitigation costs	€ kg^{-1} PO_4^{3-}-eq.]		**5.89**	**18.56**	**32.02**

4.6 Use of slow and controlled-release fertilisers and fertilisers with urease or nitrification inhibitors

From the different improved mineral fertilisers (slow and controlled-release fertilisers and fertilisers with urease or nitrification inhibitors) currently available on the market, the use of fertilisers with nitrification inhibitors (NI) was selected as a promising GHG mitigation measure for modelling. These types of specific fertilisers are already used in agriculture, and are more widely used in agricultural production than urease inhibitors. They are less expensive than slow and controlled-release fertilisers.

Usually, most of the fertiliser N applied to soils in the form of NH_4^+ or NH_4^+-producing compounds is oxidised quite rapidly to NO_3^- by nitrifying microorganisms. Specific nitrification inhibitors block the ammonium monooxygenase, which represents the key enzyme in nitrification (nitritation). This prevents the formation of nitrite and nitrous oxide during nitrification. With a lower production of nitrate as end product of nitrification, the potential for denitrification also decreases and subsequently the potential for N_2O emissions. The objective of using nitrification inhibitors is, therefore, to control leaching of nitrate by keeping nitrogen in the ammonia form for longer, to prevent denitrification of nitrate-N and N_2O emissions from nitrification and denitrification and thus to increase the efficiency of nitrogen applied by matching nutrient release with crop demand.

Since the nitrogen supply from fertilisers with nitrification inhibitors compared to common application schemes is better synchronised with the crop demand, at least one fertiliser application operation (depending on the application scheme) can be saved. Thus, for modelling the field operations within the different model farms, depending on the manure amounts available and applied, the following reductions in fertiliser application operations for the different crops were modelled compared to the standard model farms:

- Grassland: 1 instead of 2
- Grass-clover (rotational): no change
- Maize (silage): no change
- Maize (grain maize): no change
- Maize (CCM): no change
- Wheat: 2 instead of 3
- Barley: 1 instead of 2
- Rye: 1 instead of 2
- Sugar beets: no change
- Potatoes: no change
- Rape seed: 1 instead of 2
- Rape seed (set-aside): 1 instead of 2

In general, the calculation of N_2O emissions in ModelFarm was based on the IPCC (1997, 2000) emission factor (1.25 % of the N is emitted as N_2O). This emission factor was reduced (to 0.6375 %) to reflect 51 % lower N_2O emissions after nitrification inhibitor addition based on measurements by Weiske et al., 2001. The direct effect of NI on nitrate leaching was not modelled as there is insufficient data on emission factors to do so.

The impact of the application of fertilisers with nitrification inhibitors for farm level GHG mitigation was modelled for the dairy model farm DF1, the bull fattening farm BF2 and both pig fattening model farms PF1 and PF2. These have the highest share of arable land of all model farms and hence a higher GHG mitigation potential.

4.6.1 GHG emissions and mitigation costs

Table 30 shows the GHG mitigation potential arising from the use of mineral fertilisers with nitrification inhibitor (DMPP) of the dairy farm DF1, the bull fattening farm BF2, and the pig fattening model farms PF1 and PF2. In total, GHG emissions were reduced by 1.5 % (DF1), 2.2 % (BF2), 0.6 % (PF1) and 4.3 % (PF2). The GHG reduction potential was directly correlated to the extent of mineral fertiliser use ($r^2 = 0.84$) depending on the available quality of manure as well as the livestock density of the respective farms. This is represented by a negative correlation coefficient of the GHG reduction potential to livestock density ($r^2 = 0.99$). Hence, the mitigation effect was caused on the one hand by the direct N_2O reduction from crop production (DF1 –11.7 %, BF2 –13.4 %, PF1 –5.3 %, PF2 –18.6 %) and on the other hand by reduced diesel use due to less mineral fertiliser applications (DF1 –0.6 %, BF2 –0.4 %, PF1 –0.6 %, PF2 –0.7 %). Irrespective of the GHG reduction potential, the mitigation costs are negative for DF1 and PF1 and very low for BF2 and PF2 (8-9 € t^{-1} CO_2-eq.).

The modelling results confirm that nitrification inhibitors are an option to reduce the GHG emissions from farms of this kind by a few percentage points. In addition, fewer mineral fertiliser application operations are required, especially during seasonal work peaks in summer, which saves time, use of fossil fuels and money. This measure may therefore also be positive for financial reasons (DF1, PF1) although the fertiliser is more expensive than conventional ones. If an increase in yields from different crops or the same yields with less fertiliser use is verified by further studies, the mitigation potential per unit of production may also be higher than presented here. Finally, this mitigation measure can easily be implemented in all farming systems in Europe and can potentially also be adapted for the use of urease inhibitors with an equivalent measure of efficiency. Thus, this measure has a high GHG reduction potential on a European scale.

Table 30: GHG emissions and mitigation costs for the use of mineral fertilisers with nitrification inhibitors of the dairy model farm DF1, the bull fattening farm BF2 and the pig fattening farms PF1 and PF2.

		DF1		BF2		PF1		PF2	
		SMF	NI	SMF	NI	SMF	NI	SMF	NI
Farm area	[ha]	**66.5**	**66.5**	**56.1**	**56.1**	**53.8**	**53.8**	**76.1**	**76.1**
Operating income	[€ ha^{-1}]	**-24**	**-23**	**-430**	**-432**	**705**	**707**	**447**	**444**
Resources plant production	[t CO_2-eq. a^{-1}]	52.5	53.0	57.3	58.1	35.7	36.0	102.3	104.0
Direct emissions plant production	[t CO_2-eq. a^{-1}]	122.7	113.2	125.8	114.1	132.3	127.3	180.0	155.2
Total emissions plant production	[t CO_2-eq. a^{-1}]	175.2	166.3	183.1	172.2	167.9	163.2	282.3	259.3
Resources livestock farming	[t CO_2-eq. a^{-1}]	80.5	80.5	95.5	95.5	450.2	450.2	154.8	154.8
Direct emissions livestock farming	[t CO_2-eq. a^{-1}]	335.6	335.6	226.7	226.7	197.3	197.3	105.3	105.3
Total emissions livestock farming	[t CO_2-eq. a^{-1}]	416.1	416.1	322.2	322.2	647.5	647.5	260.2	260.2
Total emissions per farm	[t CO_2-eq. a^{-1}]	591.3	582.4	505.3	494.3	815.5	810.8	542.5	519.4
Total emissions per hectare	[t CO_2-eq. ha^{-1} a^{-1}]	8.89	8.76	9.01	8.81	15.16	15.07	7.13	6.83
Mitigation costs	**[€ t^{-1} CO_2-eq.]**		**-4.78**		**9.22**		**-19.45**		**8.03**

4.6.2 Environmental side-effects

In general, nitrification inhibitors should have a specific and temporary bacteriostatic effect, and no bacteriocidal effect, on nitrifying microorganisms. However, depending on climatic conditions, some nitrification inhibitors like DCD are rapidly degraded by an adapted micro flora after only a few repeated applications (Rajbanshi et al., 1992). Apart from a specific blocking of nitritation they should not affect "non-target" organisms. Several inhibitors such as nitrapyrin and etridiazole that are commonly used in the USA, but are prohibited in Europe, may affect ammonium monooxygenase and also methane monooxygenase, because of the close relationship between both enzyme activities (Bronson & Mosier, 1994; Boeckx et al., 1998). The additional inhibition of the methane monooxygenase leads to a reduction in the methane oxidation capacity of soils (Bedard & Knowles, 1989). However, some nitrification inhibitors like nitrapyrin seem to have a bactericidal effect so that at least denitrification seems to be affected (Bedard & Knowles, 1989). However, negative side-effects have not been observed on crop production according to short-term studies by Cookson & Cornforth (2002).

In contrast to other GHG mitigation measures, the use of nitrification inhibitors has no influence on emissions with an effect on acidification and eutrophication. However, due to the fact that fewer fertiliser application operations are needed, this measure may also prevent soil compaction. A direct impact on biodiversity is not likely.

Final conclusions about the side-effects of nitrification inhibitors depend on the chemical substance used and need further field and laboratory experiments.

4.7 Increase of livestock grazing in comparison to more permanent housing

At present, scientists generally disagree about whether an extension or a restriction of grazing may lead to GHG emission reductions on the farm level in comparison to animal housing systems. This disagreement seems at least partly due to the fact that a judgement on the respective management systems is often based on the effect of only one greenhouse gas. A final assessment of the mitigation effect of the extension of grazing instead of animal housing is only possible if all direct and indirect GHG emissions and operations are modelled at the farm level.

There are several operational differences that have to be taken into account for modelling when considering an extension of grazing in place of livestock housing. If more grazing is implemented, fewer field operations, such as grass cutting, silage baling, transport and storage and manure applications as well as operations for the feed supply, will take place. In contrast, there are additional operations associated with the grazing system such as the daily cattle drive as well as the construction and maintenance of fences. Such operations cause minor GHG emission changes but increase abatement costs that must be considered in the calculation of the cost-efficiency of this technical measure.

With respect to GHG emissions, besides the different energy uses for land management and husbandry operations, farm emissions are strongly influenced by the different N fertilisation regimes chosen on arable land and by animal excreta on pastures. Here especially, the different NH_3 and N_2O emissions from both grazing and animal housing systems have to be considered for modelling at the farm level. On the one hand, pastures with unevenly distributed dung and urine patches as well as varying levels of soil compaction, significantly contribute to a spatial and temporal variability of N_2O fluxes from soils and can therefore be significant sources of N_2O emissions. On the other hand, several studies reported that NH_3 emissions per animal are lower for grazing animals than for those in housing where the excreta are collected, stored and applied to land. This is mainly caused by the fact that urine excreted during grazing often infiltrates into the soil before substantial NH_3 emissions can occur. In addition, animal housing systems cause high CH_4 emissions from the storage of manure whereas CH_4 emissions from patches can be neglected and thus were not considered during modelling.

The implementation of a summer half day grazing system (153 days from May to October) was modelled for the three dairy model farms DF1, DF2 and DF3 compared to the respective standard model farms. The different summer and winter feeding plans for dairy cows, calves, heifers and bulls for the summer grazing systems are presented for DF1 in Table A 18 and Table A 19, for DF2 in Table A 20 and Table A 21 and for DF3 in Table A 22 and Table A 23. Further details of the emission factors and costs of the different systems are discussed in chapter 3.7 of MEACAP report D10a. In addition, for each model farm a second reference model farm with a year-round animal housing system was modelled with an improved manure management (IMM) system involving a straw manure storage cover (see chapter 4.4) and the use of a trail hose manure application system (see chapter 4.5).

4.7.1 GHG emissions and mitigation costs

Table 31 shows the effect of the implementation of a summer half day grazing system (GR) on GHG emissions from both crop production and livestock farming. The model calculations resulted in considerably higher N_2O emissions in crop production of, on average, +22.2 %. Depending upon the size of the grassland area, NH_3 emissions from DF1 (27 % grassland) increased (+1.9 %) whereas the emissions from DF2 and DF3 with a 65 % grassland share of the farm area decreased (on average by –3 %). In addition, due to reduced N losses during animal housing, N_2O emissions were reduced by 14.3 % on average and NH_3 emissions by

13.8 % on average. N fertiliser use was also reduced by 14.6 % (DF1), 18.5 % (DF2) and 27.3 % (DF3). Since less manure had to be applied, diesel use also decreased by 16.3 % (DF1), 28.0 % (DF2) and 27.8 % (DF3). As a result of the diminished quantities of manure stored in animal housing pits and outside storage tanks, CH_4 emissions were also reduced by 7.2-7.5 %. In total, GHG emissions were reduced by 1.1 % (DF1), 4.0 % (DF2) and 2.9 % (DF3).

In Table 32 the effect of the implementation of a half day grazing system is compared with the standard model farms (SMF) and additionally with an animal housing system with an improved manure management (IMM) system. The model results show that for DF1 for which the GHG reduction effects of introducing grazing are least, the improved animal housing system resulted in a greater reduction in the GHG emissions from the farm (GR –1.1 %, IMM –1.5 %). This is in contrast to DF2 and DF3 with a higher share of grassland. For these model farms the implementation of a grazing system resulted in a higher GHG reduction potential (DF2 –4.0 %, DF3 –2.9 %) than for an improved manure management system (DF2 and DF3 –1.8 %). The IMM system caused higher costs so that the mitigation costs range between 96 and 100 € t^{-1} CO_2-eq. whereas the implementation of the grazing system reduced costs through less diesel and fertiliser use which produced negative GHG mitigation costs (Table 32).

Table 31: GHG emissions reduction potential of plant production and livestock farming for the implementation of a summer half day grazing system (GR) of the dairy farms DF1, DF2 and DF3.

	DF1 GR	DF2 GR	DF3 GR
Plant production			
CH_4 emissions	±0 %	±0 %	±0 %
N_2O emissions	+23.5 %	+20.8 %	+22.4 %
NH_3 emissions	+1.9 %	–2.6 %	–3.3 %
Diesel use	–16.3 %	–28.0 %	–27.8 %
N fertiliser use	–14.6 %	–18.5 %	–27.3 %
Livestock farming			
CH_4 emissions	–7.2 %	–7.3 %	–7.5 %
N_2O emissions	–13.8 %	–13.9 %	–15.1 %
NH_3 emissions	–13.9 %	–13.3 %	–14.2 %
Farm greenhouse gas emissions	**–1.1 %**	**–4.0 %**	**–2.9 %**

Table 32: GHG emissions and mitigation costs for the implementation of a summer half day grazing system (GR) of the dairy farms DF1, DF2 and DF3 in comparison to standard model farms (SMF) and reference systems with an improved manure management (IMM; manure storage with straw cover, manure application by trail hose).

		DF1			DF2			DF3		
		SMF	GR	IMM	SMF	GR	IMM	SMF	GR	IMM
Farm area	[ha]	**66.5**	**66.5**	**66.5**	**68.4**	**68.4**	**68.4**	**75.4**	**75.4**	**75.4**
Operating income	[€ ha^{-1}]	**-24**	**-8**	**-37**	**-229**	**-154**	**-243**	**22**	**112**	**8**
Resources plant production	[t CO_2-eq. a^{-1}]	52.5	46.5	46.8	56.1	45.9	50.2	57.2	44.2	50.5
Direct emissions plant production	[t CO_2-eq. a^{-1}]	122.7	147.2	119.9	115.9	135.4	112.5	132.9	156.9	129.4
Total emissions plant production	[t CO_2-eq. a^{-1}]	175.2	193.7	166.7	172.0	181.3	162.7	190.1	201.2	179.9
Resources livestock farming	[t CO_2-eq. a^{-1}]	80.5	80.4	80.5	50.5	42.6	50.5	41.9	41.5	41.9
Direct emissions livestock farming	[t CO_2-eq. a^{-1}]	335.6	310.9	335.3	298.0	275.9	297.8	367.8	339.6	367.5
Total emissions livestock farming	[t CO_2-eq. a^{-1}]	416.1	391.3	415.8	348.6	318.5	348.3	409.7	381.1	409.4
Total emissions per farm	[t CO_2-eq. a^{-1}]	591.3	585.0	582.5	520.5	499.8	511.0	599.9	582.2	589.3
Total emissions per hectare	[t CO_2-eq. ha^{-1} a^{-1}]	8.89	8.80	8.76	7.61	7.31	7.47	7.96	7.72	7.82
Mitigation costs per hectare	[€ t^{-1} CO_2-eq.]		**-176.4**	**96.6**		**-249.9**	**96.0**		**-387.6**	**100.4**

This is in contrast to calculations by Beeker et al. (2006) who confirmed that a system based on dairy cows with a milk yield of an average 9000 kg cow^{-1} a^{-1} can be achieved with a summer half day grazing system but with little difference in costs to those of an animal housing system. However in this study, the considerable reduction in costs caused by N efficiency effects that lead to reduced N fertiliser use and reduced manure application operations, do not appear to be taken into account.

In conclusion, the implementation of a half day grazing system represents a promising GHG mitigation option that also has the ability to reduce farm costs. This is also the case if the system is compared with an animal housing system with improved manure management because of the fact that mitigation measures with respect to manure handling are less efficient than expected at the farm level. For animal health and welfare reasons the implementation of more grazing can also be recommended.

4.7.2 Environmental side-effects

The influence of the implementation of a summer day-only grazing system in dairy farms DF1, DF2 and DF3 on emissions with an effect on acidification is presented in Table 33 and the effect on eutrophication in Table 34. For DF1 with a lower grassland share and thus a lower reduction of NH_3 emissions, both the acidification and eutrophication potential was reduced by 2.9 %. The acidification potential of both DF2 and DF3 decreased by 6.9 % and emissions with an effect on eutrophication were reduced by 6.8 and 7.0 % respectively. The mitigation costs of this measure were negative.

Impacts of different feed and grazing regimes on biodiversity depend on the fodder crop grown and the composition of grassland. The intensity of management is a key consideration. If this is not too high, pastures grazed by cattle have potential to increase biodiversity (flora and fauna), particularly compound to heavily fertilised pasture. This is in part caused by a more continuous, though heterogeneous nutrient application (dung and urine patches) instead of mechanical, homogeneous manure applications several times per year. Biodiversity may also be increased by selective muck and trampling of cattle. In addition, grass cutting operations have a disturbance effect which can influence the whole natural system (e.g. short-term effects such as killing of fauna). Furthermore, herbicide use is expected to be higher on cut grassland than on grazed pastures. With respect to soil compaction, pastures are more affected by treading and trampling but these are less frequent occurrences due to fewer tractor operations.

Table 33: Acidification emissions and mitigation costs for the implementation of a summer half day grazing system (GR) in comparison to standard model farms (SMF) of the dairy farms DF1, DF2 and DF3.

		DF1		DF2		DF3	
		SMF	GR	SMF	GR	SMF	GR
Farm area	[ha]	**66,5**	**66,5**	**68,4**	**68,4**	**75,4**	**75,4**
Resources plant production	[kg SO_2-eq. a^{-1}]	335,6	300,2	348,6	282,3	363,0	284,3
Direct emissions plant production	[kg SO_2-eq. a^{-1}]	3.927	4.001	3.986	3.880	4.739	4.583
Total emissions plant production	[kg SO_2-eq. a^{-1}]	4.263	4.301	4.334	4.163	5.102	4.868
Resources livestock farming	[kg SO_2-eq. a^{-1}]	500,1	499,9	303,5	250,2	344,9	331,7
Direct emissions livestock farming	[kg SO_2-eq. a^{-1}]	1.682	1.460	1.489	1.291	1.781	1.528
Total emissions livestock farming	[kg SO_2-eq. a^{-1}]	2.182	1.960	1.792	1.541	2.126	1.859
Total emissions per farm	[kg SO_2-eq. a^{-1}]	6.445	6.261	6.127	5.703	7.229	6.727
Total emissions per hectare	[kg SO_2-eq. ha^{-1} a^{-1}]	96,92	94,14	89,57	83,38	95,87	89,22
Mitigation costs	**[€ kg^{-1} SO_2-eq.]**		**-5,94**		**-12,20**		**-13,62**

Table 34: Eutrophication emissions and mitigation costs for the implementation of a summer half day grazing system (GR) in comparison to standard model farms (SMF) of the dairy farms DF1, DF2 and DF3.

		DF1		DF2		DF3	
		SMF	GR	SMF	GR	SMF	GR
Farm area	**[ha]**	**66,5**	**66,5**	**68,4**	**68,4**	**75,4**	**75,4**
Resources plant production	**[kg PO_4^{3-}-eq. a^{-1}]**	51,2	44,7	53,0	41,7	55,6	42,2
Direct emissions plant production	**[kg PO_4^{3-}-eq. a^{-1}]**	731,2	744,8	742,0	722,4	882,4	853,3
Total emissions plant production	**[kg PO_4^{3-}-eq. a^{-1}]**	782,4	789,5	795,0	764,1	938,0	895,5
Resources livestock farming	**[kg PO_4^{3-}-eq. a^{-1}]**	72,3	72,3	43,8	36,1	57,1	54,5
Direct emissions livestock farming	**[kg PO_4^{3-}-eq. a^{-1}]**	313,2	271,8	277,2	240,3	331,6	284,4
Total emissions livestock farming	**[kg PO_4^{3-}-eq. a^{-1}]**	385,6	344,1	321,0	276,4	388,7	338,9
Total emissions per farm	**[kg PO_4^{3-}-eq. a^{-1}]**	1.168	1.134	1.116	1.040	1.327	1.234
Total emissions per hectare	**[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]**	17,56	17,05	16,32	15,21	17,60	16,37
Mitigation costs	**[€ kg^{-1} PO_4^{3-}-eq.]**		**-32,03**		**-68,6**		**-74,08**

4.8 Anaerobic digestion

For biogas production, only manure can be used as an organic substrate in digestion plants or, where co-digestion occurs, a homogenous mixture of two or more substrates such as residues from animal feeding and crop production is used. This means that both energy plants and residues from the food industry can be digested simultaneously. The additional organic waste products or energy plants may be taken as substrates to increase methane yields and to ensure a consistent supply of organic substrates all year round. The biogas produced can be used to produce electricity, heat or vehicle fuel, which biogas plant operators may utilise and/or sell.

As such, the biogas production from animal manure, residues and on-farm produced or imported energy crops is a very promising option for generating renewable energy whilst simultaneously reducing GHG emissions both directly, through manure management, or by offsetting CO_2 emissions from fossil fuels.

The efficiency of biogas production as a GHG mitigation measure to reduce CO_2 emissions by the substitution of fossil fuels not only depends on the amount and quality of organic matter used for biogas production to generate electricity, but is also considerably dependent on how much of the thermal energy produced is exploited. A lot of farms are unable to use all the heat produced in this process such that different scenarios of heat use need to be considered.

Apart from the substitution of fossil fuels by the biogas produced on the farm, a central aspect of the evaluation of the implementation of biogas production is that anaerobic digestion of organic material significantly affects manure handling emissions (digested compared to non-digested manure) particularly during storage and after manure application.

For farms without biogas production, CH_4, N_2O and NH_3 emissions that originate from the slurry itself dominate the GHG emissions during manure storage. The hermetically sealed manure storage within the digester for biogas production has great potential to prevent all N_2O and NH_3 emissions and in particular to reduce CH_4 emissions significantly. Since, for the model scenarios with biogas production, the manure storage subsequent to the main digester is defined as being a closed post digester, most of the greenhouse gases typically emitted by an open storage system are eliminated.

To conserve the GHG mitigation benefits of anaerobic digestion for the whole production chain, an improved manure application technique is needed, otherwise much of the benefit of abatement during manure storage in the digesters may be lost. Thus, anaerobic digestion may also prevent N_2O and NH_3 emissions if an appropriate application technique is used. Therefore, for the biogas modelling scenarios manure application by trail hose is assumed (see chapter 4.5).

Primarily because of the increased amount of plant available N within the digestate (more NH_4^+-N), as well as the N savings and the increased amount of digestate from on-farm-produced and imported organic material, the application amounts of mineral fertiliser can be reduced. Thus, anaerobic digestion also has an effect via the substitution of mineral fertilisers and accordingly on the respective high GHG emissions from fertiliser production.

For biogas production as a technical and management-based mitigation option, different scenarios were calculated for the two dairy farms DF1 and DF3 and for the bull fattening farm BF2. Due to the fact that the standard model farms in the cluster analysis are too small to operate anaerobic digestion cost-efficiently, it was assumed that a group of these farms continue to operate one collective biogas plant. For a better comparison of the different model farms it was assumed in this case that all model farms have an area of 300 ha effectively an enlargement factor of 4-5.3.

To reflect different strategies for the implementation of biogas production, three main scenarios were modelled for each model farm (see also Figure 6 of MEACAP report D10a). In the first scenario, only the manure collected from the animal stores as well as additional energy plants (maize silage) grown on set-aside land were calculated as input material for the digestion process (scenario S). In a second scenario, the livestock density of the farms was reduced by 20 % to use the surplus cropland for additional substrate (maize silage) production (scenario SR). For the calculation of the third scenario (scenario SRI), an additional annual import of co-substrates (3900 t FM maize silage) was estimated considering that the digestate produced amounts do not exceed the Nitrates Directive (Dir. 91/676/EEC) limits of 170 kg N per hectare applicable to arable land and 210 kg N per hectare for grassland each year. The different substrate input amounts of the three scenarios are listed in Table 35.

Due to the fact that not all farms are able to use all the heat produced, for each scenario two sub-scenarios were calculated to show the efficiency level either on the one hand, where the thermal energy produced is only used to heat the digester (which depends on the input amounts, fermentation process etc.) and farm houses (which is equivalent to an average heat use of 4000 l fossil fuel a^{-1}) (scenario F), or on the other hand, if all the thermal energy produced is utilised on the farm and by external users (scenario T).

In addition, with respect to the choice of the combined heat and power unit (CHP), within a sensitivity analysis for all DF1 scenarios the use of a pilot injection gas engine CHP (scenario PI) and an Otto gas engine CHP (scenario OG) was modelled as a combustion engine. In contrast, according to the low biogas production amounts of scenarios 1 and 2 of model farms DF3 and BF2, a pilot injection gas engine CHP was used. For scenario 3 with higher biogas production, an Otto gas engine CHP was chosen as the typical CHP for the combustion of the produced biogases.

Furthermore, for the calculation of the cost-efficiency of biogas production consideration must be given to the fact that in different European countries operators of biogas plants may receive support in form of capital grants, low cost loans and tax incentives etc. Thus, as the cost-efficiency of biogas production is also substantially dependent on subsidies, the model was carried out on the model farm scenarios of DF1 for both cases: 1) without any subsidies to calculate the cost-efficiency of biogas production as a mitigation measure and 2) with subsidies according to German conditions to evaluate the cost-effectiveness of biogas production.

Table 35: Annual input material for the digestion process of the three biogas scenarios of the model farms DF1, DF3 and BF2 (S = digestion of manure and energy plants from set-aside land, SR = digestion of manure, energy plants from set-aside land and surplus cropland available due to reduction of livestock density, SRI = digestion of manure, energy plants from set-aside land and surplus cropland available due to reduction of livestock density and additional imported maize silage, PI = pilot injection gas engine CHP, OG = Otto gas engine CHP).

	Manure [t FM a^{-1}]	**Maize silage (on-farm production)** [t FM a^{-1}]	**Maize silage (farm imports)** [t FM a^{-1}]
DF1-S-PI/OG	10,466	405	—
DF1-SR-PI/OG	8,371	1,347	—
DF1-SRI-PI/OG	8,371	1,347	3,900
DF3-S-PI	9,894	265	—
DF3-SR-PI	7,915	1,232	—
DF3-SRI-OG	7,915	1,232	3,900
BF2-S-PI	10,027	320	—
BF2-SR-PI	8,022	1,618	—
BF2-SRI-OG	8,022	1,618	3,900

A scheme of biogas production scenarios and further details of methane production factors, emission factors, costs and estimated energy prices for electricity and heat are discussed in chapter 3.8 of MEACAP report D10a.

4.8.1 GHG emissions and mitigation costs

The results of the model calculations within this sensitivity analysis with respect to the implementation of biogas production in model farm DF1 for the case that the thermal energy produced is only used on the farm are presented in Table 36 and for the case that the total heat produced is used are presented in Table 37. These calculations were carried out with and without considering subsidies for biogas production. Further details of the biogas production characteristics and costs of these scenarios are documented in Table A 24 to Table A 27.

The modelling results without any subsidies of a farm-scale use of the thermal energy from the biogas plant show that for scenario S (digestion of manure and energy crops from set-aside land; CHP of 77-89 kW) the total farm emissions were reduced by an average 41 % and for scenario SR (digestion of manure, energy crops from set-aside land and surplus cropland available due to the reduction of livestock density; CHP of 109-125 kW) by an average 60 %. Both scenarios show only small differences between the use of a pilot injection engine CHP (PI) or Otto gas engine CHP (OG), whereas the mitigation costs for PI were higher (72-80 € t^{-1} CO_2-eq.) than for the OG biogas combustion (61-65 € t^{-1} CO_2-eq.). This is caused by higher annual investment and operating costs for the PI system compared to the OG CHP (Table A 24) and a little higher GHG reduction potential of the OG CHP compared to the PI CHP due to the use of fossil pilot fuel. For scenario SRI with an additional digestion of imported maize silage, the GHG mitigation potential increased by up to 73 % (PI) and 81 % (OG). These results confirm that biogas production of this order of magnitude (approximately 300 kW) is more efficient for the use in an Otto gas engine for CHP than for a pilot injection engine. In addition, the use of the OG CHP is more cost-efficient, such that the mitigation costs are clearly lower (122 € t^{-1} CO_2-eq.) than for the PI CHP (193 € t^{-1} CO_2-eq.), but considerably higher compared to the scenarios S and SR, particularly due to higher costs of the additional maize silage supply (maize silage production and transport costs). For the scenarios S and SR, GHG mitigation was caused by an average 78 % (S) and 74 % (SR) CH_4, N_2O and NH_3 emission reduction arising from manure handling and the substitution of mineral fertilisers. For scenario SR, GHG mitigation was also achieved by the reduction in livestock density whereas biogas production contributed only 22 % (S) and 26 % to the farm GHG reduction. This is in contrast to scenario SRI that showed an increase in the direct influence of biogas production on the mitigation potential and reduced GHG emissions via emission credits by 43 % (PI) and 48 % (OG).

For the case where the total heat produced was used on the farm or by adjacent users (Table 37), both the GHG mitigation potential and cost-efficiency of all scenarios increased as expected. The additional mitigation effect for scenarios S and SR was small as a large part of the heat produced was already used on the farm. Therefore, this also had only a minor influence on a reduction in the GHG mitigation costs. In contrast, for scenario SRI with a significantly higher biogas production (factor 3.4 to scenario S and 2.5 to scenario SR) and also higher thermal energy production (Table A 25), the GHG mitigation potential increased comparably by up to 94 % (PI) and 99 % (OG). This higher energy efficiency also changed the ratio of the mitigation effect originating from crop and animal production or directly caused by biogas production in the way that the biogas emission credits from fossil fuel substitution reduced farm GHG emissions by an average 57 %. Agricultural production only reduced GHG emission by 43 %. The additional income from heat use also resulted in a considerable decrease in mitigation costs (78 and 124 € t^{-1} CO_2-eq.).

In Table 36 and Table 37 the scenarios described above for model farm DF1 for farm-scale and total use of the produced thermal energy are also presented for the case where the electricity and heat is subsidised according to German feed-in tariff conditions. The basic data on biogas production and costs are shown in Table A 26 and Table A 27. The results confirm that, except for scenario SRI-PI-F, the subsidies for electricity and heat production cover the costs of the biogas production and may also bring the farmer an additional farm income in the case of the heat only being used on the farm (up to 17,000 € farm $^{-1}$ a^{-1}) and especially if the opportunity exists for the heat produced to be sold (up to 109,000 € farm $^{-1}$ a^{-1}). The model results also show that for scenarios S and SR the use of a pilot injection engine CHP system is more cost-efficient if all the heat can be used for the additional combustion of the pilot fuel needed for this CHP type. This technology also increased the quantity of heat production and accordingly the income from the sale of thermal energy.

In general, the sensitivity analysis shows that with regard to the GHG mitigation potential and mitigation costs Otto gas engine CHPs are in contrast to the common practice also recommendable for small-sized biogas plants. Moreover, the GHG mitigation potential of pilot injection gas engine CHPs can be improved if instead of fossil fuels as pilot fuel biofuels are used as this is, for instance, obligatory for PI CHPs in Germany as of 2007. But this will additionally increase the costs of biogas production.

The effects of the implementation of a biogas plant on GHG emissions and mitigation costs in the model farms DF3 and BF2 are presented in Table 38 and Table 39. Basic data on biogas production and the corresponding costs are documented in Table A 28 and Table A 29.

Table 36: GHG emissions and mitigation costs for the implementation of a biogas plant (BG) and a farm-scale use of produced heat (F) on dairy farm DF1 (S = digestion of manure and energy plants from set-aside land, SR = digestion of manure, energy plants from set-aside land and surplus cropland available due to a reduction in livestock density, SRI = digestion of manure, energy plants from set-aside land and surplus cropland available due to reduction of livestock density and additional imported maize silage, PI = pilot injection gas engine CHP, OG = Otto gas engine CHP).

		DF1 BG		S-PI-F	S-OG-F	SR-PI-F	SR-OG-F	SRI-PI-F	SRI-OG-F
Farm area	**[ha]**	**66,5**	**300**	**300**	**300**	**300**	**300**	**300**	**300**
Resources plant production	**[t CO_2-eq. a^{-1}]**	52	237	192	192	184	184	147	147
Direct emissions plant production	**[t CO_2-eq. a^{-1}]**	123	554	537	537	486	486	589	589
Total emissions plant production	**[t CO_2-eq. a^{-1}]**	175	790	729	729	670	670	736	736
Resources livestock farming	**[t CO_2-eq. a^{-1}]**	80	363	363	363	241	241	241	241
Direct emissions livestock farming	**[t CO_2-eq. a^{-1}]**	336	1.514	718	718	575	575	575	575
Total emissions livestock farming	**[t CO_2-eq. a^{-1}]**	416	1.877	1.081	1.081	815	815	815	815
Emissions construction and disposal of biogas plant	**[t CO_2-eq. a^{-1}]**	0	0	48	48	48	48	62	62
Emissions operation of biogas plant	**[t CO_2-eq. a^{-1}]**	0	0	240	133	292	147	1.006	617
Emission credits	**[t CO_2-eq. a^{-1}]**	0	0	-517	-451	-726	-630	-1.910	-1.717
Total emissions biogas production	**[t CO_2-eq. a^{-1}]**	0	0	-229	-270	-385	-435	-843	-1.038
Total emissions per farm	**[t CO_2-eq. a^{-1}]**	591	2.667	1.581	1.540	1.100	1.050	709	514
Total emissions per hectare	**[t CO_2-eq. ha^{-1} a^{-1}]**	8,89	8,89	5,27	5,13	3,67	3,50	2,36	1,71
Without subsidies									
Operating income	**[€ ha^{-1}]**	**-24**	**-24**	**-312**	**-269**	**-402**	**-354**	**-1.285**	**-901**
Mitigation costs	**[€ t^{-1} CO_2-eq.]**			**79,5**	**65,1**	**72,3**	**61,2**	**193,2**	**122,1**
With subsidies									
Operating income	**[€ ha^{-1}]**	**-24**	**-24**	**-16**	**-12**	**15**	**8**	**-253**	**33**
Mitigation costs	**[€ t^{-1} CO_2-eq.]**			**-2,1**	**-3,3**	**-7,5**	**-5,9**	**35,1**	**-7,9**

According to common practice, in the case of smaller CHPs plants, pilot injection engines are mainly used (up to 150-250 kW), whereas larger CHP units (from 150 kW upwards) are usually installed as Otto gas engine CHP systems. As the model results for DF1 also showed, there were no significant differences in the results of the PI or OG CHP use for the S and SR scenarios. However, a significant higher efficiency is achieved by OG use for the SRI scenario, for the model farms DF3 and BF2; the biogas scenarios S (77-78 kW) and SR (116-136 kW) were modelled to have a PI CHP whereas the SRI scenarios use an OG CHP (255-309 kW). In addition, the scenarios were only run on the assumption that no subsidies were paid.

The model results for the DF3 and BF2 scenarios are consistent with those of the DF1 scenario, showing only minor differences due to different manure and maize silage amounts used in the digestion process. The highest mitigation potential of –103 % was calculated for scenario DF3-SRI-OG-T meaning that the high emission reductions, and in particular emission credits, caused a net reduction of GHG emissions. The lowest mitigation costs of 38 € $t^{-1} CO_2$-eq. were calculated for scenario BF2-SR-PI-T. In general, the mitigation costs of the SR and SRI scenarios were lower for BF2 than for DF3 because of the fact that for BF2 more manure, and 30 % more on-farm produced maize silage, was digested.

Table 37: GHG emissions and mitigation costs for the implementation of a biogas plant (BG) and total use of produced heat (T) on dairy farm DF1 (S = digestion of manure and energy plants from set-aside land, SR = digestion of manure, energy plants from set-aside land and surplus cropland available due to reduction of livestock density, SRI = digestion of manure, energy plants from set-aside land and surplus cropland available due to a reduction in livestock density and additional imported maize silage, PI = pilot injection gas engine CHP, OG = Otto gas engine CHP).

		DF1 BG		S-PI-T	S-OG-T	SR-PI-T	SR-OG-T	SRI-PI-T	SRI-OG-T
Farm area	**[ha]**	**66,5**	**300**	**300**	**300**	**300**	**300**	**300**	**300**
Resources plant production	**[t CO_2-eq. a^{-1}]**	52	237	192	192	184	184	147	147
Direct emissions plant production	**[t CO_2-eq. a^{-1}]**	123	554	537	537	486	486	589	589
Total emissions plant production	**[t CO_2-eq. a^{-1}]**	175	790	729	729	670	670	736	736
Resources livestock farming	**[t CO_2-eq. a^{-1}]**	80	363	363	363	241	241	241	241
Direct emissions livestock farming	**[t CO_2-eq. a^{-1}]**	336	1.514	718	718	575	575	575	575
Total emissions livestock farming	**[t CO_2-eq. a^{-1}]**	416	1.877	1.081	1.081	815	815	815	815
Emissions construction and disposal of biogas plant	**[t CO_2-eq. a^{-1}]**	0	0	48	48	48	48	62	62
Emissions operation of biogas plant	**[t CO_2-eq. a^{-1}]**	0	0	240	133	292	147	1.006	617
Emission credits	**[t CO_2-eq. a^{-1}]**	0	0	-562	-481	-878	-763	-2.470	-2.206
Total emissions biogas production	**[t CO_2-eq. a^{-1}]**	0	0	-274	-300	-538	-568	-1.402	-1.527
Total emissions per farm	**[t CO_2-eq. a^{-1}]**	591	2.667	1.536	1.510	947	917	149	25
Total emissions per hectare	**[t CO_2-eq. ha^{-1} a^{-1}]**	8,89	8,89	5,12	5,03	3,16	3,06	0,50	0,08
Without subsidies									
Operating income	**[€ ha^{-1}]**	**-24**	**-24**	**-308**	**-271**	**-353**	**-313**	**-1.066**	**-711**
Mitigation costs	**[€ t^{-1} CO_2-eq.]**			**75,3**	**64,0**	**57,4**	**49,5**	**124,2**	**78,0**
With subsidies									
Operating income	**[€ ha^{-1}]**	**-24**	**-24**	**-5**	**-9**	**91**	**70**	**69**	**338**
Mitigation costs	**[€ t^{-1} CO_2-eq.]**			**-5,2**	**-3,9**	**-20,1**	**-16,1**	**-11,1**	**-41,1**

In total, biogas production represents a very efficient and cost-effective mitigation measure, simultaneously reducing emissions of several greenhouse gases from the whole production chain. Anaerobic digestion has the ability to reduce on-farm emissions (CH_4, N_2O, NH_3) whilst also substituting the use of fossil fuels. If co-substrates are purchased from outside the farm, the transportation distance and costs of the substrates have to be considered in estimating the cost-effectiveness of this measure. In addition, the extent of thermal energy use can be the determining factor for whether the operation of a biogas plant is cost-effective or not a particular site. Thus, during the site selection process for a biogas plant, potential uses of the produced heat must be considered. It is important to bear in mind that in order to be cost-effective, in most cases, biogas production will need to be subsidised through investment support and/or through guaranteed prices for the electricity or heat produced.

Table 38: GHG emissions and mitigation costs without subsidies for the implementation of a biogas plant (BG) and a farm-scale (F) or total use of produced heat (T) on dairy farm DF3 (S = digestion of manure and energy plants from set-aside land, SR = digestion of manure, energy plants from set-aside land and surplus cropland available due to reduction of livestock density, SRI = digestion of manure, energy plants from set-aside land and surplus cropland available due to a reduction in livestock density and additional imported maize silage, PI = pilot injection gas engine CHP, OG = Otto gas engine CHP).

		DF3 BG		S-PI-F	SR-PI-F	SRI-OG-F	S-PI-T	SR-PI-T	SRI-OG-T
Farm area	**[ha]**	**75.4**	**300**	**300**	**300**	**300**	**300**	**300**	**300**
Operating income	**[€ ha^{-1}]**	**22**	**22**	**-256**	**-354**	**-843**	**-243**	**-296**	**-642**
Resources plant production	**[t CO_2-eq. a^{-1}]**	57	228	193	218	147	193	218	147
Direct emissions plant production	**[t CO_2-eq. a^{-1}]**	133	529	515	511	563	515	511	563
Total emissions plant production	**[t CO_2-eq. a^{-1}]**	190	756	709	729	710	709	729	710
Resources livestock farming	**[t CO_2-eq. a^{-1}]**	42	167	167	131	131	167	131	131
Direct emissions livestock farming	**[t CO_2-eq. a^{-1}]**	368	1,464	708	566	566	708	566	566
Total emissions livestock farming	**[t CO_2-eq. a^{-1}]**	410	1,630	875	698	698	875	698	698
Emissions construction and disposal of biogas plant	**[t CO_2-eq. a^{-1}]**	0	0	48	48	52	48	48	52
Emissions operation of biogas plant	**[t CO_2-eq. a^{-1}]**	0	0	217	273	619	217	273	619
Emission credits	**[t CO_2-eq. a^{-1}]**	0	0	-452	-673	-1,668	-482	-813	-2,148
Total emissions biogas production	**[t CO_2-eq. a^{-1}]**	0	0	-187	-352	-998	-217	-491	-1,478
Total emissions per farm	**[t CO_2-eq. a^{-1}]**	600	2,387	1,396	1,075	410	1,367	935	-70
Total emissions per hectare	**[t CO_2-eq. ha^{-1} a^{-1}]**	7.96	7.96	4.65	3.58	1.37	4.56	3.12	-0.23
Mitigation costs	**[€ t^{-1} CO_2-eq.]**			**84.0**	**85.9**	**131.2**	**77.9**	**65.6**	**81.1**

4.8.2 Environmental side-effects

With respect to environmental side-effects, the influence of biogas production on the acidification potential of model farm DF1 with farm-scale use of thermal energy is shown in Table 40 and the effect on the eutrophication potential in Table 41. In general, biogas production, as well as having the potential to reduce GHG emissions, has considerable potential to reduce emissions that effect the farms' acidification and eutrophication potential. Both the acidification and eutrophication potential are mainly influenced by changes in NH_3 emissions. However, emissions caused by the additional use of pilot fuel in the pilot injection engine CHP in comparison to the Otto gas engine CHP (with no need of pilot fuel) may decrease these reduction effects. For scenario S, the acidification potential was reduced by an average 32 % and the eutrophication potential by 34 %. The decrease in livestock density (scenario SR) increased this reduction effect by 10 % so that the overall acidification potential was reduced by 42 % and the eutrophication potential by 44 %. The import of maize silage in scenario SRI considerably reduced this abatement of NH_3 emissions since the extra substrate amounts also increased the digestate amounts, resulting in higher NH_3 emissions after manure application. Here, the operations of the different CHP types result in greater differences in the mitigation potential due to the use of extensive pilot fuel amounts for the PI CHP. Hence, the acidification and eutrophication potential for the SRI scenario were reduced by 16 and 18 % respectively for the use of a PI type of CHP. In comparison, both decreased by 21 % for the

Table 39: GHG emissions and mitigation costs without subsidies for the implementation of a biogas plant (BG) and a farm-scale (F) or total use of produced heat (T) on dairy farm BF2 (S = digestion of manure and energy plants from set-aside land, SR = digestion of manure, energy plants from set-aside land and surplus cropland available due to reduction of livestock density, SRI = digestion of manure, energy plants from set-aside land and surplus cropland available due to a reduction in livestock density and additional imported maize silage, PI = pilot injection gas engine CHP, OG = Otto gas engine CHP).

		BF2 BG		S-PI-F	SR-PI-F	SRI-OG-F	S-PI-T	SR-PI-T	SRI-OG-T
Farm area	[ha]	**56.1**	**300**	**300**	**300**	**300**	**300**	**300**	**300**
Operating income	[€ ha^{-1}]	**-430**	**-430**	**-712**	**-709**	**-1,212**	**-699**	**-635**	**-998**
Resources plant production	[t CO_2-eq. a^{-1}]	57	306	287	299	232	287	299	232
Direct emissions plant production	[t CO_2-eq. a^{-1}]	126	673	674	658	723	674	658	723
Total emissions plant production	[t CO_2-eq. a^{-1}]	183	979	960	957	955	960	957	955
Resources livestock farming	[t CO_2-eq. a^{-1}]	95	511	511	347	347	511	347	347
Direct emissions livestock farming	[t CO_2-eq. a^{-1}]	227	1,212	478	382	382	478	382	382
Total emissions livestock farming	[t CO_2-eq. a^{-1}]	322	1,723	988	729	729	988	729	729
Emissions construction and disposal of biogas plant	[t CO_2-eq. a^{-1}]	0	0	48	48	53	48	48	53
Emissions operation of biogas plant	[t CO_2-eq. a^{-1}]	0	0	218	313	640	218	313	640
Emission credits	[t CO_2-eq. a^{-1}]	0	0	-458	-786	-1,770	-487	-964	-2,284
Total emissions biogas production	[t CO_2-eq. a^{-1}]	0	0	-192	-425	-1,077	-221	-603	-1,591
Total emissions per farm	[t CO_2-eq. a^{-1}]	505	2,702	1,757	1,262	607	1,727	1,083	93
Total emissions per hectare	[t CO_2-eq. ha^{-1} a^{-1}]	9.01	9.01	5.86	4.21	2.02	5.76	3.61	0.31
Mitigation costs	**[€ t^{-1} CO_2-eq.]**			**89.2**	**58.1**	**112.0**	**82.8**	**37.9**	**65.2**

OG type of CHP. The acidification and eutrophication mitigation costs (without subsidies) were low for the S and SR scenarios (8-10 € kg^{-1} SO_2-eq., 39-50 € kg^{-1} PO_4^{3-}-eq.) but considerably higher for the SRI scenario (44-79 € kg^{-1} SO_2-eq., 233-389 € kg^{-1} PO_4^{3-}-eq.). Except for scenario SRI-PI-F, the mitigation costs for the operator were negative if subsidies were paid.

The scenarios for DF1 for the case that total thermal energy produced can be exploited are presented in Table 42 and Table 43. The results show similar emission reduction trends between the different scenarios S, SR and SRI with slightly higher mitigation effects, especially on the acidification potential and in particular for the SRI scenario which showed an approximately 3 % higher reduction potential.

The effect of the implementation of biogas production in model farms DF3 and BF2 on emissions that effect acidification and eutrophication are presented in the appendix (DF3: Table A 30, Table A 31; BF2: Table A 32, Table A 33). In general, the model farms DF3 and BF2 show a high potential to reduce emissions affecting acidification and eutrophication via biogas production, with similar reduction trends for the different scenarios S, SR and SRI to DF1. In comparison to DF1, and in line with the differences in the GHG mitigation potential of the model farms, the mitigation effect for DF3 was higher. This was due to lower digestate amounts being applied. In contrast, the abatement potential was lower for model farm BF2 because of the higher maize silage amounts used as co-substrate increasing NH_3 emissions significantly. This also had an effect on mitigation costs (Table A 30 - Table A 33).

Besides emissions which have an effect on global warming, acidification and eutrophication, anaerobic digestion may also reduce odour emissions during manure storage and after manure application. In addition, the digestion process can reduce the pathogen load and burden of weed seeds in manure spread on the land which may reduce herbicide use.

Although most of the biogas plants currently use maize silage, itself unhelpful in biodiversity terms (beside grass silage) as co-substrate, biogas production may also have a positive influence on biodiversity in future. On the one hand, new single crops (Jerusalem artichoke, cup plant etc.) or crop mixtures (maize together with sunflower) may be cultivated. On the other hand, new crop rotations may be established that integrate more catch crops and intercrops or special double cropping systems allowing two yields per year and the integration of crops such as vetch, peas, Sudan grass, oil radish, mustard or sweet sorghum. These adjustments of substrate production have the potential to increase arable crop diversity and so potentially benefit biodiversity but additionally to raise annual yields, to reduce soil erosion potential and to enhance the characteristic landscape.

Table 40: Acidification emissions and mitigation costs for the implementation of a biogas plant (BG) and a farm-scale use of produced heat (F) on dairy farm DF1 (S = digestion of manure and energy plants from set-aside land, SR = digestion of manure, energy plants from set-aside land and surplus cropland available due to a reduction in livestock density, SRI = digestion of manure, energy plants from set-aside land and surplus cropland available due to reduction of livestock density and additional imported maize silage, PI = pilot injection gas engine CHP, OG = Otto gas engine CHP).

		DF1 BG		S-PI-F	S-OG-F	SR-PI-F	SR-OG-F	SRI-PI-F	SRI-OG-F
Farm area	[ha]	**66.5**	**300**	**300**	**300**	**300**	**300**	**300**	**300**
Resources plant production	[kg SO_2-eq. a^{-1}]	335.6	1,514	1,351	1,351	1,332	1,332	1,159	1,159
Direct emissions plant production	[kg SO_2-eq. a^{-1}]	3,927	17,717	10,398	10,398	9,302	9,302	13,098	13,098
Total emissions plant production	[kg SO_2-eq. a^{-1}]	4,263	19,231	11,749	11,749	10,634	10,634	14,257	14,257
Resources livestock farming	[kg SO_2-eq. a^{-1}]	500.1	2,256	2,256	2,256	1,471	1,471	1,471	1,471
Direct emissions livestock farming	[kg SO_2-eq. a^{-1}]	1,682	7,590	5,503	5,503	4,403	4,403	4,403	4,403
Total emissions livestock farming	[kg SO_2-eq. a^{-1}]	2,182	9,846	7,759	7,759	5,874	5,874	5,874	5,874
Emissions construction and disposal of biogas plant	[kg SO_2-eq. a^{-1}]	0	0	388.4	388.4	387.0	387.0	253.2	253.2
Emissions operation of biogas plant	[kg SO_2-eq. a^{-1}]	0	0	960.9	533.3	1,247	667.6	6,768	5,259
Emission credits	[kg SO_2-eq. a^{-1}]	0	0	-773.2	-674.2	-1,085	-942.2	-2,855	-2,566
Total emissions biogas production	[kg SO_2-eq. a^{-1}]	0	0	576.0	247.6	549.1	112.4	4,166	2,946
Total emissions per farm	[kg SO_2-eq. a^{-1}]	6,445	29,077	20,084	19,756	17,058	16,621	24,298	23,077
Total emissions per hectare	[kg SO_2-eq. ha^{-1} a^{-1}]	96.9	96.9	66.9	65.9	56.9	55.4	81.0	76.9
Mitigation costs (without subsidies)	**[€ kg^{-1} SO_2-eq.]**			**9.6**	**7.9**	**9.4**	**7.9**	**79.2**	**43.8**
Mitigation costs (with subsidies)	**[€ kg^{-1} SO_2-eq.]**			**-0.3**	**-0.4**	**-1.0**	**-0.8**	**14.4**	**-2.9**

Table 41: Eutrophication emissions and mitigation costs for the implementation of a biogas plant (BG) and a farm-scale use of produced heat (F) on dairy farm DF1 (S = digestion of manure and energy plants from set-aside land, SR = digestion of manure, energy plants from set-aside land and surplus cropland available due to a reduction in livestock density, SRI = digestion of manure, energy plants from set-aside land and surplus cropland available due to reduction of livestock density and additional imported maize silage, PI = pilot injection gas engine CHP, OG = Otto gas engine CHP).

		DF1 BG		S-PI-F	S-OG-F	SR-PI-F	SR-OG-F	SRI-PI-F	SRI-OG-F
Farm area	[ha]	66.5	300	300	300	300	300	300	300
Resources plant production	[kg PO_4^{3-}-eq. a^{-1}]	51.2	231.1	206.6	206.6	200.9	200.9	181.0	181.0
Direct emissions plant production	[kg PO_4^{3-}-eq. a^{-1}]	731.2	3,298	1,936	1,936	1,732	1,732	2,438	2,438
Total emissions plant production	[kg PO_4^{3-}-eq. a^{-1}]	782.4	3,530	2,142	2,142	1,933	1,933	2,619	2,619
Resources livestock farming	[kg PO_4^{3-}-eq. a^{-1}]	72.3	326.3	326.3	326.3	212.6	212.6	212.6	212.6
Direct emissions livestock farming	[kg PO_4^{3-}-eq. a^{-1}]	313.2	1,413	1,024	1,024	819.7	819.7	819.7	819.7
Total emissions livestock farming	[kg PO_4^{3-}-eq. a^{-1}]	386	1,739	1,351	1,351	1,032	1,032	1,032	1,032
Emissions construction and disposal of biogas plant	[kg PO_4^{3-}-eq. a^{-1}]	0	0	12.9	12.9	12.7	12.7	17.5	17.5
Emissions operation of biogas plant	[kg PO_4^{3-}-eq. a^{-1}]	0	0	81.1	34.1	105	41.7	890.0	726.1
Emission credits	[kg PO_4^{3-}-eq. a^{-1}]	0	0	-64.5	-56.2	-91	-78.6	-238.8	-214.7
Total emissions biogas production	[kg PO_4^{3-}-eq. a^{-1}]	0	0	29.5	-9.1	27.3	-24.2	669	529
Total emissions per farm	[kg PO_4^{3-}-eq. a^{-1}]	1,168	5,269	3,523	3,484	2,992	2,941	4,321	4,181
Total emissions per hectare	[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]	17.6	17.6	11.7	11.6	10.0	9.8	14.4	13.9
Mitigation costs (without subsidies)	**[€ kg^{-1} PO_4^{3-}-eq.]**			**49.5**	**41.1**	**45.8**	**38.6**	**389.4**	**233.3**
Mitigation costs (with subsidies)	**[€ kg^{-1} PO_4^{3-}-eq.]**			**-1.3**	**-2.1**	**-5.1**	**-4.1**	**72.4**	**-15.7**

Table 42: Acidification emissions and mitigation costs for the implementation of a biogas plant (BG) and total use of produced heat (T) on dairy farm DF1 (S = digestion of manure and energy plants from set-aside land, SR = digestion of manure, energy plants from set-aside land and surplus cropland available due to reduction of livestock density, SRI = digestion of manure, energy plants from set-aside land and surplus cropland available due to a reduction in livestock density and additional imported maize silage, PI = pilot injection gas engine CHP, OG = Otto gas engine CHP).

		DF1 BG		S-PI-T	S-OG-T	SR-PI-T	SR-OG-T	SRI-PI-T	SRI-OG-T
Farm area	[ha]	66.5	300	300	300	300	300	300	300
Resources plant production	[kg SO_2-eq. a^{-1}]	335.6	1,514	1,351	1,351	1,332	1,332	1,159	1,159
Direct emissions plant production	[kg SO_2-eq. a^{-1}]	3,927	17,717	10,398	10,398	9,302	9,302	13,098	13,098
Total emissions plant production	[kg SO_2-eq. a^{-1}]	4,263	19,231	11,749	11,749	10,634	10,634	14,257	14,257
Resources livestock farming	[kg SO_2-eq. a^{-1}]	500.1	2,256	2,256	2,256	1,471	1,471	1,471	1,471
Direct emissions livestock farming	[kg SO_2-eq. a^{-1}]	1,682	7,590	5,503	5,503	4,403	4,403	4,403	4,403
Total emissions livestock farming	[kg SO_2-eq. a^{-1}]	2,182	9,846	7,759	7,759	5,874	5,874	5,874	5,874
Emissions construction and disposal of biogas plant	[kg SO_2-eq. a^{-1}]	0	0	388.4	388.4	387.0	387.0	253.2	253.2
Emissions operation of biogas plant	[kg SO_2-eq. a^{-1}]	0	0	960.9	533.3	1,247	667.6	6,768	5,259
Emission credits	[kg SO_2-eq. a^{-1}]	0	0	-844.7	-721.7	-1,326	-1,152.0	-3,736	-3,337
Total emissions biogas production	[kg SO_2-eq. a^{-1}]	0	0	504.6	200.1	308.4	-97.3	3,284	2,175
Total emissions per farm	[kg SO_2-eq. a^{-1}]	6,445	29,077	20,013	19,708	16,817	16,411	23,416	22,307
Total emissions per hectare	[kg SO_2-eq. ha^{-1} a^{-1}]	96.9	96.9	66.7	65.7	56.1	54.7	78.1	74.4
Mitigation costs (without subsidies)	**[€ kg^{-1} SO_2-eq.]**			**9.4**	**7.9**	**8.0**	**6.8**	**55.2**	**30.4**
Mitigation costs (with subsidies)	**[€ kg^{-1} SO_2-eq.]**			**-0.6**	**-0.5**	**-2.8**	**-2.2**	**-5.0**	**-16.0**

Table 43: Eutrophication emissions and mitigation costs for the implementation of a biogas plant (BG) and total use of produced heat (T) on dairy farm DF1 (S = digestion of manure and energy plants from set-aside land, SR = digestion of manure, energy plants from set-aside land and surplus cropland available due to reduction of livestock density, SRI = digestion of manure, energy plants from set-aside land and surplus cropland available due to a reduction in livestock density and additional imported maize silage, PI = pilot injection gas engine CHP, OG = Otto gas engine CHP).

		DF1 BG		S-PI-T	S-OG-T	SR-PI-T	SR-OG-T	SRI-PI-T	SRI-OG-T
Farm area	[ha]	**66.5**	**300**	**300**	**300**	**300**	**300**	**300**	**300**
Resources plant production	[kg PO_4^{3-}-eq. a^{-1}]	51.2	231.1	206.6	206.6	200.9	200.9	181.0	181.0
Direct emissions plant production	[kg PO_4^{3-}-eq. a^{-1}]	731.2	3,298	1,936	1,936	1,732	1,732	2,438	2,438
Total emissions plant production	[kg PO_4^{3-}-eq. a^{-1}]	782.4	3,530	2,142	2,142	1,933	1,933	2,619	2,619
Resources livestock farming	[kg PO_4^{3-}-eq. a^{-1}]	72.3	326.3	326.3	326.3	212.6	212.6	212.6	212.6
Direct emissions livestock farming	[kg PO_4^{3-}-eq. a^{-1}]	313.2	1,413	1,024	1,024	819.7	819.7	819.7	819.7
Total emissions livestock farming	[kg PO_4^{3-}-eq. a^{-1}]	386	1,739	1,351	1,351	1,032	1,032	1,032	1,032
Emissions construction and disposal of biogas plant	[kg PO_4^{3-}-eq. a^{-1}]	0	0	12.9	12.9	12.7	12.7	17.5	17.5
Emissions operation of biogas plant	[kg PO_4^{3-}-eq. a^{-1}]	0	0	81.1	34.1	105	41.7	890.0	726.1
Emission credits	[kg PO_4^{3-}-eq. a^{-1}]	0	0	-69.2	-59.3	-107	-92.5	-297.2	-265.6
Total emissions biogas production	[kg PO_4^{3-}-eq. a^{-1}]	0	0	24.8	-12.3	11.3	-38.0	610	478
Total emissions per farm	[kg PO_4^{3-}-eq. a^{-1}]	1,168	5,269	3,518	3,481	2,976	2,927	4,262	4,130
Total emissions per hectare	[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]	17.6	17.6	11.7	11.6	9.9	9.8	14.2	13.8
Mitigation costs (without subsidies)	**[€ kg^{-1} PO_4^{3-}-eq.]**			**48.6**	**41.4**	**43.0**	**37.0**	**310.6**	**180.9**
Mitigation costs (with subsidies)	**[€ kg^{-1} PO_4^{3-}-eq.]**			**-3.4**	**-2.5**	**-15.0**	**-12.0**	**-27.9**	**-95.4**

4.9 Organic farming

Although organic farming basically represents a different management system in comparison to the conventional production embodied in the standard model farms it can also be defined as a promising measure for the reduction of GHG emissions.

In the past, many studies have aimed at evaluating organic and conventional agricultural production systems in terms of the different nutrient and energy efficiency of animal and plant production, particularly with respect to the GHG emission potential (Cederberg & Mattsson, 2000; FAL, 2000; Olesen et al., 2006). However, a balanced overall assessment of the environmental impact of conventional and organic practical farms with regard to GHG emissions has been elusive as research results in this area tend to contradict each other. This is mainly caused by differing system boundaries adopted in the respective evaluation studies and by the fact that some studies have not considered all the relevant flows and cost differences arising on farms. A combined assessment of all the key issues of efficiency and sustainability is essential in order to determine the contribution of organic and conventional production systems to sustainable nutrient cycles and GHG emissions. Model calculations by ModelFarm aim to meet these conditions for a more comprehensive evaluation with respect to emission balances and additionally with regards to an integrated cost-benefit analysis.

In general, organic farming as an extensive agricultural system is characterised by low inputs of energy and agro-chemical technology, high labour input but also lower productivity per unit area. Conversely, intensive agricultural systems are characterised by high inputs of energy and agro-chemical technology, lower labour input but a high productivity per unit area. This qualitative comparison indicates that the evaluation of organic and conventional production systems will be sensitive to the choice of whether GHG emissions are calculated per unit area or per product unit. Thus, for the evaluation of organic farming as a promising mitigation measure, the GHG reduction potential was modelled on the one hand on an area basis (t CO_2-eq. ha^{-1}) and on the other hand per unit of energy in the products leaving the farm (t CO_2-eq. GJ^{-1} ME) in order to treat the different products of milk, meat and crop products (e.g. rape seed, wheat, spelt) in one uniform reference value.

For the evaluation of organic farming as GHG mitigation measure, the organic model farms were adjusted relative to the main characteristics of the standard model farms DF1 and DF3 and in relation to FADN data that were analysed by FAL referring to organic farms only (Appendix II of MEACAP report D10a). The model farm size and the share of the grassland and arable land area as well as the ratio of animal numbers were kept constant. In addition, crop rotations were adapted according to FADN data and the livestock density was reduced to meet the requirement of 100 % self-sufficient organic production, meaning that the stocking rate depends solely on the feed that can be produced on the farm. The organic farms were defined according to Council Regulations No 2091/91 and No 1804/1999, having a crop rotation with a higher than conventional share of catch crops and legumes as N fixing crops. Furthermore, the crop and milk yields were adapted according to FADN 2003 data.

The main characteristics of the adapted model farms with respect to organic plant and animal production are presented in Table 44. The new feeding plans for calves, heifers, cows and bulls are summarised in Table A 34 (DF1) and Table A 35 (DF3). In accordance with the changes as a result of the conversion to organic farming on the model farms, the production costs as well as the revenues of the agricultural products were also adapted. The changed production costs mainly concerned the costs of field operations and the corresponding labour costs due to the changed crop rotations and management system.

A discussion of recent studies comparing conventional and organic production systems with respect to GHG emissions as well as details of the calculation of cost changes are presented in chapter 3.9 of MEACAP report D10a.

Table 44: Main characteristics of the organic production systems (OF) adjusted relative to the model farms DF1 and DF3.

	DF1		DF3	
Total agricultural area [ha]	66.5		75.4	
Grassland [ha]	24.7		48.9	
Arable land [ha]	41.8		26.5	
Calves (0-6 months) [number]	11.9		12.0	
Heifers (6-27 months) [number]	29.6		33.1	
Dairy cows [number]	29.6		39.1	
Milk production [kg milk farm^{-1} a^{-1}]	181,359		255,822	
Milk production [kg milk cow^{-1} a^{-1}]	6,127		6,548	
Bulls [amount]	14.4		11.6	
Livestock density [LU ha^{-1}]	1.14		1.06	
Plant production	[ha]	[t DM]	[ha]	[t DM]
Grassland	24.7	175.4	48.9	283.4
Grass-clover (rotational)	10.4	73.8	5.3	36.0
Maize silage	5.2	53.6	5.3	56.7
Wheat [a)]	5.2	22.4	5.3	21.7
Barley [b)]	5.2	19.8	—	—
Rye [c)]	5.2	8.8	—	—
Spelt [d)]	5.2	16.6	5.3	17.0
Peas [e)]	5.2	15.6	5.3	15.9

[a)] Catch crop: DF1: pea + oil radish mix, DF3: vetch + oil radish mix
[b)] Catch crop: DF1: grass-clover
[c)] Catch crop: DF1: vetch + oil radish mix
[d)] Catch crop: DF1 and DF3: pea + oil radish mix
[e)] Catch crop: DF1: pea + oil radish mix, DF3: grass-clover

4.9.1 GHG emissions and mitigation costs

The effect of a full conversion of conventional dairy model farms to organic production on GHG emissions and the respective mitigation costs relative to the farm area are presented in Table 45. In total, GHG emissions per hectare of farmland were reduced by 47.5 % for DF1 and by 41.0 % for DF3. With respect to crop production, apart from emission reductions due to the fact that no mineral fertilisers and agro-chemicals and less diesel were used for organic production, biogenic GHG emissions were reduced by 43 % (DF1) and 45 % (DF3). This emission abatement was mainly caused by reductions in N_2O (DF1 –44 %, DF3 –46 %) and partly by reduced NH_3 emissions (DF1 –23 %, DF3 –25 %) due to the reduced N input amounts because of less manure (reduced livestock density) and no mineral fertiliser use.

With respect to livestock farming, apart from a significant reduction of GHG emissions arising from the fact that no feed was imported as organic farms were defined to be 100 %

self-sufficient and less diesel and electricity was used for a reduced number of livestock, biogenic GHG emissions were reduced by 40 % (DF1) and 35 % (DF3). This percentage reduction from livestock farming is lower than for crop production but the effective reduction of biogenic emission abatement (in CO_2 equivalents) is considerably higher (crop production: DF1 –53, DF3 –60 t CO_2-eq.; livestock production: DF1 –134, DF3 –129 t CO_2-eq.).

Considering all direct and indirect biogenic emissions and prechain emissions, greenhouse gases of crop production were reduced by 77.2 (DF1) and 88.5 t CO_2-eq. (DF3) whereas GHG emissions of livestock production were reduced by 203.8 (DF1) and 157.3 t CO_2-eq. (DF3). The higher reduction potential of DF1 compared to DF3 was mainly caused by a larger decrease of feed import emissions from soy extraction grist (DF1) than from rape seed extraction grist (DF3).

The higher revenues from products and lower expenses for feed imports etc. of organic farming led to an increase in farm income so that the mitigation costs are negative (DF1 –123 € $t^{-1}CO_2$-eq., DF3 –21 € $t^{-1}CO_2$-eq.). The higher income of DF1 was mainly caused by a reduction in feed imports and higher crop sales.

Due to the fact that the extensification insisted in organic production also resulted in considerably lower productivity, for a balanced evaluation on a product unit basis, the conventional and organic farming systems were also compared per unit of energy in the products sold by the farm (Table 46). The results show that on an energy basis the GHG mitigation effect decreased by –16.7 % (DF1) and –4.2 % (DF3). The mitigation costs were still negative but significantly lower than in relation to the farm area (DF1 –7.8 € $t^{-1}CO_2$-eq., DF3 –0.9 € $t^{-1}CO_2$-eq.).

These modelling results confirm that extensification of organic production could be an effective management-based mitigation measure to reduce GHG emissions per area and also per product unit. However, extensification implies a reduction in productivity depending on the assumptions made, and therefore a general extensification of European agricultural land would reduce agricultural production, thus increasing the import of foods from non-European countries.

Table 45: GHG emissions and mitigation costs for the change in the agricultural management system into organic production (OF) for the standard model farms (SMF) DF1 and DF3 relative to farm area.

		DF1		DF3	
		SMF	OF	SMF	OF
Farm area	[ha]	**66.5**	**66.5**	**75.4**	**75.4**
Operating income	[€ ha^{-1}]	**-24**	**497**	**22**	**91**
Resources plant production	[t CO_2-eq. a^{-1}]	52.5	28.0	57.2	28.9
Direct emissions plant production	[t CO_2-eq. a^{-1}]	122.7	70.1	132.9	72.8
Total emissions plant production	[t CO_2-eq. a^{-1}]	175.2	98.0	190.1	101.6
Resources livestock farming	[t CO_2-eq. a^{-1}]	80.5	10.9	41.9	13.3
Direct emissions livestock farming	[t CO_2-eq. a^{-1}]	335.6	201.3	367.8	239.1
Total emissions livestock farming	[t CO_2-eq. a^{-1}]	416.1	212.3	409.7	252.4
Total emissions per farm	[t CO_2-eq. a^{-1}]	591.3	310.3	599.9	354.0
Total emissions per hectare	[t CO_2-eq. ha^{-1} a^{-1}]	8.89	4.67	7.96	4.69
Mitigation costs	[€ t^{-1} CO_2-eq.]		**-123.3**		**-21.2**

Table 46: GHG emissions and mitigation costs for the change in the agricultural management system into organic production (OF) for the standard model farms (SMF) DF1 and DF3 relative to energy units of the exported products.

		DF1		DF3	
		SMF	OF	SMF	OF
Farm area	[ha]	**66.5**	**66.5**	**75.4**	**75.4**
Operating income	[€ ha^{-1}]	**-24**	**497**	**22**	**91**
Total emissions produced GJ ME	[t CO_2-eq. GJ^{-1} ME]	0.1055	0.0879	0.0986	0.0945
Mitigation costs	[€ t^{-1} CO_2-eq.]		**-7.84**		**-0.92**

4.9.2 Environmental side-effects

The effects of a full conversion to organic production on emissions causing acidification and eutrophication are presented in Table 47 and Table 48, relative to farm area and to energy units of the farm output. If the effect of the emission reduction is calculated relative to the farm area, the acidification potential is reduced by an average 32 % and the eutrophication potential by 31 %. However, if the emissions with an effect on acidification and eutrophication are related to the farm's energy output, the influence on the acidification potential increased by 7 % (DF1) and 8 % (DF3) and, with respect to the eutrophication potential for both model farms, by 13 %. This means that the positive effects of the implementation of organic production on GHG mitigation were counteracted by the negative effects on acidification and eutrophication.

As well as the positive effects of not using pesticides on the GHG emission balance of the farms, this measure may also improve the quality of feed and foodstuffs. In addition, changing the crop rotations to include more catch crops may reduce the risk of soil erosion due to a more continuous plant cover.

In addition, the lack of pesticides together with a total extensification of agricultural production and a change in crop rotations with a higher share of different crops and a more continuous plant cover will probably increase the biodiversity potential of the farms.

Table 47: Acidification emissions and mitigation costs for the change in the agricultural management system into organic production (OF) for the standard model farms (SMF) DF1 and DF3 relative to farm area and to energy units of the farm products.

		DF1		DF3	
		SMF	OF	SMF	OF
Farm area	[ha]	**66.5**	**66.5**	**75.4**	**75.4**
Resources plant production	[kg SO_2-eq. a^{-1}]	335.6	309.7	363.0	301.5
Direct emissions plant production	[kg SO_2-eq. a^{-1}]	3,927	3,031	4,739	3,568
Total emissions plant production	[kg SO_2-eq. a^{-1}]	4,263	3,340	5,102	3,870
Resources livestock farming	[kg SO_2-eq. a^{-1}]	500.1	49.2	344.9	58.3
Direct emissions livestock farming	[kg SO_2-eq. a^{-1}]	1,682	938.9	1,781	1,101
Total emissions livestock farming	[kg SO_2-eq. a^{-1}]	2,182	988.1	2,126	1,159
Total emissions per farm	[kg SO_2-eq. a^{-1}]	6,445	4,328	7,229	5,029
Total emissions per hectare	[kg SO_2-eq. ha^{-1} a^{-1}]	96.92	65.09	95.87	66.69
Mitigation costs (hectare related)	[€ kg^{-1} SO_2-eq.]		**-16.4**		**-2.4**
Mitigation costs (energy related)	[€ kg^{-1} SO_2-eq.]		**—**		**—**

Table 48: Eutrophication emissions and mitigation costs for the change in the agricultural management system into organic production (OF) for the standard model farms (SMF) DF1 and DF3 relative to farm area and to energy units of the farm products.

		DF1		DF3	
		SMF	OF	SMF	OF
Farm area	**[ha]**	**66.5**	**300**	**300**	**300**
Resources plant production	**[kg PO_4^{3-}-eq. a^{-1}]**	51.2	49.4	55.6	47.4
Direct emissions plant production	**[kg PO_4^{3-}-eq. a^{-1}]**	731.2	564	882	664
Total emissions plant production	**[kg PO_4^{3-}-eq. a^{-1}]**	782.4	614	938	712
Resources livestock farming	**[kg PO_4^{3-}-eq. a^{-1}]**	72.3	7.0	57.1	8.2
Direct emissions livestock farming	**[kg PO_4^{3-}-eq. a^{-1}]**	313.2	175	332	205
Total emissions livestock farming	**[kg PO_4^{3-}-eq. a^{-1}]**	386	182	389	213
Total emissions per farm	**[kg PO_4^{3-}-eq. a^{-1}]**	1,168	795	1,327	925
Total emissions per hectare	**[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]**	17.6	12.0	17.6	12.3
Mitigation costs (hectare related)	**[€ kg^{-1} PO_4^{3-}-eq.]**		**-93.0**		**-13.0**
Mitigation costs (energy related)	**[€ kg^{-1} PO_4^{3-}-eq.]**		**—**		**—**

5 Summary

Nine targeted technical and management-based mitigation measures with a focus on manure handling were modelled for a set of dairy, bull fattening and pig fattening model farms with respect to their potential to reduce GHG emissions. These were modelled to take account of the upstream production chain as well as farm operations. In addition, a cost-benefit analysis was carried out for each of the modelled options to calculate the respective mitigation costs. The farms and cost assumptions were based on German conditions for the year 2004. The results of the model calculations are summarised in Figure 1. We can conclude that:

- Changing livestock feeding regimes to match the animals' nutrient requirements more precisely can make a respectable contribution to the mitigation of GHG from livestock farms. Phase feeding systems for fattening pigs appeared to have the most potential. Mitigation costs seemed to be negative because of the greater efficiency of nutrient use.
- The modelling of the straw- and slurry-based housing systems confirms that the value of an uncertain emission factor can determine whether a measure is assumed to increase or decrease the total farm GHG balance. If a methane conversion factor (MCF) of 39 % (IPCC, 2001) for emissions from manure storage was used, the farm GHG emissions were reduced when tied and straw-based systems were introduced whereas an emission factor of 10 % (IPCC, 1997) increased the GHG potential of these animal housing systems.
- The use of scraping systems together with frequent removal of manure from animal housing into a covered storage facility resulted in a considerable GHG reduction for pig fattening farms (even though high mitigation cost) whereas the mitigation effect for cattle farms was completely counterbalanced through losses within subsequent steps of manure management.
- The results for the introduction of various manure storage cover techniques were different in results for cattle manure with an already existing natural surface crust and for pig manure without a surface crust. For cattle farms the mitigation potential was negative or low but with high mitigation costs whereas for pig fattening farms a higher mitigation potential with negative or low mitigation costs was suggested by the model exercise.
- From all the manure application techniques that were modelled, the trailing hose system appeared to be the best choice in terms of GHG mitigation as it resulted in the highest mitigation potential to lowest mitigation costs whereas the higher energy use required by the trailing shoe system and more so injection compensated or partly exceeded the achieved emission reductions.
- The use of improved mineral fertilisers with nitrification inhibitors to increase the N efficiency in crop production represents a successful GHG mitigation measure reducing GHG emissions at a low or negative mitigation cost.
- Model calculations for the implementation of a half-day cattle grazing system in comparison to a completely house system show a considerable GHG mitigation potential. Less energy intensive operations associated with the grazing system also reduced farm production costs so that mitigation costs were negative.
- Biogas production introduced as a technical but also management-based measure influencing the entire production of the farm has by far the highest GHG mitigation potential of the mitigation measures modelled. The high GHG mitigation potential of biogas production derives on the one hand from the reduction of biogenic emissions due to a change in manure handling, and on the other hand from the generation of renewable energy that substitutes for fossil fuels and thus offsets CO_2 emissions arising from them.

However, the efficiency and also the extent of the mitigation costs mainly depend on the use of the heat produced.

- Organic farming as a management-based mitigation measure affecting the entire farming system reduced GHG emissions per hectare of farm land (t CO_2-eq. ha^{-1}) but also per unit of energy in products sold from the farm (t CO_2-eq. GJ^{-1} ME). On the assumptions used for dairy farms, lower input costs and higher product prices were expected to raise farm income compared to conventional production systems so that the mitigation costs for organic production as a mitigation option can be negative. The sustained cost-efficiency of organic production, however, depends on existent premiums under agri-environment programmes and the currently commercially available premia for products that originate from organic farming.

In conclusion, many mitigation measures feasible for a large part of European farming systems were identified, between them offering significant GHG mitigation potential. Most of them mainly affect the efficiency of one part of the nutrient cycle but the most efficient mitigation measures are those that simultaneously reduce emissions of several greenhouse gases from the whole production chain. Measures in this category are changes in livestock feeding strategies, organic farming and most of all investment in the tight circumstances in biogas production. If only one greenhouse gas is affected by a mitigation option in only one step of agricultural production system the mitigation effect can be counterbalanced by losses of other greenhouse gases or by losses in other steps in the production chain.

The mitigation potential of the mitigation measures on a European scale will be considered in a further MEACAP paper.

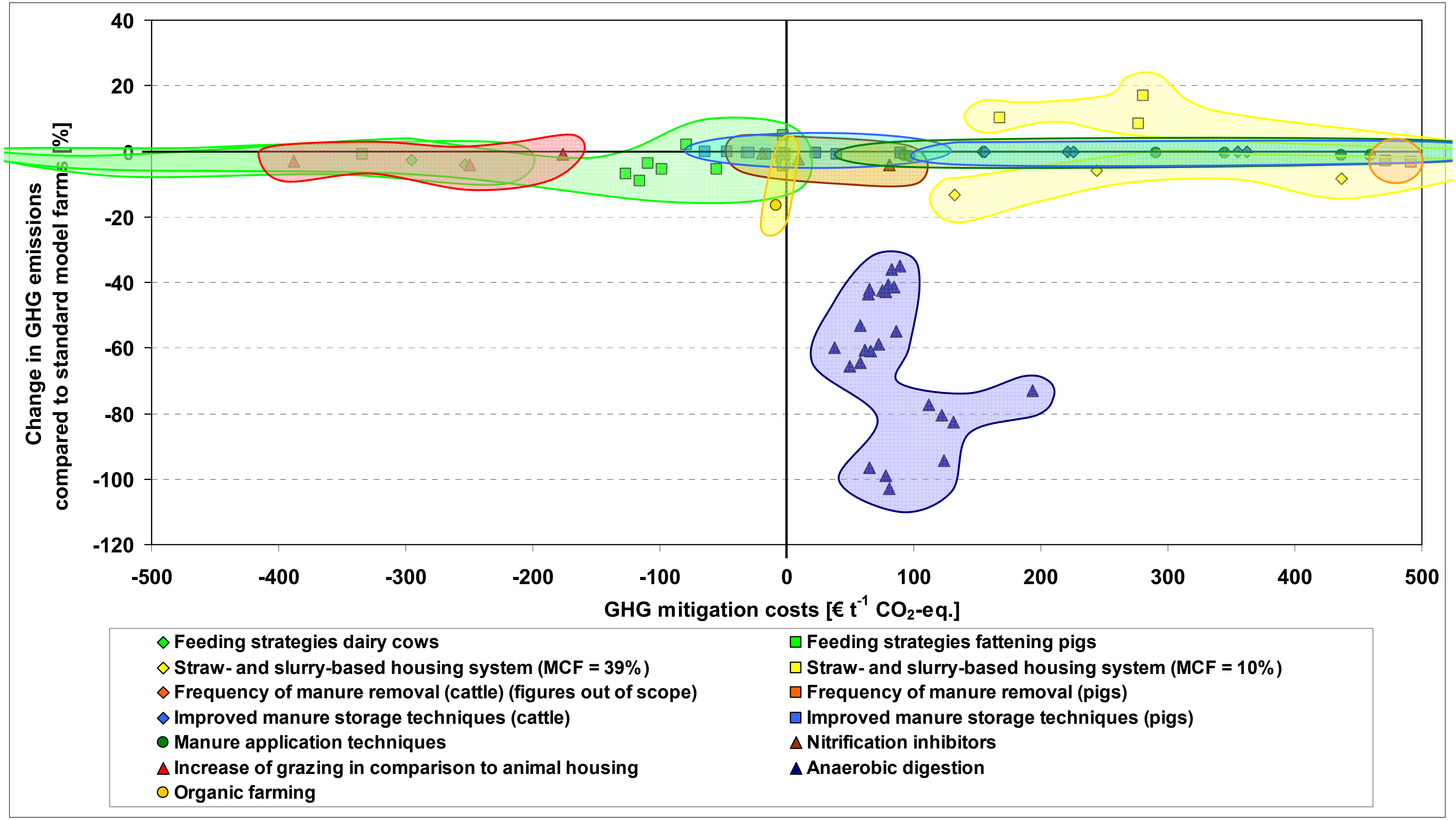

Figure 1: Percentage change of GHG emissions and the associated mitigation costs of nine technical and management-based mitigation measures.

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Appendix

Table A 1: Feeding plans of DF1 dairy cows, calves, heifers and bulls.

Feeding plan DF1 dairy cows

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
10,1	Grass silage	377	2,2	92	48,3	0,4	2,8	1,5	0,1	3808	22,1	929	487,4	3,8	28,2	14,9	1,1
5,6	Grass-clover silage	350	2,1	90	46,5	1,5	2,8	1,5	0,1	1960	11,8	504	260,7	8,4	15,5	8,2	0,6
15,3	Maize silage	350	2,4	59	48,3	-3,1	0,8	0,9	0,1	5355	37,3	910	739,0	-48,2	11,8	13,4	1,1
									Total roughage:	11123	71,1	2343	1487,1	-36,0	55,4	36,6	2,8
									Maintenance requirements:		37,7		450,0				
									Milk production from roughage:		10,5		12,1				

	Concentrate	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
3,5	Concentrate	870	7,5	39	196,8	11,3	1,5	4,6	0,2	3002	25,8	136	679,1	39,0	5,3	15,7	0,6
									Ration including concentrates:	14125	96,9	2479	2166,2	3,0	60,7	52,3	3,4
									Milk production including concentrates:		**18,7**		**20,0**				

	Concentrate composition per kg	Nutrients in 1kg								Nutrients per kg concentrate							
%	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
55	Wheat	870	7,4	25	147,9	-4,3	0,6	3,3	0,2	479	4,1	14	81,3	-2,4	0,3	1,8	0,1
45	Soy extraction grist	870	7,5	57	256,6	30,4	2,7	6,1	0,2	392	3,4	26	115,5	13,7	1,2	2,7	0,1
										870	7,5	39	196,8	11,3	1,5	4,6	0,2

Feeding plan DF1 calves

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
8,3	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	3129	29,7	764	488,0	3,1	23,2	12,2	0,9
									Total roughage:	3129	29,7	764	488,0	3,1	23,2	12,2	0,9
									Target value:		29,8		410,0				
									Deviation:		**-0,1**		**78,0**				

Feeding plan DF1 heifers

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
9,3	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	3506	33,3	855	547,0	3,5	25,9	13,7	1,1
6,0	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	2100	23,9	357	174,3	-18,9	4,6	5,3	0,4
									Total roughage:	5606	57,2	1212	721,3	-15,4	30,6	18,9	1,5
									Target value:		57,0		650,0				
									Deviation:		**0,2**		**71,3**				

Feeding plan DF1 bulls

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
3,5	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	1320	12,5	322	205,8	1,3	9,8	5,1	0,4
3,1	Clover-grass silage	350	3,6	90	72,1	1,5	2,8	1,5	0,1	1085	11,2	279	223,5	4,7	8,6	4,6	0,3
11,9	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	4165	47,5	708	345,7	-37,5	9,2	10,4	0,8
									Total roughage:	6570	71,2	1309	775,0	-31,5	27,5	20,1	1,6
									Target value:		77,2		997,0				
									Deviation:		-6,0		-222,1				

	Concentrate	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
0,5	Concentrate (100 % soy extraction grist)	870	12,0	57	446,3	30,4	2,7	6,1	0,2	435	6,0	28	223,2	15,2	1,3	3,0	0,1
									Ration including concentrates:	7005	77,2	1337	998,2	-16,3	28,8	23,2	1,6
									Deviation:		**0,0**		**1,2**				

Table A 2: Feeding plans of DF2 dairy cows, calves, heifers and bulls.

Feeding plan DF2 dairy cows

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
20,1	Grass silage	377	2,2	92	48,3	0,4	2,8	1,5	0,1	7578	44,0	1849	969,9	7,6	56,1	29,6	2,3
2,2	Grass-clover silage	350	2,1	90	46,5	1,5	2,8	1,5	0,1	770	4,6	198	102,4	3,3	6,1	3,2	0,2
11,9	Maize silage	350	2,4	59	48,3	-3,1	0,8	0,9	0,1	4165	29,0	708	574,8	-37,5	9,2	10,4	0,8
									Total roughage:	12513	77,6	2755	1647,1	-26,6	71,3	43,2	3,3

	NEL (MJ)	uCP
Maintenance requirements:	37,7	450,0
Milk production from roughage:	12,6	13,9

	Concentrate	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
1,7	Concentrate	870	7,4	57	207,8	17,1	2,2	5,3	0,3	1479	12,5	98	353,3	29,1	3,8	9,1	0,5
									Ration including concentrates:	13992	90,1	2853	2000,5	2,5	75,1	52,3	3,8

	NEL (MJ)	uCP
Milk production including concentrates:	**16,5**	**18,0**

	Concentrate composition per kg	Nutrients in 1kg								Nutrients per kg concentrate							
%	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
35	Wheat	870	7,4	25	147,9	-4,3	0,6	3,3	0,2	305	2,6	9	51,8	-1,5	0,2	1,2	0,1
65	Soy extraction grist	870	7,4	57	240,1	28,7	3,1	6,4	0,2	566	4,8	49	156,1	18,7	2,0	4,2	0,2
										870	7,4	57	207,8	17,1	2,2	5,3	0,3

Feeding plan DF2 calves

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
8,4	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	3167	30,1	773	494,0	3,2	23,4	12,4	1,0
									Total roughage:	3167	30,1	773	494,0	3,2	23,4	12,4	1,0

	ME (MJ)	uCP
Target value:	29,8	410,0
Deviation:	**0,3**	**84,0**

Feeding plan DF2 heifers

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
13,1	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	4939	46,9	1205	770,4	4,9	36,5	19,3	1,5
2,6	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	910	10,4	155	75,5	-8,2	2,0	2,3	0,2
									Total roughage:	5849	57,3	1360	846,0	-3,3	38,5	21,5	1,7

	ME (MJ)	uCP
Target value:	57,0	650,0
Deviation:	**0,2**	**196,0**

Feeding plan DF2 bulls

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
16,0	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	6032	57,3	1472	941,0	6,0	44,6	23,5	1,8
5,0	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	1750	20,0	298	145,3	-15,8	3,9	4,4	0,4
									Total roughage:	7782	77,3	1769	1086,2	-9,7	48,5	27,9	2,2

	ME (MJ)	uCP
Target value:	77,2	997,0
Deviation:	**0,1**	**89,2**

Table A 3: Feeding plans of DF3 dairy cows, calves, heifers and bulls.

Feeding plan DF3 dairy cows

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed			g	g	g	g	g	g			g	g	g	g	g	g
		DM (g)	NEL (MJ)	CF	uCP	RNB	Ca	P	Na	DM (g)	NEL (MJ)	CF	uCP	RNB	Ca	P	Na
13,8	Grass silage	377	2,2	92	48,3	0,4	2,8	1,5	0,1	5203	30,2	1269	665,9	5,2	38,5	20,3	1,6
1,7	Grass-clover silage	350	2,1	90	46,5	1,5	2,8	1,5	0,1	595	3,6	153	79,1	2,6	4,7	2,5	0,2
17,3	Maize silage	350	2,4	59	48,3	-3,1	0,8	0,9	0,1	6055	42,1	1029	835,6	-54,5	13,3	15,1	1,2
									Total roughage:	11853	75,9	2452	1580,7	-46,7	56,5	37,9	3,0

Maintenance requirements:	37,7	450,0
Milk production from roughage:	12,0	13,1

	Concentrate	Nutrients in 1kg								Nutrients in the ration							
kg	Feed			g	g	g	g	g	g			g	g	g	g	g	g
		DM (g)	NEL (MJ)	CF	uCP	RNB	Ca	P	Na	DM (g)	NEL (MJ)	CF	uCP	RNB	Ca	P	Na
3,7	Concentrate	882	6,7	92	199,1	16,2	4,7	8,7	0,1	3263	24,9	341	736,7	59,9	17,5	32,3	0,4
									Ration including concentrates:	15116	100,8	2793	2317,4	13,2	74,0	70,2	3,4

Milk production including concentrates:	**19,9**	**21,7**

%	Concentrate composition per kg Feed	Nutrients in 1kg								Nutrients per kg concentrate							
				g	g	g	g	g	g			g	g	g	g	g	g
		DM (g)	NEL (MJ)	CF	uCP	RNB	Ca	P	Na	DM (g)	NEL (MJ)	CF	uCP	RNB	Ca	P	Na
25	Wheat	870	7,4	25	147,9	-4,3	0,6	3,3	0,2	218	1,9	6	37,0	-1,1	0,2	0,8	0,0
75	Rape seed extraction grist	886	6,5	114	216,2	23,0	6,1	10,5	0,1	665	4,9	86	162,2	17,3	4,6	7,9	0,1
										882	6,7	92	199,1	16,2	4,7	8,7	0,1

Feeding plan DF3 calves

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed			g	g	g	g	g	g			g	g	g	g	g	g
		DM (g)	ME (MJ)	CF	uCP	RNB	Ca	P	Na	DM (g)	ME (MJ)	CF	uCP	RNB	Ca	P	Na
8,4	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	3167	30,1	773	494,0	3,2	23,4	12,4	1,0
									Total roughage:	3167	30,1	773	494,0	3,2	23,4	12,4	1,0

Target value:	29,8	410,0
Deviation:	**0,3**	**84,0**

Feeding plan DF3 heifers

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed			g	g	g	g	g	g			g	g	g	g	g	g
		DM (g)	ME (MJ)	CF	uCP	RNB	Ca	P	Na	DM (g)	ME (MJ)	CF	uCP	RNB	Ca	P	Na
14,2	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	5353	50,9	1306	835,1	5,4	39,6	20,9	1,6
1,7	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	595	6,8	101	49,4	-5,4	1,3	1,5	0,1
									Total roughage:	5948	57,7	1407	884,5	0,0	30,6	18,9	1,7

Target value:	57,0	650,0
Deviation:	**0,7**	**234,5**

Feeding plan DF3 bulls

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed			g	g	g	g	g	g			g	g	g	g	g	g
		DM (g)	NEL (MJ)	CF	uCP	RNB	Ca	P	Na	DM (g)	NEL (MJ)	CF	uCP	RNB	Ca	P	Na
13,0	Grass silage	377	2,2	92	58,8	0,4	2,8	1,5	0,1	4901	46,6	1196	764,6	4,9	36,3	19,1	1,5
6,6	Maize silage	350	2,4	60	29,1	-3,1	0,8	0,9	0,1	2310	26,3	393	191,7	-20,8	5,1	5,8	0,5
									Total roughage:	7211	72,9	1589	956,3	-15,9	41,3	24,9	1,9

	Concentrate	Nutrients in 1kg								Nutrients in the ration							
kg	Feed			g	g	g	g	g	g			g	g	g	g	g	g
		DM (g)	NEL (MJ)	CF	uCP	RNB	Ca	P	Na	DM (g)	NEL (MJ)	CF	uCP	RNB	Ca	P	Na
0,4	Concentrate	877	11,2	65	227,9	8,0	3,1	6,6	0,1	351	4,5	26	91,2	3,2	1,2	2,6	0,1
									Ration including concentrates:	7562	77,4	1615	1047,5	-12,7	42,6	27,5	2,0

Target value:	77,2	997,0
Deviation:	0,2	50,4

%	Concentrate composition per kg Feed	Nutrients in 1kg								Nutrients per kg concentrate							
				g	g	g	g	g	g			g	g	g	g	g	g
		DM (g)	NEL (MJ)	CF	uCP	RNB	Ca	P	Na	DM (g)	NEL (MJ)	CF	uCP	RNB	Ca	P	Na
55	Wheat	870	7,4	25	120,1	-4,3	0,6	3,3	0,2	479	6,4	14	66,0	-2,4	0,3	1,8	0,1
45	Rape seed extraction grist	886	10,7	114	359,7	23,0	6,1	10,5	0,1	399	4,8	51	161,9	10,4	2,8	4,7	0,0

Deviation:	**-72,6**	**-886**

Table A 4: Feeding plans of BF1 bulls, calves and heifers.

Feeding plan BF1 bulls

	Roughage	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
7,0	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	2639	25,1	644	411,7	2,6	19,5	10,3	0,8
0,7	Clover-grass silage	350	3,6	90	72,1	1,5	2,8	1,5	0,1	245	2,5	63	50,5	1,1	1,9	1,0	0,1
10,7	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	3745	42,7	637	310,8	-33,7	8,2	9,4	0,7
									Total roughage:	6629	70,3	1344	773,0	-30,0	29,7	20,7	1,6
									Target value:		77,2		997,0				
									Deviation:		-6,9		-224,0				

	Concentrate	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
0,6	Concentrate (100 % soy extraction grist)	870	12,0	57	446,3	30,4	2,7	6,1	0,2	522	7,2	34	267,8	18,3	1,6	3,7	0,1
									Ration including concentrates:	7151	77,5	1377	1040,8	-11,7	31,3	24,3	1,7
									Deviation:		**0,3**		**43,8**				

Feeding plan BF1 calves

	Roughage	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
8,4	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	3167	30,1	773	494,0	3,2	23,4	12,4	1,0
									Total roughage:	3167	30,1	773	494,0	3,2	23,4	12,4	1,0
									Target value:		29,8		410,0				
									Deviation:		**0,3**		**84,0**				

Feeding plan BF1 heifers

	Roughage	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
8,0	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	3016	28,7	736	470,5	3,0	22,3	11,8	0,9
0,9	Clover-grass silage	350	3,6	90	72,1	1,5	2,8	1,5	0,1	315	3,2	81	64,9	1,4	2,5	1,3	0,1
6,3	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	2205	25,1	375	183,0	-19,8	4,9	5,5	0,4
									Total roughage:	5536	57,0	1192	718,4	-15,5	29,7	18,6	1,4
									Target value:		57,0		650,0				
									Deviation:		**0,0**		**68,4**				

Table A 5: Feeding plans of BF2 bulls, calves and heifers.

Feeding plan BF2 bulls

kg	Roughage Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
1,2	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	452	4,3	110	70,6	0,5	3,3	1,8	0,1
0,3	Clover-grass silage	350	3,6	90	72,1	1,5	2,8	1,5	0,1	105	1,1	27	21,6	0,5	0,8	0,4	0,0
14,7	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	5145	58,7	875	427,0	-46,3	11,3	12,9	1,0
									Total roughage:	5702	64,1	1012	519,2	-45,4	15,5	15,1	1,2
									Target value:		77,2		997,0				
									Deviation:		-13,1		-477,8				

kg	Concentrate Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
1,1	Concentrate (100 % soy extraction grist)	870	12,0	57	446,3	30,4	2,7	6,1	0,2	957	13,2	62	490,9	33,5	3,0	6,7	0,2
									Ration including concentrates:	6659	77,2	1074	1010,2	-11,9	18,5	21,8	1,4
									Deviation:		**0,0**		**13,2**				

Feeding plan BF2 calves

kg	Roughage Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
6,1	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	2300	21,8	561	358,8	2,3	17,0	9,0	0,7
2,0	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	700	8,0	119	58,1	-6,3	1,5	1,8	0,1
									Total roughage:	3000	29,8	680	416,9	-4,0	18,6	10,7	0,8
									Target value:		29,8		410,0				
									Deviation:		**0,0**		**6,9**				

Feeding plan BF2 heifers

kg	Roughage Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
1,1	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	415	3,9	101	64,7	0,4	3,1	1,6	0,1
1,5	Clover-grass silage	350	3,6	90	72,1	1,5	2,8	1,5	0,1	525	5,4	135	108,1	2,3	4,1	2,2	0,2
10,8	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	3780	43,1	643	313,7	-34,0	8,3	9,5	0,8
									Total roughage:	4720	52,4	879	486,5	-31,3	15,5	13,3	1,0
									Target value:		57,0		650,0				
									Deviation:		-4,6		-163,5				

kg	Concentrate Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
0,4	Concentrate (100 % soy extraction grist)	870	12,0	57	446,3	30,4	2,7	6,1	0,2	348	4,8	23	178,5	12,2	1,1	2,4	0,1
									Ration including concentrates:	5068	57,2	901	665,1	-19,2	16,6	15,7	1,1
									Deviation:		**0,2**		**15,1**				

Table A 6: Feeding plans of PF1 piglets and fattening pigs (25-60 kg, 60-85 kg, 85-110 kg).

Feeding plan PF1 piglets

kg	Roughage Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
0,61	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	531	6,8	30	66,3	-3,2	0,4	2,2	0,5
0,42	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	365	4,9	11	50,4	-1,8	0,3	1,4	0,1
0,20	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	174	2,4	11	89,3	6,1	0,5	1,2	0,0
									Total roughage:	1070	14,1	52	206,0	1,1	1,2	4,8	0,6
									Target value:		14,1		206,0				
									Deviation:		**0,0**		**0,0**				

Feeding plan PF1 fattening pigs 25-60 kg

kg	Roughage Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
1,08	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	940	12,1	54	117,5	-5,6	0,7	3,9	0,8
0,61	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	531	7,1	15	73,3	-2,7	0,4	2,0	0,1
0,31	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	270	3,7	18	138,4	9,4	0,8	1,9	0,1
									Total roughage:	1740	22,9	86	329,0	1,1	1,9	7,8	1,0
									Target value:		22,9		329,0				
									Deviation:		**0,0**		**0,0**				

Feeding plan PF1 fattening pigs 60-85 kg

kg	Roughage Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
0,60	CCM	600	7,6	32	63,0	-5,4	0,5	1,8	0,1	360	4,6	19	37,8	-3,2	0,3	1,1	0,0
1,57	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	1366	17,5	78	170,7	-8,2	1,0	5,6	1,2
0,69	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	600	8,1	17	82,8	-3,0	0,4	2,3	0,1
0,25	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	218	3,0	14	111,6	7,6	0,7	1,5	0,1
									Total roughage:	2544	33,2	128	403,0	-6,8	2,3	10,5	1,4
									Target value:		33,2		402,9				
									Deviation:		**0,0**		**0,1**				

Feeding plan PF1 fattening pigs 85-110 kg

kg	Roughage Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
0,67	CCM	600	7,6	32	63,0	-5,4	0,5	1,8	0,1	402	5,1	21	42,2	-3,6	0,3	1,2	0,0
1,73	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	1505	19,3	86	188,1	-9,0	1,1	6,2	1,4
0,76	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	661	8,9	19	91,2	-3,3	0,5	2,5	0,1
0,27	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	235	3,2	15	120,5	8,2	0,7	1,6	0,0
									Total roughage:	2803	36,5	142	442,1	-7,7	2,6	11,5	1,6
									Target value:		36,5		443,9				
									Deviation:		**0,0**		**-1,8**				

Table A 7: Feeding plans of PF2 piglets and fattening pigs (25-60 kg, 60-85 kg, 85-110 kg).

Feeding plan PF2 piglets

	Roughage	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
0,61	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	531	6,8	30	66,3	-3,2	0,4	2,2	0,5
0,42	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	365	4,9	11	50,4	-1,8	0,3	1,4	0,1
0,20	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	174	2,4	11	89,3	6,1	0,5	1,2	0,0
									Total roughage:	1070	14,1	52	206,0	1,1	1,2	4,8	0,6
									Target value:		14,1		206,0				
									Deviation:		**0,0**		**0,0**				

Feeding plan PF2 fattening pigs 25-60 kg

	Roughage	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
1,08	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	940	12,1	54	117,5	-5,6	0,7	3,9	0,8
0,61	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	531	7,1	15	73,3	-2,7	0,4	2,0	0,1
0,31	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	270	3,7	18	138,4	9,4	0,8	1,9	0,1
									Total roughage:	1740	22,9	86	329,0	1,1	1,9	7,8	1,0
									Target value:		22,9		329,0				
									Deviation:		**0,0**		**0,0**				

Feeding plan PF2 fattening pigs 60-85 kg

	Roughage	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
0,39	CCM	600	7,6	32	63,0	-5,4	0,5	1,8	0,1	234	3,0	12	24,6	-2,1	0,2	0,7	0,0
1,10	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	957	12,3	55	119,6	-5,7	0,7	3,9	0,9
1,30	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	1131	15,2	33	156,1	-5,7	0,8	4,3	0,2
0,23	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	200	2,8	13	102,7	7,0	0,6	1,4	0,0
									Total roughage:	2522	33,2	113	402,9	-6,5	2,3	10,3	1,2
									Target value:		33,2		402,9				
									Deviation:		**0,0**		**0,0**				

Feeding plan PF2 fattening pigs 85-110 kg

	Roughage	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
0,43	CCM	600	7,6	32	63,0	-5,4	0,5	1,8	0,1	258	3,3	14	27,1	-2,3	0,2	0,8	0,0
1,21	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	1053	13,5	60	131,6	-6,3	0,7	4,3	0,9
1,43	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	1244	16,7	36	171,7	-6,2	0,9	4,7	0,2
0,25	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	218	3,0	14	111,6	7,6	0,7	1,5	0,0
									Total roughage:	2772	36,5	124	441,9	-7,2	2,5	11,3	1,3
									Target value:		36,5		443,9				
									Deviation:		**0,0**		**-2,0**				

Table A 8: Adapted feeding plans of DF1 dairy cows, calves, heifers and bulls for the feeding strategy with a 50 % use of rotational grassland for maize silage production.

Feeding plan DF1 dairy cows (50 % rotational grassland)

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
4,90	Grass silage	377	2,2	92	48,3	0,4	2,8	1,5	0,1	1847	10,7	451	236,5	1,8	13,7	7,2	0,6
3,55	Grass-clover silage	350	2,1	90	46,5	1,5	2,8	1,5	0,1	1243	7,5	319	165,3	5,3	9,8	5,2	0,4
20,75	Maize silage	350	2,4	59	48,3	-3,1	0,8	0,9	0,1	7263	50,5	1235	1002,2	-65,4	16,0	18,2	1,5
									Total roughage:	10352	68,7	2005	1403,9	-58,2	39,5	30,6	2,4
									Maintenance requirements:		37,7		450,0				
									Milk production from roughage:		9,8		11,1				

	Concentrate	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
3,8	Concentrate	870	7,4	32	171,8	3,3	1,1	3,9	0,2	3306	28,3	122	652,9	12,6	4,1	14,9	0,7
0,08	Feed urea	1000	0,0	0	0,0	460,0	0,0	0,0	0,0	80	0,0	0	0,0	36,8	0,0	0,0	0,0
									Ration including concentrates:	13738	97,0	2127	2056,8	-8,8	43,5	45,5	3,0
									Milk production including concentrates:		**18,7**		**18,7**				

%	Concentrate composition per kg Feed	Nutrients in 1kg								Nutrients per kg concentrate							
		DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
78	Wheat	870	7,4	25	147,9	-4,3	0,6	3,3	0,2	679	5,8	20	115,4	-3,4	0,5	2,6	0,2
22	Soy extraction grist	870	7,5	57	256,6	30,4	2,7	6,1	0,2	191	1,7	12	56,5	6,7	0,6	1,3	0,0
										870	7,4	32	171,8	3,3	1,1	3,9	0,2

Feeding plan DF1 calves (50 % rotational grassland)

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
8,3	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	3129	29,7	764	488,1	3,1	23,2	12,2	0,9
									Total roughage:	3129	29,7	764	488,1	3,1	23,2	12,2	0,9
									Target value:		29,8		410,0				
									Deviation:		**-0,1**		**78,1**				

Feeding plan DF1 heifers (50 % rotational grassland)

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
7,1	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	2677	25,4	653	417,6	2,7	19,8	10,4	0,8
8,0	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	2800	31,9	476	232,4	-25,2	6,2	7,0	0,6
									Total roughage:	5477	57,3	1129	650,0	-22,5	26,0	17,4	1,4
									Target value:		57,0		650,0				
									Deviation:		**0,3**		**0,0**				

Feeding plan DF1 bulls (50 % rotational grassland)

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
6,2	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	2322	22,1	567	362,3	2,3	17,2	9,1	0,7
11,9	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	4155	47,5	706	344,8	-37,4	9,1	10,4	0,8
									Total roughage:	6477	69,4	1273	707,1	-35,1	26,3	19,4	1,5
									Target value:		77,2		997,0				
									Deviation:		-7,8		-289,9				

	Concentrate	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
0,7	Concentrate (100 % soy extraction grist)	870	12,0	57	446,3	30,4	2,7	6,1	0,2	566	7,8	37	290,1	19,8	1,8	4,0	0,1
									Ration including concentrates:	7042	77,2	1310	997,2	-15,3	28,1	23,4	1,6
									Deviation:		**0,0**		**0,2**				

Table A 9: Adapted feeding plans of DF1 dairy cows, calves, heifers and bulls for the feeding strategy with a 100 % use of rotational grassland for maize silage production.

Feeding plan DF1 dairy cows (0 % rotational grassland)

	Roughage	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*	*DM (g)*	*NEL (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*NEL (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
4,9	Grass silage	377	2,2	92	48,3	0,4	2,8	1,5	0,1	1847	10,7	451	236,5	1,8	13,7	7,2	0,6
28,2	Maize silage	350	2,4	59	48,3	-3,1	0,8	0,9	0,1	9853	68,6	1675	1359,6	-88,7	21,7	24,6	2,0
									Total roughage:	11700	79,3	2126	1596,1	-86,8	35,3	31,8	2,5

	NEL (MJ)	uCP (g)
Maintenance requirements:	37,7	450,0
Milk production from roughage:	13,1	13,3

	Concentrate	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*	*DM (g)*	*NEL (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*NEL (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
2,4	Concentrate	870	7,5	39	196,8	11,3	1,5	4,6	0,2	2045	17,6	92	462,6	26,6	3,6	10,7	0,4
0,1	Feed urea	1000	0,0	0	0,0	460,0	0,0	0,0	0,0	100	0,0	0	0,0	46,0	0,0	0,0	0,0
									Ration including concentrates:	13844	96,8	2218	2058,7	-14,2	39,0	42,5	2,9

	NEL (MJ)	uCP (g)
Milk production including concentrates:	**18,7**	**18,7**

	Concentrate composition per kg	*Nutrients in 1kg*								*Nutrients per kg concentrate*							
%	*Feed*	*DM (g)*	*NEL (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*NEL (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
55	Wheat	870	7,4	25	147,9	-4,3	0,6	3,3	0,2	479	4,1	14	81,3	-2,4	0,3	1,8	0,1
45	Soy extraction grist	870	7,5	57	256,6	30,4	2,7	6,1	0,2	392	3,4	25	115,5	13,7	1,2	2,7	0,1
										870	7,5	39	196,8	11,3	1,5	4,6	0,2

Feeding plan DF1 calves (0 % rotational grassland)

	Roughage	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
8,3	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	3129	29,7	764	488,0	3,1	23,2	12,2	0,9
									Total roughage:	3129	29,7	764	488,0	3,1	23,2	12,2	0,9

	ME (MJ)	uCP (g)
Target value:	29,8	410,0
Deviation:	**-0,1**	**78,0**

Feeding plan DF1 heifers (0 % rotational grassland)

	Roughage	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
7,1	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	2677	25,4	653	417,6	2,7	19,8	10,4	0,8
8,0	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	2800	31,9	476	232,4	-25,2	6,2	7,0	0,6
									Total roughage:	5477	57,3	1129	650,0	-22,5	26,0	17,4	1,4

	ME (MJ)	uCP (g)
Target value:	57,0	650,0
Deviation:	**0,3**	**0,0**

Feeding plan DF1 bulls (0 % rotational grassland)

	Roughage	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
6,2	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	2322	22,1	567	362,3	2,3	17,2	9,1	0,7
11,9	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	4155	47,5	706	344,8	-37,4	9,1	10,4	0,8
									Total roughage:	6477	69,4	1273	707,1	-35,1	26,3	19,4	1,5

	ME (MJ)	uCP (g)
Target value:	77,2	997,0
Deviation:	-7,8	-289,9

	Concentrate	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
0,7	Concentrate (100 % soy extraction grist)	870	12,0	57	446,3	30,4	2,7	6,1	0,2	566	7,8	37	290,1	19,8	1,8	4,0	0,1
									Ration including concentrates:	7042	77,2	1310	997,2	-15,3	28,1	23,4	1,6

	ME (MJ)	uCP (g)
Deviation:	**0,0**	**0,2**

Table A 10: Adapted feeding plans of DF2 dairy cows, calves, heifers and bulls for feeding strategy.

Feeding plan DF2 dairy cows

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
9,3	Grass silage	377	2,2	92	48,3	0,4	2,8	1,5	0,1	3487	20,2	851	446,4	3,5	25,8	13,6	1,0
17,0	Maize silage	350	2,4	60	48,3	-3,1	0,8	0,9	0,1	5950	41,4	1012	821,1	-53,5	13,1	14,9	1,2
									Total roughage:	9437	61,6	1862	1267,5	-50,1	38,9	28,5	2,2

Maintenance requirements:	37,7	450,0
Milk production from roughage:	7,5	9,5

	Concentrate	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
3,8	Concentrate	870	7,4	30	157,1	-1,0	0,9	3,6	0,2	3323	28,3	115	600,2	-4,0	3,3	13,8	0,7
0,1	Feed urea	1000	0,0	0	0,0	460,0	0,0	0,0	0,0	100	0,0	0	0,0	46,0	0,0	0,0	0,0
									Ration including concentrates:	12861	90,0	1978	1867,7	-8,1	42,2	42,3	3,0

Milk production including concentrates:	**16,5**	**16,5**

	Concentrate composition per kg	Nutrients in 1kg								Nutrients per kg concentrate							
%	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
90	Wheat	870	7,4	25	147,9	-4,3	0,6	3,3	0,2	783	6,7	23	133,1	-3,9	0,5	3,0	0,2
10	Soy extraction grist	870	7,5	57	256,6	30,4	2,7	6,1	0,2	87	0,7	7	24,0	2,9	0,3	0,6	0,0
										870	7,4	30	157,1	-1,0	0,9	3,6	0,2

Feeding plan DF2 calves

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
8,4	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	3167	30,1	773	494,0	3,2	23,4	12,4	1,0
									Total roughage:	3167	30,1	773	494,0	3,2	23,4	12,4	1,0

Target value:	29,8	410,0
Deviation:	**0,3**	**84,0**

Feeding plan DF2 heifers

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
13,1	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	4939	46,9	1205	770,4	4,9	36,5	19,3	1,5
2,6	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	910	10,4	155	75,5	-8,2	2,0	2,3	0,2
									Total roughage:	5849	57,3	1360	846,0	-3,3	38,5	21,5	1,7

Target value:	57,0	650,0
Deviation:	**0,2**	**196,0**

Feeding plan DF2 bulls

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
16,0	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	6032	57,3	1472	941,0	6,0	44,6	23,5	1,8
5,0	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	1750	20,0	298	145,3	-15,8	3,9	4,4	0,4
									Total roughage:	7782	77,3	1769	1086,2	-9,7	48,5	27,9	2,2

Target value:	77,2	997,0
Deviation:	**0,1**	**89,2**

Table A 11: Adapted feeding plans of DF3 dairy cows, calves, heifers and bulls for feeding strategy.

Feeding plan DF3 dairy cows

Roughage		Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
5,85	Grass silage	377	2,2	92	48,3	0,4	2,8	1,5	0,1	2205	12,8	538	282,3	2,2	16,3	8,6	0,7
21,84	Maize silage	350	2,4	60	48,3	-3,2	0,8	0,9	0,1	7644	53,2	1299	1054,9	-68,8	16,8	19,1	1,5
									Total roughage:	9849	66,0	1838	1337,2	-66,6	33,1	27,7	2,2

	NEL (MJ)	uCP (g)
Maintenance requirements:	37,7	450,0
Milk production from roughage:	8,9	10,3

Concentrate		Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
4,9	Concentrate	875	7,1	53	169,1	4,1	2,3	5,5	0,1	4279	34,9	258	826,7	20,2	11,3	27,1	0,7
0,08	Feed urea	1000	0,0	0	0,0	460,0	0,0	0,0	0,0	100	0,0	0	0,0	46,0	0,0	0,0	0,0
									Ration including concentrates:	14208	100,9	2096	2163,9	-9,5	44,5	54,8	2,9

	NEL (MJ)	uCP (g)
Milk production including concentrates:	**19,9**	**19,9**

Concentrate composition per kg		Nutrients in 1kg								Nutrients per kg concentrate							
%	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
69	Wheat	870	7,4	25	147,9	-4,4	0,6	3,3	0,2	600	5,1	17	102,1	-3,0	0,4	2,3	0,1
31	Soy extraction grist	870	6,5	114	216,2	23,0	6,1	10,5	0,1	275	2,0	35	67,0	7,1	1,9	3,3	0,0
										875	7,1	53	169,1	4,1	2,3	5,5	0,1

Feeding plan DF3 calves

Roughage		Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
8,4	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	3167	30,1	773	494,0	3,2	23,4	12,4	1,0
									Total roughage:	3167	30,1	773	494,0	3,2	23,4	12,4	1,0

	ME (MJ)	uCP (g)
Target value:	29,8	410,0
Deviation:	**0,3**	**84,0**

Feeding plan DF3 heifers

Roughage		Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
14,2	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	5353	50,9	1306	835,1	5,4	39,6	20,9	1,6
1,7	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	595	6,8	101	49,4	-5,4	1,3	1,5	0,1
									Total roughage:	5948	57,7	1407	884,5	0,0	30,6	18,9	1,7

	ME (MJ)	uCP (g)
Target value:	57,0	650,0
Deviation:	**0,7**	**234,5**

Feeding plan DF3 bulls

Roughage		Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
13,0	Grass silage	377	2,2	92	58,8	0,4	2,8	1,5	0,1	4901	46,6	1196	764,6	4,9	36,3	19,1	1,5
6,6	Maize silage	350	2,4	60	29,1	-3,1	0,8	0,9	0,1	2310	26,3	393	191,7	-20,8	5,1	5,8	0,5
									Total roughage:	7211	72,9	1589	956,3	-15,9	41,3	24,9	1,9

Concentrate		Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
0,4	Concentrate	874	11,4	47	180,0	2,5	2,0	5,1	0,2	332	4,3	18	68,4	0,9	0,8	1,9	0,1
									Ration including concentrates:	7543	77,2	1607	1024,7	-15,0	42,6	26,8	2,0

	NEL (MJ)	uCP (g)
Target value:	77,2	997,0
Deviation:	0,0	50,4

Concentrate composition per kg		Nutrients in 1kg								Nutrients per kg concentrate							
%	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
75	Wheat	870	7,4	25	120,1	-4,3	0,6	3,3	0,2	653	8,8	19	90,0	-3,3	0,5	2,5	0,1
25	Rape seed extraction grist	886	10,7	114	359,7	23,0	6,1	10,5	0,1	221	2,7	29	89,9	5,8	1,5	2,6	0,0

	NEL (MJ)	uCP (g)
Deviation:	**-74,5**	**-935**

Table A 12: Feeding plans of PF1 piglets and fattening pigs (25-60 kg, 60-85 kg, 85-110 kg) for a 1-phase feeding (universal diet).

Feeding plan PF1 piglets

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	*Feed*			*g*	*g*	*g*	*g*	*g*	*g*			*g*	*g*	*g*	*g*	*g*	*g*
		DM (g)	*ME (MJ)*	*CF*	*uCP*	*RNB*	*Ca*	*P*	*Na*	*DM (g)*	*ME (MJ)*	*CF*	*uCP*	*RNB*	*Ca*	*P*	*Na*
0,61	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	531	6,8	30	66,3	-3,2	0,4	2,2	0,5
0,42	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	365	4,9	11	50,4	-1,8	0,3	1,4	0,1
0,20	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	174	2,4	11	89,3	6,1	0,5	1,2	0,0
									Total roughage:	1070	14,1	52	206,0	1,1	1,2	4,8	0,6
									Target value:		14,1		206,0				
									Deviation:		**0,0**		**0,0**				

Feeding plan PF1 fattening pigs 25-60 kg

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	*Feed*			*g*	*g*	*g*	*g*	*g*	*g*			*g*	*g*	*g*	*g*	*g*	*g*
		DM (g)	*ME (MJ)*	*CF*	*uCP*	*RNB*	*Ca*	*P*	*Na*	*DM (g)*	*ME (MJ)*	*CF*	*uCP*	*RNB*	*Ca*	*P*	*Na*
0,28	CCM	600	7,6	32	63,0	-5,4	0,5	1,8	0,1	168	2,1	9	117,6	-1,5	0,1	0,5	0,0
0,54	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	470	6,0	27	58,7	-2,8	0,3	3,3	0,2
0,99	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	861	11,6	25	118,9	-4,3	0,6	3,3	0,2
0,26	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	226	3,1	15	116,0	7,9	0,7	1,6	0,0
									Total roughage:	1726	22,8	75	311,3	-0,7	1,8	7,3	0,7
									Target value:		22,9		309,8				
									Deviation:		**0,0**		**1,5**				

Feeding plan PF1 fattening pigs 60-85 kg

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	*Feed*			*g*	*g*	*g*	*g*	*g*	*g*			*g*	*g*	*g*	*g*	*g*	*g*
		DM (g)	*ME (MJ)*	*CF*	*uCP*	*RNB*	*Ca*	*P*	*Na*	*DM (g)*	*ME (MJ)*	*CF*	*uCP*	*RNB*	*Ca*	*P*	*Na*
0,40	CCM	600	7,6	32	63,0	-5,4	0,5	1,8	0,1	240	3,1	13	25,2	-2,2	0,2	0,7	0,0
1,47	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	1279	16,4	73	159,9	-7,7	0,9	5,2	1,2
0,78	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	679	9,1	20	93,6	-3,4	0,5	2,6	0,1
0,38	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	331	4,6	21	169,6	11,6	1,0	2,3	0,1
									Total roughage:	2528	33,1	127	448,3	-1,7	2,6	10,9	1,4
									Target value:		33,1		448,8				
									Deviation:		**0,0**		**-0,5**				

Feeding plan PF1 fattening pigs 85-110 kg

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	*Feed*			*g*	*g*	*g*	*g*	*g*	*g*			*g*	*g*	*g*	*g*	*g*	*g*
		DM (g)	*ME (MJ)*	*CF*	*uCP*	*RNB*	*Ca*	*P*	*Na*	*DM (g)*	*ME (MJ)*	*CF*	*uCP*	*RNB*	*Ca*	*P*	*Na*
0,44	CCM	600	7,6	32	63,0	-5,4	0,5	1,8	0,1	264	3,4	14	27,7	-2,4	0,2	0,8	0,0
1,62	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	1409	18,1	80	176,2	-8,5	1,0	5,8	1,3
0,86	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	748	10,0	22	103,3	-3,7	0,5	2,8	0,1
0,42	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	365	5,0	24	187,5	12,8	1,1	2,6	0,1
									Total roughage:	2787	36,5	140	494,6	-1,8	2,9	12,0	1,5
									Target value:		36,5		494,6				
									Deviation:		**0,0**		**0,0**				

Table A 13: Feeding plans of PF1 piglets and fattening pigs (25-60 kg, 60-85 kg, 85-110 kg) for a 3-phase feeding.

Feeding plan PF1 piglets

kg	Roughage Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
0,61	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	531	6,8	30	66,3	-3,2	0,4	2,2	0,5
0,42	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	365	4,9	11	50,4	-1,8	0,3	1,4	0,1
0,20	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	174	2,4	11	89,3	6,1	0,5	1,2	0,0
									Total roughage:	1070	14,1	52	206,0	1,1	1,2	4,8	0,6
									Target value:		14,1		206,0				
									Deviation:		**0,0**		**0,0**				

Feeding plan PF1 fattening pigs 25-60 kg

kg	Roughage Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
1,11	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	966	12,4	55	120,7	-5,8	0,7	4,0	0,9
0,60	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	522	7,0	15	72,0	-2,6	0,4	2,0	0,1
0,29	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	252	3,5	16	129,4	8,8	0,8	1,8	0,1
									Total roughage:	1740	22,9	87	322,2	0,4	1,8	7,7	1,0
									Target value:		22,9		322,1				
									Deviation:		**0,0**		**0,1**				

Feeding plan PF1 fattening pigs 60-85 kg

kg	Roughage Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
0,60	CCM	600	7,6	32	63,0	-5,4	0,5	1,8	0,1	360	4,6	19	37,8	-3,2	0,3	1,1	0,0
1,67	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	1453	18,7	83	181,6	-8,7	1,0	6,0	1,3
0,61	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	531	7,1	15	73,2	-2,7	0,4	2,0	0,1
0,23	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	200	2,8	13	102,7	7,0	0,6	1,4	0,0
									Total roughage:	2544	33,1	130	395,3	-7,6	2,3	10,5	1,5
									Target value:		33,1		395,3				
									Deviation:		**0,0**		**0,0**				

Feeding plan PF1 fattening pigs 85-110 kg

kg	Roughage Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
0,67	CCM	600	7,6	32	63,0	-5,4	0,5	1,8	0,1	402	5,1	21	42,2	-3,6	0,3	1,2	0,0
2,05	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	1783	22,9	102	222,9	-10,7	1,2	7,3	1,6
0,64	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	557	7,5	16	76,8	-2,8	0,4	2,1	0,1
0,09	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	78	1,1	5	40,2	2,7	0,2	0,5	0,0
									Total roughage:	2821	36,6	144	382,2	-14,4	2,2	11,2	1,8
									Target value:		36,5		382,2				
									Deviation:		**0,1**		**0,0**				

Table A 14: Feeding plans of PF1 piglets and fattening pigs (25-60 kg, 60-85 kg, 85-110 kg) for a 3-phase feeding with addition of amino acids.

Feeding plan PF1 piglets

kg	Roughage Feed	Nutrients in 1kg								Nutrients in the ration							
		DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
0,61	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	531	6,8	30	66,3	-3,2	0,4	2,2	0,5
0,42	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	365	4,9	11	50,4	-1,8	0,3	1,4	0,1
0,20	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	174	2,4	11	89,3	6,1	0,5	1,2	0,0
									Total roughage:	1070	14,1	52	206,0	1,1	1,2	4,8	0,6
									Target value:		14,1		206,0				
									Deviation:		**0,0**		**0,0**				

Feeding plan PF1 fattening pigs 25-60 kg

kg	Roughage Feed	Nutrients in 1kg								Nutrients in the ration							
		DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
1,32	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	1148	14,7	65	143,6	-6,9	0,8	4,7	1,0
0,51	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	444	6,0	13	61,2	-2,2	0,3	1,7	0,1
0,18	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	157	2,2	10	80,3	5,5	0,5	1,1	0,0
0,01	Amino acids	1000	0,0	0	0,0	0,0	0,0	0,0	0,0	10	0,0	0	0,0	0,0	0,0	0,0	0,0
									Total roughage:	1758	22,9	89	285,1	-3,6	1,6	7,5	1,2
									Target value:		22,9		285,1				
									Deviation:		**0,0**		**0,0**				

Feeding plan PF1 fattening pigs 60-85 kg

kg	Roughage Feed	Nutrients in 1kg								Nutrients in the ration							
		DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
0,30	CCM	600	7,6	32	63,0	-5,4	0,5	1,8	0,1	180	2,3	10	18,9	-1,6	0,1	0,5	0,0
2,07	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	1801	23,1	103	225,1	-10,8	1,3	7,4	1,6
0,58	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	505	6,8	15	69,6	-2,5	0,4	1,9	0,1
0,08	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	70	1,0	5	35,7	2,4	0,2	0,5	0,0
0,01	Amino acids	1000	0,0	0	0,0	0,0	0,0	0,0	0,0	10	0,0	0	0,0	0,0	0,0	0,0	0,0
									Total roughage:	2565	33,1	131	349,4	-12,5	2,0	10,3	1,8
									Target value:		33,1		349,4				
									Deviation:		**0,0**		**0,0**				

Feeding plan PF1 fattening pigs 85-110 kg

kg	Roughage Feed	Nutrients in 1kg								Nutrients in the ration							
		DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
0,90	CCM	600	7,6	32	63,0	-5,4	0,5	1,8	0,1	540	6,9	29	56,7	-4,9	0,4	1,6	0,1
2,66	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	2314	29,7	132	289,3	-13,9	1,6	9,5	2,1
0,01	Amino acids	1000	0,0	0	0,0	0,0	0,0	0,0	0,0	10	0,0	0	0,0	0,0	0,0	0,0	0,0
									Total roughage:	2854	36,6	161	346,0	-18,7	2,1	11,1	2,1
									Target value:		36,5		337,2				
									Deviation:		**0,1**		**8,8**				

Table A 15: Feeding plans of PF2 piglets and fattening pigs (25-60 kg, 60-85 kg, 85-110 kg) for a 1-phase feeding (universal diet).

Feeding plan PF2 piglets

	Roughage	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*			*g*	*g*	*g*	*g*	*g*	*g*			*g*	*g*	*g*	*g*	*g*	*g*
		DM (g)	*ME (MJ)*	*CF*	*uCP*	*RNB*	*Ca*	*P*	*Na*	*DM (g)*	*ME (MJ)*	*CF*	*uCP*	*RNB*	*Ca*	*P*	*Na*
0,61	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	531	6,8	30	66,3	-3,2	0,4	2,2	0,5
0,42	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	365	4,9	11	50,4	-1,8	0,3	1,4	0,1
0,20	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	174	2,4	11	89,3	6,1	0,5	1,2	0,0
									Total roughage:	1070	14,1	52	206,0	1,1	1,2	4,8	0,6
									Target value:		14,1		206,0				
									Deviation:		**0,0**		**0,0**				

Feeding plan PF2 fattening pigs 25-60 kg

	Roughage	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*			*g*	*g*	*g*	*g*	*g*	*g*			*g*	*g*	*g*	*g*	*g*	*g*
		DM (g)	*ME (MJ)*	*CF*	*uCP*	*RNB*	*Ca*	*P*	*Na*	*DM (g)*	*ME (MJ)*	*CF*	*uCP*	*RNB*	*Ca*	*P*	*Na*
0,18	CCM	600	7,6	32	63,0	-5,4	0,5	1,8	0,1	108	1,4	6	11,3	-1,0	0,1	0,3	0,0
0,94	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	818	10,5	47	102,2	-4,9	0,6	3,4	0,7
0,68	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	592	7,9	17	81,6	-3,0	0,4	2,2	0,1
0,26	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	226	3,1	15	116,0	7,9	0,7	1,6	0,1
									Total roughage:	1744	22,9	84	311,2	-0,9	1,8	7,5	0,9
									Target value:		22,9		309,8				
									Deviation:		**0,0**		**1,4**				

Feeding plan PF2 fattening pigs 60-85 kg

	Roughage	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*			*g*	*g*	*g*	*g*	*g*	*g*			*g*	*g*	*g*	*g*	*g*	*g*
		DM (g)	*ME (MJ)*	*CF*	*uCP*	*RNB*	*Ca*	*P*	*Na*	*DM (g)*	*ME (MJ)*	*CF*	*uCP*	*RNB*	*Ca*	*P*	*Na*
0,25	CCM	600	7,6	32	63,0	-5,4	0,5	1,8	0,1	150	1,9	8	15,8	-1,4	0,1	0,5	0,0
1,36	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	1183	15,2	67	147,9	-7,1	0,8	4,9	1,1
1,00	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	870	11,7	25	120,1	-4,3	0,6	3,3	0,2
0,37	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	322	4,4	21	165,1	11,3	1,0	2,3	0,1
									Total roughage:	2525	33,2	122	448,8	-1,5	2,6	10,9	1,3
									Target value:		33,2		448,8				
									Deviation:		**0,0**		**0,0**				

Feeding plan PF2 fattening pigs 85-110 kg

	Roughage	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*			*g*	*g*	*g*	*g*	*g*	*g*			*g*	*g*	*g*	*g*	*g*	*g*
		DM (g)	*ME (MJ)*	*CF*	*uCP*	*RNB*	*Ca*	*P*	*Na*	*DM (g)*	*ME (MJ)*	*CF*	*uCP*	*RNB*	*Ca*	*P*	*Na*
0,28	CCM	600	7,6	32	63,0	-5,4	0,5	1,8	0,1	168	2,1	9	17,6	-1,5	0,1	0,5	0,0
1,50	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	1305	16,8	74	163,1	-7,8	0,9	5,4	1,2
1,09	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	948	12,7	28	130,9	-4,7	0,7	3,6	0,2
0,41	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	357	4,9	23	183,0	12,5	1,1	2,5	0,1
									Total roughage:	2778	36,5	134	494,6	-1,6	2,8	12,0	1,5
									Target value:		36,5		494,6				
									Deviation:		**0,0**		**0,0**				

Table A 16: Feeding plans of PF2 piglets and fattening pigs (25-60 kg, 60-85 kg, 85-110 kg) for a 3-phase feeding.

Feeding plan PF2 piglets

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed			g	g	g	g	g	g			g	g	g	g	g	g
		DM (g)	ME (MJ)	CF	uCP	RNB	Ca	P	Na	DM (g)	ME (MJ)	CF	uCP	RNB	Ca	P	Na
0,61	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	531	6,8	30	66,3	-3,2	0,4	2,2	0,5
0,42	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	365	4,9	11	50,4	-1,8	0,3	1,4	0,1
0,20	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	174	2,4	11	89,3	6,1	0,5	1,2	0,0
									Total roughage:	1070	14,1	52	206,0	1,1	1,2	4,8	0,6
									Target value:		14,1		206,0				
									Deviation:		**0,0**		**0,0**				

Feeding plan PF2 fattening pigs 25-60 kg

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed			g	g	g	g	g	g			g	g	g	g	g	g
		DM (g)	ME (MJ)	CF	uCP	RNB	Ca	P	Na	DM (g)	ME (MJ)	CF	uCP	RNB	Ca	P	Na
1,11	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	966	12,4	55	120,7	-5,8	0,7	4,0	0,9
0,60	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	522	7,0	15	72,0	-2,6	0,4	2,0	0,1
0,29	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	252	3,5	16	129,4	8,8	0,8	1,8	0,1
									Total roughage:	1740	22,9	87	322,2	0,4	1,8	7,7	1,1
									Target value:		22,9		322,1				
									Deviation:		**0,0**		**0,1**				

Feeding plan PF2 fattening pigs 60-85 kg

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed			g	g	g	g	g	g			g	g	g	g	g	g
		DM (g)	ME (MJ)	CF	uCP	RNB	Ca	P	Na	DM (g)	ME (MJ)	CF	uCP	RNB	Ca	P	Na
0,39	CCM	600	7,6	32	63,0	-5,4	0,5	1,8	0,1	234	3,0	12	24,6	-2,1	0,2	0,7	0,0
1,31	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	1140	14,6	65	142,5	-6,8	0,8	4,7	1,0
1,12	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	974	13,1	28	134,5	-4,9	0,7	3,7	0,2
0,21	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	183	2,5	12	93,7	6,4	0,6	1,3	0,0
									Total roughage:	2531	33,2	117	395,2	-7,4	2,2	10,4	1,3
									Target value:		33,2		395,3				
									Deviation:		**0,0**		**0,0**				

Feeding plan PF2 fattening pigs 85-110 kg

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed			g	g	g	g	g	g			g	g	g	g	g	g
		DM (g)	ME (MJ)	CF	uCP	RNB	Ca	P	Na	DM (g)	ME (MJ)	CF	uCP	RNB	Ca	P	Na
0,43	CCM	600	7,6	32	63,0	-5,4	0,5	1,8	0,1	258	3,3	14	27,1	-2,3	0,2	0,8	0,0
1,52	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	1322	17,0	75	165,3	-7,9	0,9	5,4	1,2
1,32	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	1148	15,4	33	158,5	-5,7	0,8	4,4	0,2
0,07	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	61	0,8	4	31,2	2,1	0,2	0,4	0,1
									Total roughage:	2790	36,5	126	382,1	-13,9	2,1	11,0	1,5
									Target value:		36,5		382,2				
									Deviation:		**0,0**		**0,0**				

Table A 17: Feeding plans of PF2 piglets and fattening pigs (25-60 kg, 60-85 kg, 85-110 kg) for a 3-phase feeding with addition of amino acids.

Feeding plan PF2 piglets

kg	Roughage Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
0,61	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	531	6,8	30	66,3	-3,2	0,4	2,2	0,5
0,42	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	365	4,9	11	50,4	-1,8	0,3	1,4	0,1
0,20	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	174	2,4	11	89,3	6,1	0,5	1,2	0,0
									Total roughage:	1070	14,1	52	206,0	1,1	1,2	4,8	0,6
									Target value:		14,1		206,0				
									Deviation:		**0,0**		**0,0**				

Feeding plan PF2 fattening pigs 25-60 kg

kg	Roughage Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
1,32	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	1148	14,7	65	143,6	-6,9	0,8	4,7	1,0
0,51	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	444	6,0	13	72,0	-2,2	0,3	1,7	0,1
0,18	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	157	2,2	10	80,3	5,5	0,5	1,1	0,0
0,01	Amino acids	1000	0,0	0	0,0	0,0	0,0	0,0	0,0	10	0,0	0	0,0	0,0	0,0	0,0	0,0
									Total roughage:	1759	22,9	89	285,1	-3,6	1,6	7,5	1,2
									Target value:		22,9		285,1				
									Deviation:		**0,0**		**0,0**				

Feeding plan PF2 fattening pigs 60-85 kg

kg	Roughage Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
1,84	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	1601	20,6	91	200,1	-9,6	1,1	6,6	1,4
1,02	Wheat	870	11,7	25	120,1	-4,3	0,6	3,3	0,2	887	11,9	26	134,5	-4,4	0,6	3,4	0,2
0,06	Soy extraction grist	870	12,0	57	446,3	30,4	2,7	6,1	0,2	52	0,7	3	26,8	1,8	0,2	0,4	0,0
0,01	Amino acids	1000	0,0	0	0,0	0,0	0,0	0,0	0,0	10	0,0	0	0,0	0,0	0,0	0,0	0,0
									Total roughage:	2550	33,2	120	349,3	-12,2	1,9	10,3	1,6
									Target value:		33,2		349,4				
									Deviation:		**0,0**		**0,0**				

Feeding plan PF2 fattening pigs 85-110 kg

kg	Roughage Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
0,75	CCM	600	7,6	32	63,0	-5,4	0,5	1,8	0,1	450	5,7	24	47,3	-4,1	0,4	1,4	0,0
2,76	Barley	870	11,2	50	108,8	-5,2	0,6	3,6	0,8	2401	30,8	137	300,1	-14,4	1,7	9,8	2,2
0,01	Amino acids	1000	0,0	0	0,0	0,0	0,0	0,0	0,0	10	0,0	0	0,0	0,0	0,0	0,0	0,0
									Total roughage:	2861	36,6	161	347,4	-18,5	2,0	11,2	2,2
									Target value:		36,5		337,2				
									Deviation:		**0,0**		**0,0**				

Table A 18: Summer feeding plans of DF1 dairy cows, calves, heifers and bulls for the GHG mitigation measure 'grazing'.

Feeding plan DF1 dairy cows

	Roughage	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*	*DM (g)*	*NEL (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*NEL (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
35,3	Grass	200	1,2	55	26,0	0,4	1,5	0,8	0,1	7050	41,5	1953	916,5	14,1	52,2	27,5	2,1
12,1	Maize silage	350	2,4	60	48,3	-3,1	0,8	0,9	0,1	4235	29,5	720	584,4	-38,1	9,3	10,6	0,8
									Total roughage:	11285	71,0	2673	1500,9	-24,0	61,5	38,1	2,9

Maintenance requirements:	37,7	450,0
Milk production from roughage:	10,5	12,2

	Concentrate	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*	*DM (g)*	*NEL (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*NEL (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
3,5	Concentrate	870	7,5	36	186,0	7,8	1,3	4,3	0,2	3045	26,1	127	650,9	27,4	4,7	15,0	0,6
									Ration including concentrates:	14330	97,1	2799	2151,8	3,4	66,2	53,1	3,6

Milk production including concentrates:	**18,7**	**19,8**

	Concentrate composition per kg	*Nutrients in 1kg*								*Nutrients per kg concentrate*							
%	*Feed*	*DM (g)*	*NEL (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*NEL (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
65	Wheat	870	7,4	25	147,9	-4,3	0,6	3,3	0,2	566	4,8	16	96,1	-2,8	0,4	2,1	0,1
35	Soy extraction grist	870	7,5	57	256,6	30,4	2,7	6,1	0,2	305	2,6	20	89,8	10,7	0,9	2,1	0,1
										870	7,5	36	186,0	7,8	1,3	4,3	0,2

Feeding plan DF1 calves

	Roughage	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
8,3	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	3129	29,7	764	488,0	3,1	23,2	12,2	0,9
									Total roughage:	3129	29,7	764	488,0	3,1	23,2	12,2	0,9

Target value:	29,8	410,0
Deviation:	**-0,1**	**78,0**

Feeding plan DF1 heifers

	Roughage	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
19,5	Grass	200	2,0	55	28,3	0,4	1,5	0,8	0,1	3900	38,7	1080	551,9	7,8	28,9	15,2	1,2
4,6	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	1614	18,4	274	133,9	-14,5	3,5	4,0	0,3
									Total roughage:	5514	57,1	1355	685,8	-6,7	32,4	19,2	1,5

Target value:	57,0	650,0
Deviation:	**0,1**	**35,8**

Feeding plan DF1 bulls

	Roughage	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
3,5	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	1320	12,5	322	205,8	1,3	9,8	5,1	0,4
3,1	Clover-grass silage	350	3,6	90	72,1	1,5	2,8	1,5	0,1	1085	11,2	279	223,5	4,7	8,6	4,6	0,3
11,9	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	4165	47,5	708	345,7	-37,5	9,2	10,4	0,8
									Total roughage:	6570	71,2	1309	775,0	-31,5	27,5	20,1	1,6

Target value:	77,2	997,0
Deviation:	-6,0	-222,1

	Concentrate	*Nutrients in 1kg*								*Nutrients in the ration*							
kg	*Feed*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*	*DM (g)*	*ME (MJ)*	*g CF*	*g uCP*	*g RNB*	*g Ca*	*g P*	*g Na*
0,5	Concentrate (100 % soy extraction grist)	870	12,0	57	446,3	30,4	2,7	6,1	0,2	435	6,0	28	223,2	15,2	1,3	3,0	0,1
									Ration including concentrates:	7005	77,2	1337	998,2	-16,3	28,8	23,2	1,6

Deviation:	**0,0**	**1,2**

Table A 19: Winter feeding plans of DF1 dairy cows, calves, heifers and bulls for the GHG mitigation measure 'grazing'.

Feeding plan DF1 dairy cows

Roughage		Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
5,6	Grass silage	377	2,2	92	48,3	0,4	2,8	1,5	0,1	2092	12,1	511	267,8	2,1	15,5	8,2	0,6
7,1	Grass-clover silage	350	2,1	90	46,5	1,5	2,8	1,5	0,1	2485	14,9	639	330,5	10,7	19,6	10,4	0,7
18,7	Maize silage	350	2,4	60	48,3	-3,1	0,8	0,9	0,1	6545	45,6	1113	903,2	-58,9	14,4	16,4	1,3
									Total roughage:	11122	72,6	2262	1501,5	-46,1	49,5	35,0	2,7
									Maintenance requirements:		37,7		450,0				
									Milk production from roughage:		11,0		12,2				

Concentrate		Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
3,3	Concentrate	870	7,5	42	207,7	14,8	1,8	4,8	0,2	2828	24,3	138	675,1	48,1	5,7	15,7	0,6
									Ration including concentrates:	13950	96,9	2400	2176,6	1,9	55,2	50,7	3,2
									Milk production including concentrates:		**18,7**		**20,1**				

Concentrate composition per kg		Nutrients in 1kg								Nutrients per kg concentrate							
%	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
45	Wheat	870	7,4	25	147,9	-4,3	0,6	3,3	0,2	392	3,3	11	66,6	-2,0	0,3	1,5	0,1
55	Soy extraction grist	870	7,5	57	256,6	30,4	2,7	6,1	0,2	479	4,1	31	141,2	16,7	1,5	3,3	0,1
										870	7,5	42	207,7	14,8	1,8	4,8	0,2

Feeding plan DF1 calves

Roughage		Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
8,3	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	3129	29,7	764	488,0	3,1	23,2	12,2	0,9
									Total roughage:	3129	29,7	764	488,0	3,1	23,2	12,2	0,9
									Target value:		29,8		410,0				
									Deviation:		**-0,1**		**78,0**				

Feeding plan DF1 heifers

Roughage		Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
6,75	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	2545	24,2	621	397,0	2,5	18,8	9,9	0,8
6,0	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	2100	23,9	357	174,3	-18,9	4,6	5,3	0,4
2,5	Grass-clover silage	350	3,6	90	72,1	1,5	2,8	1,5	0,1	875	9,0	225	180,3	3,8	6,9	3,7	0,3
									Total roughage:	5520	57,1	1203	751,5	-12,6	30,4	18,8	1,4
									Target value:		57,0		650,0				
									Deviation:		**0,1**		**101,5**				

Feeding plan DF1 bulls

Roughage		Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
3,5	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	1320	12,5	322	205,8	1,3	9,8	5,1	0,4
3,1	Clover-grass silage	350	3,6	90	72,1	1,5	2,8	1,5	0,1	1085	11,2	279	223,5	4,7	8,6	4,6	0,3
11,9	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	4165	47,5	708	345,7	-37,5	9,2	10,4	0,8
									Total roughage:	6570	71,2	1309	775,0	-31,5	27,5	20,1	1,6
									Target value:		77,2		997,0				
									Deviation:		-6,0		-222,1				

Concentrate		Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
0,5	Concentrate (100 % soy extraction grist)	870	12,0	57	446,3	30,4	2,7	6,1	0,2	435	6,0	28	223,2	15,2	1,3	3,0	0,1
									Ration including concentrates:	7005	77,2	1337	998,2	-16,3	28,8	23,2	1,6
									Deviation:		**0,0**		**1,2**				

Table A 20: Summer feeding plans of DF2 dairy cows, calves, heifers and bulls for the GHG mitigation measure 'grazing'.

Feeding plan DF2 dairy cows

kg	Roughage Feed	Nutrients in 1kg DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
50,5	Grass	200	1,2	55	26,0	0,4	1,5	0,8	0,1	10100	59,5	2798	1313,0	20,2	74,7	39,4	3,0
2,2	Grass-clover silage	350	2,1	90	46,5	1,5	2,8	1,5	0,1	770	4,6	198	102,4	3,3	6,1	3,2	0,2
6,7	Maize silage	350	2,4	60	48,3	-3,1	0,8	0,9	0,1	2345	16,3	399	323,6	-21,1	5,2	5,9	0,5
									Total roughage:	13215	80,4	3394	1739,0	2,4	86,0	48,5	3,7

	NEL (MJ)	uCP (g)
Maintenance requirements:	37,7	450,0
Milk production from roughage:	13,5	15,0

kg	Concentrate Feed	Nutrients in 1kg DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
1,3	Concentrate	870	7,4	31	169,6	2,6	1,0	3,9	0,2	1131	9,7	41	220,5	3,4	1,3	5,0	0,2
									Ration including concentrates:	14346	90,1	3435	1959,6	5,8	87,3	53,5	4,0

	NEL (MJ)	uCP (g)
Milk production including concentrates:	**16,5**	**17,6**

%	Concentrate composition per kg Feed	Nutrients in 1kg DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients per kg concentrate DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
80	Wheat	870	7,4	25	147,9	-4,3	0,6	3,3	0,2	696	5,9	20	118,3	-3,5	0,5	2,6	0,1
20	Soy extraction grist	870	7,5	57	256,6	30,4	2,7	6,1	0,2	174	1,5	11	51,3	6,1	0,5	1,2	0,0
										870	7,4	31	169,6	2,6	1,0	3,9	0,2

Feeding plan DF2 calves

kg	Roughage Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
8,4	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	3167	30,1	773	494,0	3,2	23,4	12,4	1,0
									Total roughage:	3167	30,1	773	494,0	3,2	23,4	12,4	1,0

	ME (MJ)	uCP (g)
Target value:	29,8	410,0
Deviation:	**0,3**	**84,0**

Feeding plan DF2 heifers

kg	Roughage Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
28,76	Grass	200	2,0	55	28,3	0,4	1,5	0,8	0,1	5752	57,1	1593	813,9	11,5	42,6	22,4	1,7
									Total roughage:	5752	57,1	1593	813,9	11,5	42,6	22,4	1,7

	ME (MJ)	uCP (g)
Target value:	57,0	650,0
Deviation:	**0,2**	**163,9**

Feeding plan DF2 bulls

kg	Roughage Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
16,0	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	6032	57,3	1472	941,0	6,0	44,6	23,5	1,8
5,0	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	1750	20,0	298	145,3	-15,8	3,9	4,4	0,4
									Total roughage:	7782	77,3	1769	1086,2	-9,7	48,5	27,9	2,2

	ME (MJ)	uCP (g)
Target value:	77,2	997,0
Deviation:	**0,1**	**89,2**

Table A 21: Winter feeding plans of DF2 dairy cows, calves, heifers and bulls for the GHG mitigation measure 'grazing'.

Feeding plan DF2 dairy cows

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
16,75	Grass silage	377	2,2	92	48,3	0,4	2,8	1,5	0,1	6315	36,6	1541	808,3	6,3	46,7	24,6	1,9
2,2	Grass-clover silage	350	2,1	90	46,5	1,5	2,8	1,5	0,1	770	4,6	198	102,4	3,3	6,1	3,2	0,2
14,8	Maize silage	350	2,4	60	48,3	-3,1	0,8	0,9	0,1	5180	36,1	881	714,8	-46,6	11,4	13,0	1,0
									Total roughage:	12265	77,3	2620	1625,5	-37,0	64,2	40,8	3,1

Maintenance requirements: 37,7 450,0
Milk production from roughage: 12,5 13,7

	Concentrate	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
1,7	Concentrate	870	7,5	49	229,4	21,8	2,2	5,4	0,2	1479	12,8	83	390,1	37,0	3,7	9,2	0,3
									Ration including concentrates:	13744	90,1	2702	2015,6	0,0	67,9	50,0	3,5

Milk production including concentrates: **16,5** **18,2**

%	Concentrate composition per kg Feed	Nutrients in 1kg								Nutrients per kg concentrate							
		DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
25	Wheat	870	7,4	25	147,9	-4,3	0,6	3,3	0,2	218	1,9	6	37,0	-1,1	0,2	0,8	0,1
75	Soy extraction grist	870	7,5	57	256,6	30,4	2,7	6,1	0,2	653	5,7	42	192,5	22,8	2,0	4,6	0,1
										870	7,5	49	229,4	21,8	2,2	5,4	0,2

Feeding plan DF2 calves

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
8,4	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	3167	30,1	773	494,0	3,2	23,4	12,4	1,0
									Total roughage:	3167	30,1	773	494,0	3,2	23,4	12,4	1,0

Target value: 29,8 410,0
Deviation: **0,3** **84,0**

Feeding plan DF2 heifers

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
10,0	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	3770	35,8	920	588,1	3,8	27,9	14,7	1,1
5,3	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	1862	21,2	317	154,5	-16,8	4,1	4,7	0,4
									Total roughage:	5632	57,0	1237	742,7	-13,0	32,0	19,4	1,5

Target value: 57,0 650,0
Deviation: **0,2** **92,7**

Feeding plan DF2 bulls

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
16,0	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	6032	57,3	1472	941,0	6,0	44,6	23,5	1,8
5,0	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	1750	20,0	298	145,3	-15,8	3,9	4,4	0,4
									Total roughage:	7782	77,3	1769	1086,2	-9,7	48,5	27,9	2,2

Target value: 77,2 997,0
Deviation: **0,1** **89,2**

Table A 22: Summer feeding plans of DF3 dairy cows, calves, heifers and bulls for the GHG mitigation measure 'grazing'.

Feeding plan DF3 dairy cows

Roughage		Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
33,6	Grass	200	1,2	55	26,0	0,4	1,5	0,8	0,1	6720	39,6	1861	873,6	13,4	49,7	26,2	2,0
1,7	Grass-clover silage	350	2,1	90	46,5	1,5	2,8	1,5	0,1	595	3,6	153	79,1	2,6	4,7	2,5	0,2
13,6	Maize silage	350	2,4	60	48,3	-3,1	0,8	0,9	0,1	4760	33,1	809	656,9	-42,8	10,5	11,9	1,0
									Total roughage:	12075	76,3	2824	1609,6	-26,9	64,9	40,6	3,1

	NEL (MJ)	uCP
Maintenance requirements:	37,7	450,0
Milk production from roughage:	12,0	13,5

Concentrate		Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
3,5	Concentrate	0	0,0	0	0,0	0,0	0,0	6,6	0,0	3070	24,5	229	625,2	27,9	10,8	23,0	0,5
									Ration including concentrates:	15145	100,8	3052	2234,8	1,1	75,7	63,6	3,6

	NEL (MJ)	uCP
Milk production including concentrates:	**19,9**	**20,8**

Concentrate composition per kg		Nutrients in 1kg								Nutrients per kg concentrate							
%	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
55	Wheat	870	7,4	25	147,9	-4,3	0,6	3,3	0,2	479	4,1	14	81,3	-2,4	0,3	1,8	0,1
45	Rape seed extraction grist	886	6,5	114	216,2	23,0	6,1	10,5	0,1	399	2,9	51	97,3	10,4	2,8	4,7	0,0
										877	7,0	65	178,6	8,0	3,1	6,6	0,1

Feeding plan DF3 calves

Roughage		Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
8,4	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	3167	30,1	773	494,0	3,2	23,4	12,4	1,0
									Total roughage:	3167	30,1	773	494,0	3,2	23,4	12,4	1,0

	ME (MJ)	uCP
Target value:	29,8	410,0
Deviation:	**0,3**	**84,0**

Feeding plan DF3 heifers

Roughage		Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
14,2	Grass silage	200	2,0	55	28,3	0,4	1,5	0,8	0,1	5760	57,1	1596	815,0	11,5	42,6	22,5	1,7
									Total roughage:	5760	57,1	1596	815,0	11,5	42,5	22,5	1,7

	ME (MJ)	uCP
Target value:	57,0	650,0
Deviation:	**0,1**	**165,0**

Feeding plan DF3 bulls

Roughage		Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
13,0	Grass silage	377	2,2	92	58,8	0,4	2,8	1,5	0,1	4901	46,6	1196	764,6	4,9	36,3	19,1	1,5
6,6	Maize silage	350	2,4	60	29,1	-3,1	0,8	0,9	0,1	2310	26,3	393	191,7	-20,8	5,1	5,8	0,5
									Total roughage:	7211	72,9	1589	956,3	-15,9	41,3	24,9	1,9

Concentrate		Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
0,4	Concentrate	877	11,2	65	227,9	8,0	3,1	6,6	0,1	351	4,5	26	91,2	3,2	1,2	2,6	0,1
									Ration including concentrates:	7562	77,4	1615	1047,5	-12,7	42,6	27,5	2,0

	NEL (MJ)	uCP
Target value:	77,2	997,0
Deviation:	0,2	50,4

Concentrate composition per kg		Nutrients in 1kg								Nutrients per kg concentrate							
%	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
55	Wheat	870	7,4	25	120,1	-4,3	0,6	3,3	0,2	479	6,4	14	66,0	-2,4	0,3	1,8	0,1
45	Rape seed extraction grist	886	10,7	114	359,7	23,0	6,1	10,5	0,1	399	4,8	51	161,9	10,4	2,8	4,7	0,0

	NEL (MJ)	uCP
Deviation:	**-72,6**	**-886**

Table A 23: Winter feeding plans of DF3 dairy cows, calves, heifers and bulls for the GHG mitigation measure 'grazing'.

Feeding plan DF3 dairy cows

kg	Roughage Feed	Nutrients in 1kg DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
10,3	Grass silage	377	2,2	92	48,3	0,4	2,8	1,5	0,1	3883	22,5	947	497,0	3,9	28,7	15,1	1,2
1,7	Grass-clover silage	350	2,1	90	46,5	1,5	2,8	1,5	0,1	595	3,6	153	79,1	2,6	4,7	2,5	0,2
21,1	Maize silage	350	2,4	60	48,3	-3,1	0,8	0,9	0,1	7385	51,4	1255	1019,1	-66,5	16,2	18,5	1,5
									Total roughage:	11863	77,5	2356	1595,3	-60,0	49,7	36,1	2,8
									Maintenance requirements:		37,7		450,0				
									Milk production from roughage:		12,0		13,3				

kg	Concentrate Feed	Nutrients in 1kg DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
3,5	Concentrate	0	0,0	0	0,0	17,6	0,0	0,0	0,0	3090	23,4	338	708,8	61,5	17,5	31,8	0,4
									Ration including concentrates:	14953	100,9	2694	2304,1	1,4	67,2	67,9	3,2
									Milk production including concentrates:		**19,9**		**21,6**				

%	Concentrate composition per kg Feed	Nutrients in 1kg DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients per kg concentrate DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
20	Wheat	870	7,4	25	147,9	-4,3	0,6	3,3	0,2	174	1,5	5	29,6	-0,9	0,1	0,7	0,0
80	Rape seed extraction grist	886	6,5	114	216,2	23,0	6,1	10,5	0,1	709	5,2	91	172,9	18,4	4,9	8,4	0,1
										883	6,7	96	202,5	17,6	5,0	9,1	0,1

Feeding plan DF3 calves

kg	Roughage Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
8,4	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	3167	30,1	773	494,0	3,2	23,4	12,4	1,0
									Total roughage:	3167	30,1	773	494,0	3,2	23,4	12,4	1,0
									Target value:		29,8		410,0				
									Deviation:		**0,3**		**84,0**				

Feeding plan DF3 heifers

kg	Roughage Feed	Nutrients in 1kg DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
14,2	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	5353	50,9	1306	835,1	5,4	39,6	20,9	1,6
1,7	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	595	6,8	101	49,4	-5,4	1,3	1,5	0,1
									Total roughage:	5948	57,7	1407	884,5	0,0	30,6	18,9	1,7
									Target value:		57,0		650,0				
									Deviation:		**0,6**		**234,5**				

Feeding plan DF3 bulls

kg	Roughage Feed	Nutrients in 1kg DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
13,0	Grass silage	377	2,2	92	58,8	0,4	2,8	1,5	0,1	4901	46,6	1196	764,6	4,9	36,3	19,1	1,5
6,6	Maize silage	350	2,4	60	29,1	-3,1	0,8	0,9	0,1	2310	26,3	393	191,7	-20,8	5,1	5,8	0,5
									Total roughage:	7211	72,9	1589	956,3	-15,9	41,3	24,9	1,9

kg	Concentrate Feed	Nutrients in 1kg DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients in the ration DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
0,4	Concentrate	877	11,2	65	227,9	8,0	3,1	6,6	0,1	351	4,5	26	91,2	3,2	1,2	2,6	0,1
									Ration including concentrates:	7562	77,4	1615	1047,5	-12,7	42,6	27,5	2,0
									Target value:		77,2		997,0				
									Deviation:		0,2		50,4				

%	Concentrate composition per kg Feed	Nutrients in 1kg DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	Nutrients per kg concentrate DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
55	Wheat	870	7,4	25	120,1	-4,3	0,6	3,3	0,2	479	6,4	14	66,0	-2,4	0,3	1,8	0,1
45	Rape seed extraction grist	886	10,7	114	359,7	23,0	6,1	10,5	0,1	399	4,8	51	161,9	10,4	2,8	4,7	0,0
									Deviation:		**-72,6**		**-886**				

Table A 24: Biogas production characteristics and costs for farm-scale use of thermal energy and without any subsidies of model farm DF1.

DF1		S-PI-F	S-OG-F	SR-PI-F	SR-OG-F	SRI-PI-F	SRI-OG-F
Biogas production	**[m^3 a^{-1}]**	357.795	357.795	481.155	481.155	1.224.397	1.224.397
CH_4 production	**[m^3 a^{-1}]**	201.222	201.222	277.930	277.930	723.876	723.876
Electric power	**[kW]**	89	77	125	109	333	300
Produced energy (el.)	**[MWh a^{-1}]**	778	676	1.099	952	2.921	2.624
Max. usuable heat energy	**[MWh a^{-1}]**	253	185	734	646	2.556	2.240
Supplementary energy	**[MWh a^{-1}]**	119	119	110	109	292	262
Pilot fuel	**[kg a^{-1}]**	17.191	0	23.745	0	61.843	0
Investment biogas plant	**[€]**	329.300	355.000	334.200	373.500	690.000	706.900
Investment heat use	**[€]**	14.500	14.500	14.500	14.500	14.500	14.500
Specific investment	**[€ kW^{-1}]**	3.700	4.610	2.674	3.427	2.072	2.356
Annual investment	**[€ a^{-1}]**	55.354	47.672	58.807	51.371	126.464	97.817
Annual operating costs	**[€ a^{-1}]**	50.021	38.585	57.465	41.610	195.785	91.162
Annual personnel costs	**[€ a^{-1}]**	12.660	12.660	15.825	15.825	25.320	25.320
Annual substrate costs	**[€ a^{-1}]**	0	0	0	0	157.819	157.819
Annual costs for heat use	**[€ a^{-1}]**	1.290	1.290	1.290	1.290	1.290	1.290
Total costs	**[€ a^{-1}]**	119.325	100.207	133.387	110.096	506.678	373.408
Revenues electricity	**[€ a^{-1}]**	46.680	40.560	65.940	57.120	175.260	157.440
Revenues heat	**[€ a^{-1}]**	1.400	1.400	1.400	1.400	1.400	1.400
Total gain	**[€ a^{-1}]**	-71.245	-58.247	-66.047	-51.576	-330.018	-214.568

Table A 25: Biogas production characteristics and costs for total use of thermal energy and without any subsidies of model farm DF1.

DF1		S-PI-T	S-OG-T	SR-PI-T	SR-OG-T	SRI-PI-T	SRI-OG-T
Biogas production	**[m^3 a^{-1}]**	357.795	357.795	481.155	481.155	1.224.397	1.224.397
CH_4 production	**[m^3 a^{-1}]**	201.222	201.222	277.930	277.930	723.876	723.876
Electric power	**[kW]**	89	77	125	109	333	300
Produced energy (el.)	**[MWh a^{-1}]**	778	676	1.099	952	2.921	2.624
Max. usuable heat energy	**[MWh a^{-1}]**	253	185	734	646	2.556	2.240
Supplementary energy	**[MWh a^{-1}]**	119	119	110	109	292	262
Pilot fuel	**[kg a^{-1}]**	17.191	0	23.745	0	61.843	0
Investment biogas plant	**[€]**	329.300	355.000	334.200	373.500	690.000	706.900
Investment heat use	**[€]**	64.500	64.500	64.500	64.500	64.500	64.500
Specific investment	**[€ kW^{-1}]**	3.700	4.610	2.674	3.427	2.072	2.356
Annual investment	**[€ a^{-1}]**	55.354	47.672	58.807	51.371	126.464	97.817
Annual operating costs	**[€ a^{-1}]**	50.021	38.585	57.465	41.610	195.785	91.162
Annual personnel costs	**[€ a^{-1}]**	12.660	12.660	15.825	15.825	25.320	25.320
Annual substrate costs	**[€ a^{-1}]**	0	0	0	0	157.819	157.819
Annual costs for heat use	**[€ a^{-1}]**	5.738	5.738	5.738	5.738	5.738	5.738
Total costs	**[€ a^{-1}]**	123.773	104.655	137.835	114.544	511.126	377.856
Revenues electricity	**[€ a^{-1}]**	46.680	40.560	65.940	57.120	175.260	157.440
Revenues heat	**[€ a^{-1}]**	7.084	5.180	20.552	18.088	71.568	62.720
Total gain	**[€ a^{-1}]**	-70.009	-58.915	-51.343	-39.336	-264.298	-157.696

Table A 26: Biogas production characteristics and costs for farm-scale use of thermal energy and subsidies according to German conditions of model farm DF1.

DF1		S-PI-F	S-OG-F	SR-PI-F	SR-OG-F	SRI-PI-F	SRI-OG-F
Biogas production	**[m^3 a^{-1}]**	357.795	357.795	481.155	481.155	1.224.397	1.224.397
CH_4 production	**[m^3 a^{-1}]**	201.222	201.222	277.930	277.930	723.876	723.876
Electric power	**[kW]**	89	77	125	109	333	300
Produced energy (el.)	**[MWh a^{-1}]**	778	676	1.099	952	2.921	2.624
Max. usuable heat energy	**[MWh a^{-1}]**	253	185	734	646	2.556	2.240
Supplementary energy	**[MWh a^{-1}]**	119	119	110	109	292	262
Pilot fuel	**[kg a^{-1}]**	17.191	0	23.745	0	61.843	0
Investment biogas plant	**[€]**	329.300	355.000	334.200	373.500	690.000	706.900
Investment heat use	**[€]**	14.500	14.500	14.500	14.500	14.500	14.500
Specific investment	**[€ kW^{-1}]**	3.700	4.610	2.674	3.427	2.072	2.356
Annual investment	**[€ a^{-1}]**	55.354	47.672	58.807	51.371	126.464	97.817
Annual operating costs	**[€ a^{-1}]**	50.021	38.585	57.465	41.610	195.785	91.162
Annual personnel costs	**[€ a^{-1}]**	12.660	12.660	15.825	15.825	25.320	25.320
Annual substrate costs	**[€ a^{-1}]**	0	0	0	0	157.819	157.819
Annual costs for heat use	**[€ a^{-1}]**	1.290	1.290	1.290	1.290	1.290	1.290
Total costs	**[€ a^{-1}]**	119.325	100.207	133.387	110.096	506.678	373.408
Revenues electricity	**[€ a^{-1}]**	135.395	117.676	191.046	165.524	484.971	437.520
Revenues heat	**[€ a^{-1}]**	1.400	1.400	1.400	1.400	1.400	1.400
Total gain	**[€ a^{-1}]**	17.470	18.869	59.059	56.828	-20.307	65.512

Table A 27: Biogas production characteristics and costs for total use of thermal energy and subsidies according to German conditions of model farm DF1.

DF1		S-PI-T	S-OG-T	SR-PI-T	SR-OG-T	SRI-PI-T	SRI-OG-T
Biogas production	**[m^3 a^{-1}]**	357.795	357.795	481.155	481.155	1.224.397	1.224.397
CH_4 production	**[m^3 a^{-1}]**	201.222	201.222	277.930	277.930	723.876	723.876
Electric power	**[kW]**	89	77	125	109	333	300
Produced energy (el.)	**[MWh a^{-1}]**	778	676	1.099	952	2.921	2.624
Max. usuable heat energy	**[MWh a^{-1}]**	253	185	734	646	2.556	2.240
Supplementary energy	**[MWh a^{-1}]**	119	119	110	109	292	262
Pilot fuel	**[kg a^{-1}]**	17.191	0	23.745	0	61.843	0
Investment biogas plant	**[€]**	329.300	355.000	334.200	373.500	690.000	706.900
Investment heat use	**[€]**	64.500	64.500	64.500	64.500	64.500	64.500
Specific investment	**[€ kW^{-1}]**	3.700	4.610	2.674	3.427	2.072	2.356
Annual investment	**[€ a^{-1}]**	55.354	47.672	58.807	51.371	126.464	97.817
Annual operating costs	**[€ a^{-1}]**	50.021	38.585	57.465	41.610	195.785	91.162
Annual personnel costs	**[€ a^{-1}]**	12.660	12.660	15.825	15.825	25.320	25.320
Annual substrate costs	**[€ a^{-1}]**	0	0	0	0	157.819	157.819
Annual costs for heat use	**[€ a^{-1}]**	5.738	5.738	5.738	5.738	5.738	5.738
Total costs	**[€ a^{-1}]**	123.773	104.655	137.835	114.544	511.126	377.856
Revenues electricity	**[€ a^{-1}]**	137.698	119.095	199.113	171.995	516.006	472.158
Revenues heat	**[€ a^{-1}]**	7.084	5.180	20.552	18.088	71.568	62.720
Total gain	**[€ a^{-1}]**	21.009	19.620	81.830	75.539	76.448	157.022

Table A 28: Biogas production characteristics and costs for farm-scale and total use of thermal energy and without any subsidies of model farm DF3.

DF3		S-PI-F	SR-PI-F	SRI-OG-F	S-PI-T	SR-PI-T	SRI-OG-T
Biogas production	[m^3 a^{-1}]	317.738	448.575	1.191.818	317.738	448.575	1.191.818
CH_4 production	[m^3 a^{-1}]	177.420	258.567	704.512	177.420	258.567	704.512
Electric power	[kW]	77	116	291	77	116	291
Produced energy (el.)	[MWh a^{-1}]	678	1.018	2.549	678	1.018	2.549
Max. usuable heat energy	[MWh a^{-1}]	183	675	2.199	183	675	2.199
Supplementary energy	[MWh a^{-1}]	112	104	255	112	104	255
Pilot fuel	[kg a^{-1}]	15.158	22.090	0	15.158	22.090	0
Investment biogas plant	[€]	312.700	325.100	694.600	312.700	325.100	694.600
Investment heat use	[€]	14.500	14.500	14.500	14.500	14.500	14.500
Specific investment	[€ kW^{-1}]	4.061	2.803	2.387	4.061	2.803	2.387
Annual investment	[€ a^{-1}]	52.127	57.237	95.980	52.127	57.237	95.980
Annual operating costs	[€ a^{-1}]	45.943	54.120	88.886	45.943	54.120	88.886
Annual personnel costs	[€ a^{-1}]	12.660	15.825	25.320	12.660	15.825	25.320
Annual substrate costs	[€ a^{-1}]	0	0	157.819	0	0	157.819
Annual costs for heat use	[€ a^{-1}]	1.290	1.290	1.290	1.290	1.290	1.290
Total costs	[€ a^{-1}]	112.020	128.472	369.295	112.020	128.472	369.295
Revenues electricity	[€ a^{-1}]	40.680	61.080	152.940	40.680	61.080	152.940
Revenues heat	[€ a^{-1}]	1.400	1.400	1.400	5.124	18.900	61.572
Total gain	[€ a^{-1}]	-69.940	-65.992	-214.955	-66.216	-48.492	-154.783

Table A 29: Biogas production characteristics and costs for farm-scale and total use of thermal energy and without any subsidies of model farm BF2.

BF2		S-PI-F	SR-PI-F	SRI-OG-F	S-PI-T	SR-PI-T	SRI-OG-T
Biogas production	[m^3 a^{-1}]	314.360	511.062	1.254.304	314.360	511.062	1.254.304
CH_4 production	[m^3 a^{-1}]	179.529	299.367	745.313	179.529	299.367	745.313
Electric power	[kW]	78	136	309	78	136	309
Produced energy (el.)	[MWh a^{-1}]	687	1.192	2.706	687	1.192	2.706
Max. usuable heat energy	[MWh a^{-1}]	180	848	2.349	180	848	2.349
Supplementary energy	[MWh a^{-1}]	114	119	271	114	119	271
Pilot fuel	[kg a^{-1}]	15.338	25.576	0	15.338	25.576	0
Investment biogas plant	[€]	313.300	338.800	718.000	313.300	338.800	718.000
Investment heat use	[€]	14.500	14.500	14.500	14.500	14.500	14.500
Specific investment	[€ kW^{-1}]	4.017	2.491	2.324	4.017	2.491	2.324
Annual investment	[€ a^{-1}]	52.238	60.377	99.155	52.238	60.377	99.155
Annual operating costs	[€ a^{-1}]	46.375	60.941	93.274	46.375	60.941	93.274
Annual personnel costs	[€ a^{-1}]	12.660	15.825	25.320	12.660	15.825	25.320
Annual substrate costs	[€ a^{-1}]	0	0	157.819	0	0	157.819
Annual costs for heat use	[€ a^{-1}]	1.290	1.290	1.290	1.290	1.290	1.290
Total costs	[€ a^{-1}]	112.563	138.433	376.858	112.563	138.433	376.858
Revenues electricity	[€ a^{-1}]	41.220	71.520	162.360	41.220	71.520	162.360
Revenues heat	[€ a^{-1}]	1.400	1.400	1.400	5.040	23.744	65.772
Total gain	[€ a^{-1}]	-69.943	-65.513	-213.098	-66.303	-43.169	-148.726

Table A 30: Acidification emissions and mitigation costs without subsidies for the implementation of a biogas plant (BG) and a farm-scale (F) or total use of produced heat (T) of dairy farm DF3 (S = digestion of manure and energy plants from set-aside land, SR = digestion of manure, energy plants from set-aside land and surplus cropland available due to reduction of livestock density, SRI = digestion of manure, energy plants from set-aside land and surplus cropland available due to reduction of livestock density and addition, PI = pilot injection gas engine CHP, OG = Otto gas engine CHP).

		DF3 BG		S-PI-F	SR-PI-F	SRI-OG-F	S-PI-T	SR-PI-T	SRI-OG-T
Farm area	**[ha]**	**75.4**	**300**	**300**	**300**	**300**	**300**	**300**	**300**
Resources plant production	**[kg SO_2-eq. a^{-1}]**	363.0	1,444	1,325	1,427	1,127	1,325	1,427	1,127
Direct emissions plant production	**[kg SO_2-eq. a^{-1}]**	4,739	18,857	10,522	10,135	13,935	10,522	10,135	13,935
Total emissions plant production	**[kg SO_2-eq. a^{-1}]**	5,102	20,302	11,847	11,562	15,062	11,847	11,562	15,062
Resources livestock farming	**[kg SO_2-eq. a^{-1}]**	344.9	1,372	1,372	1,002	1,002	1,372	1,002	1,002
Direct emissions livestock farming	**[kg SO_2-eq. a^{-1}]**	1,781	7,087	5,115	4,093	4,093	5,115	4,093	4,093
Total emissions livestock farming	**[kg SO_2-eq. a^{-1}]**	2,126	8,460	6,488	5,095	5,095	6,488	5,095	5,095
Emissions construction and disposal of biogas plant	**[kg SO_2-eq. a^{-1}]**	0	0	387.0	386.0	207.8	387.0	386.0	207.8
Emissions operation of biogas plant	**[kg SO_2-eq. a^{-1}]**	0	0	858.8	1,163.8	5,293	858.8	1,164	5,293
Emission credits	**[kg SO_2-eq. a^{-1}]**	0	0	-676.1	-1,006.3	-2,493	-722.9	-1,226	-3,250
Total emissions biogas production	**[kg SO_2-eq. a^{-1}]**	0	0	569.7	543.4	3,007.5	522.9	323.5	2,251
Total emissions per farm	**[kg SO_2-eq. a^{-1}]**	7,229	28,761	18,904	17,200	23,164	18,858	16,980	22,408
Total emissions per hectare	**[kg SO_2-eq. ha^{-1} a^{-1}]**	95.9	95.9	63.0	57.3	77.2	62.9	56.6	74.7
Mitigation costs (without subsidies)	**[€ kg^{-1} SO_2-eq.]**			**8.4**	**9.7**	**46.3**	**8.0**	**8.1**	**31.4**

Table A 31: Eutrophication emissions and mitigation costs without subsidies for the implementation of a biogas plant (BG) and a farm-scale (F) or total use of produced heat (T) of dairy farm DF3 (S = digestion of manure and energy plants from set-aside land, SR = digestion of manure, energy plants from set-aside land and surplus cropland available due to reduction of livestock density, SRI = digestion of manure, energy plants from set-aside land and surplus cropland available due to reduction of livestock density and addition, PI = pilot injection gas engine CHP, OG = Otto gas engine CHP).

		DF3 BG		S-PI-F	SR-PI-F	SRI-OG-F	S-PI-T	SR-PI-T	SRI-OG-T
Farm area	**[ha]**	**75.4**	**300**	**300**	**300**	**300**	**300**	**300**	**300**
Resources plant production	**[kg PO_4^{3-}-eq. a^{-1}]**	55.6	221.4	203.5	217.1	176.4	203.5	217.1	176.4
Direct emissions plant production	**[kg PO_4^{3-}-eq. a^{-1}]**	882.4	3,511	1,959	1,887	2,594	1,959	1,887	2,594
Total emissions plant production	**[kg PO_4^{3-}-eq. a^{-1}]**	938.0	3,732	2,162	2,104	2,771	2,162	2,104	2,771
Resources livestock farming	**[kg PO_4^{3-}-eq. a^{-1}]**	57.1	227.1	227.0	162.8	162.8	227.0	162.8	162.8
Direct emissions livestock farming	**[kg PO_4^{3-}-eq. a^{-1}]**	331.6	1,319	952.4	762.0	762.0	952.4	762.0	762.0
Total emissions livestock farming	**[kg PO_4^{3-}-eq. a^{-1}]**	388.7	1,547	1,179	924.7	924.7	1,179	924.7	924.7
Emissions construction and disposal of biogas plant	**[kg PO_4^{3-}-eq. a^{-1}]**	0	0	12.8	12.6	14.8	12.8	12.6	14.8
Emissions operation of biogas plant	**[kg PO_4^{3-}-eq. a^{-1}]**	0	0	72.5	98.1	734.3	72.5	98.1	734.3
Emission credits	**[kg PO_4^{3-}-eq. a^{-1}]**	0	0	-56.3	-84.0	-208.6	-59.4	-98.5	-258.6
Total emissions biogas production	**[kg PO_4^{3-}-eq. a^{-1}]**	0	0	28.9	26.7	540.5	25.8	12.2	490.5
Total emissions per farm	**[kg PO_4^{3-}-eq. a^{-1}]**	1,327	5,279	3,371	3,055	4,236	3,368	3,041	4,186
Total emissions per hectare	**[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]**	17.6	17.6	11.2	10.2	14.1	11.2	10.1	14.0
Mitigation costs (without subsidies)	**[€ kg^{-1} PO_4^{3-}-eq.]**			**43.6**	**50.7**	**248.7**	**41.6**	**42.5**	**182.3**

Table A 32: Acidification emissions and mitigation costs without subsidies for the implementation of a biogas plant (BG) and a farm-scale (F) or total use of produced heat (T) of dairy farm BF2 (S = digestion of manure and energy plants from set-aside land, SR = digestion of manure, energy plants from set-aside land and surplus cropland available due to reduction of livestock density, SRI = digestion of manure, energy plants from set-aside land and surplus cropland available due to reduction of livestock density and addition, PI = pilot injection gas engine CHP, OG = Otto gas engine CHP).

		BF2 BG		S-PI-F	SR-PI-F	SRI-OG-F	S-PI-T	SR-PI-T	SRI-OG-T
Farm area	**[ha]**	**56.1**	**300**	**300**	**300**	**300**	**300**	**300**	**300**
Resources plant production	**[kg SO_2-eq. a^{-1}]**	354.8	1,898	1,831	1,877	1,603	1,831	1,877	1,603
Direct emissions plant production	**[kg SO_2-eq. a^{-1}]**	2,893	15,472	9,486	9,048	11,444	9,486	9,048	11,444
Total emissions plant production	**[kg SO_2-eq. a^{-1}]**	3,248	17,370	11,318	10,926	13,047	11,318	10,926	13,047
Resources livestock farming	**[kg SO_2-eq. a^{-1}]**	631.1	3,375	3,375	2,292	2,292	3,375	2,292	2,292
Direct emissions livestock farming	**[kg SO_2-eq. a^{-1}]**	1,588	8,492	6,509	5,208	5,208	6,509	5,208	5,208
Total emissions livestock farming	**[kg SO_2-eq. a^{-1}]**	2,219	11,867	9,883	7,500	7,500	9,883	7,500	7,500
Emissions construction and disposal of biogas plant	**[kg SO_2-eq. a^{-1}]**	0	0	387.4	386.5	210.5	387.4	386.5	210.5
Emissions operation of biogas plant	**[kg SO_2-eq. a^{-1}]**	0	0	854.7	1,328.7	5,382	854.7	1,329	5,382
Emission credits	**[kg SO_2-eq. a^{-1}]**	0	0	-684.9	-1,175.3	-2,646	-730.6	-1,456	-3,455
Total emissions biogas production	**[kg SO_2-eq. a^{-1}]**	0	0	557.3	539.9	2,946.3	511.5	259.1	2,137
Total emissions per farm	**[kg SO_2-eq. a^{-1}]**	5,467	29,237	21,758	18,965	23,493	21,713	18,684	22,684
Total emissions per hectare	**[kg SO_2-eq. ha^{-1} a^{-1}]**	97.5	97.5	72.5	63.2	78.3	72.4	62.3	75.6
Mitigation costs (without subsidies)	**[€ kg^{-1} SO_2-eq.]**			**11.3**	**8.1**	**40.8**	**10.7**	**5.8**	**26.0**

Table A 33: Eutrophication emissions and mitigation costs without subsidies for the implementation of a biogas plant (BG) and a farm-scale (F) or total use of produced heat (T) of dairy farm BF2 (S = digestion of manure and energy plants from set-aside land, SR = digestion of manure, energy plants from set-aside land and surplus cropland available due to reduction of livestock density, SRI = digestion of manure, energy plants from set-aside land and surplus cropland available due to reduction of livestock density and addition, PI = pilot injection gas engine CHP, OG = Otto gas engine CHP).

		BF2 BG		S-PI-F	SR-PI-F	SRI-OG-F	S-PI-T	SR-PI-T	SRI-OG-T
Farm area	**[ha]**	**56.1**	**300**	**300**	**300**	**300**	**300**	**300**	**300**
Resources plant production	**[kg PO_4^{3-}-eq. a^{-1}]**	54.8	292.9	283.3	289.3	252.6	283.3	289.3	252.6
Direct emissions plant production	**[kg PO_4^{3-}-eq. a^{-1}]**	538.7	2,880	1,766	1,685	2,130	1,766	1,685	2,130
Total emissions plant production	**[kg PO_4^{3-}-eq. a^{-1}]**	593.4	3,173	2,049	1,974	2,383	2,049	1,974	2,383
Resources livestock farming	**[kg PO_4^{3-}-eq. a^{-1}]**	91.8	490.9	490.9	334.1	334.1	490.9	334.1	334.1
Direct emissions livestock farming	**[kg PO_4^{3-}-eq. a^{-1}]**	295.6	1,581	1,211.7	969.5	969.5	1,211.7	969.5	969.5
Total emissions livestock farming	**[kg PO_4^{3-}-eq. a^{-1}]**	387.4	2,072	1,703	1,303.6	1,303.6	1,703	1,303.6	1,303.6
Emissions construction and disposal of biogas plant	**[kg PO_4^{3-}-eq. a^{-1}]**	0	0	12.8	12.7	15.1	12.8	12.7	15.1
Emissions operation of biogas plant	**[kg PO_4^{3-}-eq. a^{-1}]**	0	0	72.0	111.9	739.9	72.0	111.9	739.9
Emission credits	**[kg PO_4^{3-}-eq. a^{-1}]**	0	0	-57.1	-98.1	-221.3	-60.1	-116.7	-274.9
Total emissions biogas production	**[kg PO_4^{3-}-eq. a^{-1}]**	0	0	27.8	26.4	533.6	24.8	7.9	480.1
Total emissions per farm	**[kg PO_4^{3-}-eq. a^{-1}]**	980.9	5,245	3,780	3,304	4,220	3,777	3,285	4,167
Total emissions per hectare	**[kg PO_4^{3-}-eq. ha^{-1} a^{-1}]**	17.5	17.5	12.6	11.0	14.1	12.6	11.0	13.9
Mitigation costs (without subsidies)	**[€ kg^{-1} PO_4^{3-}-eq.]**			**57.6**	**43.1**	**228.8**	**55.0**	**31.3**	**157.8**

Table A 34: Feeding plans of DF1 dairy cows, calves, heifers and bulls for organic production.

Feeding plan DF1 dairy cows

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
15,00	Grass silage	377	2,2	92	48,3	0,4	2,8	1,5	0,1	5655	32,8	1380	723,8	5,7	41,8	22,1	1,7
13,25	Grass-clover silage	350	2,1	90	46,5	1,5	2,8	1,5	0,1	4638	27,8	1192	616,8	19,9	36,6	19,5	1,4
7,25	Maize silage	350	2,4	60	48,3	-3,1	0,8	0,9	0,1	2538	17,7	431	350,2	-22,8	5,6	6,3	0,5
									Total roughage:	12830	78,3	3003	1690,8	2,8	84,1	47,9	3,6
									Maintenance requirements:		37,7		450,0				
									Milk production from roughage:		12,8		14,4				

	Concentrate	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
1,8	Concentrate	870	7,2	51	149,8	0,5	0,7	3,7	0,3	1523	12,6	90	262,2	0,9	1,3	6,5	0,5
									Ration including concentrates:	14353	90,9	3093	1953,0	3,7	85,3	54,4	4,1
									Milk production including concentrates:		**16,8**		**17,5**				

	Concentrate composition per kg	Nutrients in 1kg								Nutrients per kg concentrate							
%	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
60	Barley	870	7,1	46	141,8	-6,1	0,7	3,4	0,3	522	4,3	28	85,1	-3,7	0,4	2,0	0,2
40	Peas	870	7,4	59	161,8	10,4	0,8	4,2	0,3	348	3,0	24	64,7	4,2	0,3	1,7	0,1
										870	7,2	51	149,8	0,5	0,7	3,7	0,3

Feeding plan DF1 calves

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
6,8	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	2545	24,2	621	397,0	2,5	18,8	9,9	0,8
1,6	Grass-clover silage	350	3,6	90	72,1	1,5	2,8	1,5	0,1	543	5,6	139	111,8	2,3	4,3	2,3	0,2
									Total roughage:	3087	29,8	760	508,7	4,9	23,1	12,2	0,9
									Target value:		29,8		410,0				
									Deviation:		**0,0**		**98,7**				

Feeding plan DF1 heifers

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
12,6	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	4750	45,1	1159	741,0	4,8	35,2	18,5	1,4
3,0	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	1050	12,0	179	87,2	-9,4	2,3	2,6	0,2
									Total roughage:	5800	57,1	1338	828,2	-4,7	37,5	21,2	1,6
									Target value:		57,0		650,0				
									Deviation:		**0,0**		**178,2**				

Feeding plan DF1 bulls

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
8,5	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	3205	30,4	782	499,9	3,2	23,7	12,5	1,0
5,5	Clover-grass silage	350	3,6	90	72,1	1,5	2,8	1,5	0,1	1925	19,8	495	396,5	8,3	15,2	8,1	0,6
3,5	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	1225	14,0	208	101,7	-11,0	2,7	3,1	0,2
									Total roughage:	6355	64,2	1485	998,1	0,5	41,6	23,6	1,8
									Target value:		72,8		945,0				
									Deviation:		0,1		185,8				

	Concentrate	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
0,8	Concentrate	870	11,5	54	177,0	3,8	0,7	3,9	0,3	653	8,6	40	132,7	2,9	0,6	2,9	0,2
									Ration including concentrates:	7007	72,9	1525	1130,8	3,3	42,2	26,5	2,0

	Concentrate composition per kg	Nutrients in 1kg								Nutrients per kg concentrate							
%	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
60	Barley	870	11,2	46	104,4	-6,1	0,7	3,4	0,3	348	4,5	18	41,8	-2,4	0,3	1,4	0,1
40	Peas	870	11,7	59	225,3	10,4	0,8	4,2	0,3	522	7,0	35	135,2	6,3	0,5	2,5	0,2
										870	11,5	54	177,0	3,8	0,7	3,9	0,3

Table A 35: Feeding plans of DF3 dairy cows, calves, heifers and bulls for organic production.

Feeding plan DF3 dairy cows

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
22,75	Grass silage	377	2,2	92	48,3	0,4	2,8	1,5	0,1	8577	49,8	2093	1097,8	8,6	63,5	33,4	2,6
5,25	Grass-clover silage	350	2,1	90	46,5	1,5	2,8	1,5	0,1	1838	11,0	472	244,4	7,9	14,5	7,7	0,6
7,65	Maize silage	350	2,4	60	48,3	-3,1	0,8	0,9	0,1	2678	18,6	455	369,5	-24,1	5,9	6,7	0,5
									Total roughage:	13092	79,5	3020	1711,7	-7,6	83,9	47,9	3,7

Maintenance requirements:	37,7	450,0
Milk production from roughage:	12,0	14,7

	Concentrate	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
2,0	Concentrate	870	7,4	45	156,0	4,2	0,7	3,8	0,2	1783	15,2	92	319,7	8,7	1,5	7,8	0,5
									Ration including concentrates:	14875	94,6	3112	2031,5	1,0	85,3	55,7	4,1

Milk production including concentrates:	**17,9**	**18,4**

	Concentrate composition per kg	Nutrients in 1kg								Nutrients per kg concentrate							
%	Feed	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	NEL (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
42	Wheat	870	7,4	25	147,9	-4,3	0,6	3,3	0,2	365	3,1	11	62,1	-1,8	0,3	1,4	0,1
58	Peas	870	7,4	59	161,8	10,4	0,8	4,2	0,3	505	4,3	34	93,8	6,1	0,5	2,4	0,2
										870	7,4	45	156,0	4,2	0,7	3,8	0,2

Feeding plan DF3 calves

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
8,35	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	3148	29,9	768	491,1	3,1	23,3	12,3	0,9
									Total roughage:	3148	29,9	768	491,1	3,1	23,3	12,3	0,9

Target value:	29,8	410,0
Deviation:	**0,1**	**81,1**

Feeding plan DF3 heifers

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
14,4	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	5429	51,6	1325	846,9	5,4	40,2	21,2	1,6
1,4	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	490	5,6	83	40,7	-4,4	1,1	1,2	0,1
									Total roughage:	5919	57,2	1408	887,6	1,0	41,3	22,4	1,7

Target value:	57,0	650,0
Deviation:	**0,1**	**237,6**

Feeding plan DF3 bulls

	Roughage	Nutrients in 1kg								Nutrients in the ration							
kg	Feed	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na	DM (g)	ME (MJ)	g CF	g uCP	g RNB	g Ca	g P	g Na
16,1	Grass silage	377	3,6	92	58,8	0,4	2,8	1,5	0,1	6070	57,7	1481	946,9	6,1	44,9	23,7	1,8
1,5	Clover-grass silage	350	3,6	90	72,1	1,5	2,8	1,5	0,1	525	5,4	135	108,1	2,3	4,1	2,2	0,2
2,5	Maize silage	350	4,0	60	29,1	-3,1	0,8	0,9	0,1	875	10,0	149	72,6	-7,9	1,9	2,2	0,2
									Total roughage:	7470	73,0	1765	1127,6	0,5	51,0	28,1	2,2

Target value:	72,8	945,0
Deviation:	0,1	185,8