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A FARM SYSTEM APPROACH TO ANALYZE GREENHOUSE GAS (GHG) MITIGATION STRATEGIES FOR RUMINANT PRODUCTION SYSTEMS

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ABSTRACT Agriculture is a significant emitter of GHGs. Especially ruminant production systems that contribute substantially to global warming due to the enteric fermentation. Ruminant production systems are often integrated in mixed farm systems, including arable production, grassland systems and possibly energy production, which may provide opportunities for mitigation of GHGs when considered as a whole system. The paper analyzes systematically the GHG mitigation potentials of a mixed farm system, which represents a typical farm in northeastern Germany by modeling interactions and substance flows between different subsystems within a model farm. The following mitigation strategies are compared: 1) increased milk production per dairy cow, 2) integration of a biogas plant. The results show that the integration of the biogas plant has the greatest mitigation effect, followed by increased performance of the dairy system. Each mitigation practice has specific uncertainties which determine the overall results substantially. Uncertainties in the biogas mitigation option are due to emissions from the digestate spread to the fields. In option 2 the mitigation of methane production due to increased milk production per animal is partly compensated by increased methane emissions per animal and increased emissions due to feed production. The integration of the biogas system requires additional land to be cultivated, which may lead to induced emissions and thus lower the positive GHG effect.

Keywords: CO2-Mitigation, Greenhouse gases, dairy system, anaerobic digestion

INTRODUCTION Greenhouse gas mitigation with agriculture can be realized by reducing emissions e.g. by reduced input use, enhancing removals e.g. by increasing carbon stocks or by avoiding emissions by using bioenergy feedstocks and replacing the use of fossil resources (Smith et al., 2008). However, in each mitigation path the realization of mitigation potentials in agriculture faces specific uncertainties and constraints, which need to be addressed before significant effects from the agricultural sector can be expected (Smith et al., 2007). The paper analyzes systematically the GHG mitigation potentials of a mixed farm system, which represents a typical farm in northeastern Germany by modeling interactions and substance flows between different subsystems within a model farm. The following mitigation strategies are compared: 1) increased milk production per dairy cow, 2) integration of a biogas plant.

MATERIALS AND METHODS The constructed farm model represents a typical dairy farm system in north-eastern Germany with the main production systems dairy production and cash crop production. The farm produces roughage (corn and grass silage) and partially concentrate for 360 milking cows and their replacement. Available acreage for the farm is 1300 ha, of which 300 ha are permanent grassland and 1000 ha are arable land. Besides corn and grass the fields are planted with winter-wheat, winter-barley, winter-rye, and rapeseed (canola). The share of acreage for the considered crops equal the share of these crops planted in the state of Brandenburg.

Scenario analysis Land use change with the three investigated mitigation scenarios were modeled according to the requirements given with the mitigation scenarios. The scenarios "milk performance" and "biogas" need more corn than is used in the reference scenario. The acreage of the other crops decreased accordingly.

Table 1. Land use in the reference scenario and three GHG mitigation scenarios.

	Scenario		
	Reference Scenario	Milk performance (10,000 kg)	Biogas
Land use			
Grassland (ha)	300	300	300
Canola (ha)	190	166	130
Corn (ha)	70	210	330
Grass (ha)	27	0	27
Oat (ha)	31	28	23
Sunflower (ha)	17	15	13
Winterbarley (ha)	109	95	80
Winterrye (ha)	371	324	261
Winterwheat (ha)	185	162	136

<u>Milk performance scenario</u> In the milk performance scenario we analyzed to what extent a higher milk yield per dairy cow contributes to a mitigation of GHG emissions in total and per kg milk. The reference scenario represents the current state of German milk production (VIT, 2006), while the milk performance scenario can be assumed as a future scenario for many dairy farms in Brandenburg. Table 2 shows performance parameters for the two scenarios. All calculations are related to milk production of a herd with 360 dairy cows of the breed Holstein Friesian with 8,000 kg milk per dairy cow in a year. Consequently, in the milk performance scenario fewer dairy cows are needed to provide the same amount of milk. Increasing milk yields may influence the replacement rate of the livestock due to fertility problems and higher risks of diseases (Rossow, 2008). Therefore, we conservatively assumed a replacement rate of 45 % in the milk performance scenario.

Table 2. Definition of the milk performance scenarios

	Unit	Reference Scenario	Milk performance scenario
Milk yield	kg milk cow^{-1} $year^{-1}$	8,000*	10,000
Dairy cows	Number of heads $year^{-1}$	360	288
Calves and heifers	Number of heads $year^{-1}$	326	355
Body mass	kg cow^{-1}	650	700
Replacement rate	%	35*	45
Birth rate	calves $cow^{-1}year^{-1}$	0.95	0.95
Age of cows at first calving	Months	29.5*	25

* VIT, 2006

Because of the different milk yields the both scenarios differ in their diets. All diets were calculated in form of total mixed rations with a balanced proportion between roughage and concentrate. Typical for this feeding procedure is sharing the cows into performance groups. Diets were calculated for two performance groups of the lactating cows and two groups of dry cows for summer and winter, for both scenarios respectively. Therefore, the requirements of the dairy cows regarding a performance orientated feeding with the parameters net energy lactation (NEL) and usable crude protein (CP) as well as a balanced and ruminant appropriate feeding with the parameters fibre content (XF > 18%), ruminant nitrogen balance (RNB $\geq$ 0) and dry matter intake (DMI) were considered (Kirchgeßner, 2004).

Table 3. Needed cultivable acreage for feed supply

		Scenario	
Feed-stuff	Unit	Reference	Milk performance
Corn for silage	ha	60	178
Pasture	ha	85	92
Grass for silage	ha	329	170
Grass for hay	ha	2	3
Concentrate	Mg	906	885

Calculation of the mitigation potential of increased milk performance was estimated based on animal production coefficients and emission factors based on feed intake and food production. Estimates for emissions for concentrate feed vary in great ranges from 0.232 to 1.156 kg CO_{2eq} per kg feed (Lovett et al., 2006; Casey and Holden, 2005). Emissions for crop production, grass production and pasture were based on all inputs necessary to produce the desired product and N_2O emissions as a function of 1 % of all N input. Allocation of emissions to meat production was neglected, since meat production in both scenarios do not vary substantially. It can be assumed that meat production is slightly higher in the milk performance scenario. Hence, this assumption provides conservative mitigation potentials for the milk performance scenario.

Biogas scenario For the biogas scenario it has been assumed that the slurry from the dairy system along with plant substrates from cultivated corn were fermented in a biogas plant producing methane, which is combusted in a combined heat and power unit (CHP). To operate a 500 kW_{el} CHP with a capacity utilization of 93 % plant substrates from 260 hectare corn additionally to the dairy slurry are necessary. The mitigation potential of biogas production was estimated based on the potential substitution of fossil resources with renewable resources based on biomass. It is assumed that the electrical energy produced with biogas substitutes electrical energy produced with fossile ressources with GHG emissions of 612 g CO_2 kW_{el}^{-1}. CO_2 emissions due to the combustion of biomass based energy carriers were not accounted for since the released CO_2 was drawn from the atmosphere during plant growth before. However, all emissions due to corn cultivation including emissions from pre chains were accounted for. Greenhouse gas emissions due to the corn production were calculated according to the necessary inputs for corn production. We assumed diffuse emissions of methane during the fermentation process of 1 % of all produced methane. 0.5 % of methane was assumed to slip at the CHP. Requirements to support electric devices of the biogas plant have been set to 8 % of the produced electricity. The digestate is stored in a gastight storage to prevent GHG emissions and finally used as organic fertilizer, which substitutes mineral fertilizer. The average distance between biogas plant and fields is set to 5 km and for application a spreader in combination with an incorporation after 6 hours is assumed, leading to ammonia emissions of 28 % of NH_4-N and 1 % N_2O emissions.

Calculation of GHG emissions Gaseous emissions as CO_2, CH_4 and NH_3 were taken into account according to their global warming potential for a 100 year time frame (Table 4). Even though NH_3 is not considered as a greenhouse gas, it can be expected that part of the NH_3, which is released into the environment will be transformed to N_2O, which significantly contributes to the global warming effect. The default estimates of IPCC suggest that 1% of the NH_3-N will be emitted as N_2O-N into the atmosphere, which results in a GWP of 3.9 (Dong et al., 2006). The global warming potential is expressed as CO_{2eq}.

Table 4. Global warming potential of greenhouse gases

Gas	GWP	Reference
CO_2	1	Forster et al. 2007
CH_4	25	Forster et al. 2007
N_2O	298	Forster et al. 2007
NH_3	3.9	Dong et al. 2006

RESULTS

Mitigation potential of increased milk performance Increased milk performance per dairy cow substantially reduces GHG relevant emissions per kg milk. Related to the produced milk methane emissions are 11% less in the milk performance scenario than in the reference (26.4 g CH_4 kg^{-1} milk instead of 29.6 g CH_4 kg^{-1} milk). The methane emissions from cows and the replacement are reduced, even though the replacement rate is lower. Based on a milk production of 2.9 Million kg per year total mitigation potential sums up to 300 – 500 Mg CO_{2eq} (Table 5). This is a reduction of 0.1 to 0.2 kg CO_{2eq} per kg milk.

Table 5. GHG emissions from two milk production scenarios

	Reference	Milk performance
	($Mg\ CO_{2eq}$)	
Dairy cows	1,361	1,224
Calves and heifers	772	672
Emissions due to concentrate feed	210 – 1,047	205 – 1,022
Corn cultivation	138	411
Grass cultivation	621	323
Sum	3,148 – 4,170	2,835 – 3,652

GHG mitigation potential of anaerobic fermentation is higher than mitigation potential with increased milk performance. Table 6 shows emissions of different production processes to produce biogas and the credits for the substitution of electrical energy based on fossil resources. Furthermore, credits were accounted for avoided emissions due to covered storage of slurry and the fertilizer substitution effect of the digestate. In total almost 2 Million kg CO_{2eq} can be mitigated with the integration of a biogas plant. However, additional 260 ha are needed to produce the required plant material unless other resources can be used for this purpose.

Table 6. GHG emission and credits due to biogas production

	CO_2-Emission $Mg\ CO_{2\ eq}\ a^{-1}$)
Fermenter and CHP construction (annualized emissions)	8
Methane emissions from leakages (1 % of total methane production)	295
Electric energy consumption of the fermenter	198
Corn cultivation	602
Digestate storage	7
Application of digestate (incl. transport (5 km))	116
Credit for substituted mineral fertilizer	-150
Credit for avoided emissions during storage of slurry	-528
Substitution of fossil energy	-2, 504
Sum GHG mitigation effect	-1, 957

CONCLUSION Increased milk production per dairy cow and the introduction of a biogas plant into a dairy farm system have been identified as effective measures to mitigate GHG emissions with agriculture. While with increased milk performance less acerage is used for producing the same amount of outputs, the biogas scenario requires more ha to provide biomass resources for energy production. In both mitigation scenarios corn production is extended and less grassland is used.

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