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Estimation of the Green House Gas (GHG) emission from the Manure application system SyreN+

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Abstract

The effect on slurry acidification and substitution of mineral fertilizers from AN to NH_4^+ on the ammonia and Green House Gas (GHG) emission with the manure application system SyreN+ has been estimated for wheat crops under Danish and default European conditions. SyreN+ both reduce the ammonia emission and the GHG emission. To which extend depends on the actual situation and especially on the nitrogen fertilization level. Under the current Danish environmental regulation a maximum reduction in the GHG emission of 0.028-0.133 mio. ton kg CO_2-eq./ha is obtainable under given conditions. The major effect is primarily due to a reduced ammonia emission and a reduced leaching. Under European conditions is the potential effect larger, up to twice the effect of the Danish estimate. Also here is the major effect due to a reduced leaching.

Description of the manure application system

SyreN+ is liquid manure application system with hosing trails where the liquid manure is acidified with H_2SO_4 during application in the field. SyreN+ is a further development of SyreN. The SyreN version is only acidifying the liquid manure whereas SyreN+ is a further development where liquid NH_3 from a canister in the slurry application equipment can be added to the trailing hose during application to optimize the nitrogen application rate to actual crop need.

Description of the system can be found at http://www.biocover.dk/

The basic application system (SyreN) has been tested for ammonia emission in a VERA-test where a 49% reduction in the ammonia emission has been observed

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(SyreN VERA test). It is assumed that SyreN+ will have the same ammonia emission reduction potential.

The SyreN trailing hose system has been accepted as a BAT technology in Denmark. The trailing hose system application methodology has been accepted as an replacement for injection of animal manure in growing crops where otherwise injection is mandatory to abate the ammonia emission.

Background

EUs nitrate directive (http://ec.europa.eu/environment/water/water-nitrates/index_en.html) or other national regulations restrict the amount of nitrogen in animal manure in nitrate vulnerable zones to 170 kg N/ha in animal manure. This amount of nitrogen in animal manure is in many cases not sufficient for an optimal crop production and a second application with mineral fertilizer is often taking place. In this second application is normally used ammonium-nitrate (AN).

The advantage of SyreN+ in terms of GHG emission is among others:

- Fuel saving because only one application are sufficient in many cases
- AN can be substituted with NH_4^+ which has a lower GHG emission during its production phase
- The acidification of the manure with H_2SO_4 lowers the is ammonia emission into the air and hereby the indirect GHG emission
- The decreased ammonia emission increase the plant available nitrogen in the manure which either can increase the plant uptake or that the application rate can be lowered to the planned plant available nitrogen level
- If the application rate is lowered a secondary effect is a decreased leaching of nitrogen. This decrease also the N2O emission from leached nitrogen
- When animal manure is applied to the limits according to the Nitrate directive or other national legislation a surplus of phosphorous in relation to plant need is taking place. The SyreN+ system has therefore the ability to reduce the manure application rate to the crop need for phosphorous and increase the nitrogen application (NH_3) so that the optimum crop need is maintained in the same application run.

SyreN has been tested in different trials in Denmark in 2010-2012.

In official Danish trials in winter wheat an increased crop (dry matter) and protein yield were obtained compared to not-acidified trailing hose application (Trial no: 070101010 – wheat in 2010 and Trial no: 070101111 wheat in 2011). In winter wheat has an average increase in the crop yield of 4.5 Hkg kernel per ha been observed.

In cut grass for silage has an increase in yield and the protein content been found (Trial no: 030101010 cut grass in 2010, 030221212-001 cut grass in 2012).

In a green maize trial (Trial no: 030181111 maize in 2011) where acidified manure with SyreN were injected (not the trailing hose system) and compared with other manure injection systems no differences in crop yield were obtained. Based on this is it concluded that the increased crop and protein yield in the acidified trials is related to the lower ammonia emission which gives a higher availability of nitrogen for the crops.

Furthermore has Biocover A/S provided documentation from field measurements in wheat, winter barley and rape where yield data from actual fields was monitored with and without acidified slurry. The results from this vary from no changes in crop yield to increased yield. These results are not included in the calculations.

Methodology

Two different effect estimates has been calculated. One for winter wheat under Danish conditions and one for winter wheat grown under average European conditions.

For Danish conditions is used GHG data from the Danish GHG inventory (Nielsen et al. 2012). For European conditions is used basic data from the EMEP/EEA guidebook (EMEP 2013) and IPCC (2006) Tier 1 methodology.

GHG data from the production of mineral fertilizer is provided by Fertilizer Europe (Frank Brentrup, YARA, pers. communication).

Yield estimates for Danish conditions are from official Danish trials conducted by the Knowledge Centre for Agriculture (www.vfl.dk). Description of the trials can be found here: Landsforsøgene.

The replacement of AN with NH4+ is according to Knudsen (2013) assumed to lower the leaching with 2.5 kg N/ha. This is included in 3, 4, and 5.

The slurry is acidified to pH of 6.0 with an injection of 4 litre H_2SO_4 per ton slurry. In the VERA test was obtained a 49% reduction in the ammonia with 1.5 litre of H_2SO_4 per ton slurry giving a pH of 6.4. According to data provided by Biocover A/S is 4 litre per ton sufficient to give a pH of 6.0. It is assumed that a pH of 6.0 has a 75% reduction in the ammonia emission (out of TAN, Total Ammonical Nitrogen) compared to the default method with trailing hoses in growing crops.

The reference data used for the emission estimates are given in the Appendix.

Five different estimates are given for the Danish and the European conditions respectively.

1. Default methodology: Slurry application with trailing hose with maximum manure application rate and with supplemental Ammonium Nitrate (AN) in mineral fertilizer to maximum application rate
2. SyreN trailing hose application without correction for that the acidified slurry increase the nitrogen available in the soil for plant production and with the same amount of supplemental AN application as in the default scenario
3. SyreN+ application methodology where the AN has been replaced by NH_4^+.
4. SyreN+ application methodology where the NH_4^+ application rate has been reduced to the same plant available TAN in soil as with normal trailing hose application (method 1). This lower the NH_4^+ application compared to method (3)

5. SyreN+ application methodology where the application rate is adjusted to the plant need for phosphorous for winter wheat (22 kg P/ha/yr) according to the P content in liquid manure (source: the Danish Normative values) and adjusted to the same TAN availability in the soil as method 1. Here is a lower slurry application rate taking place because there is a surplus of P in the manure with an application rate of 170 kg N/ha. In terms of GHG emission is here an increased emission from fuel consumption because the total amount of slurry shall be hauled for a longer distance.

Results

For Danish conditions

In Table 1 is given the estimates for average Danish conditions.

Table 1. Emission estimates for Danish conditions.

Winter wheat, per ha		1	2	3	4	5
		Trailing hose and AN Default	No changes in min. Fert. SyreN	No changes in min. fert. AN replaced with NH4+ SyreN+	Optimized min. Fert to default level. reduction of NH4 to N app. rate. SyreN+	Optimized ammonium addition to optimum P level SyreN+
	N application rate (norm), kg/ha	159	159	159	159	159
	P (norm), kg/ha	22	22	22	22	22
	Cattle slurry, kg total N	170	170	170	170	141
	Cattle slurry, kg P	26.6	26.6	26.6	26.6	22.0
	TAN, %	60%	60%	60%	60%	60%
	TAN, kg/ha	102	102	102	102	84
	Utilization, %	70%	70%	70%	70%	70%
	N mineral fertiliser, kg AN/ha	40	40			
	N mineral fertiliser as NH4+/ha			40	20.2	40.8
	Ammonia emission, % of TAN	27.2%	6.8%	6.8%	6.8%	6.8%
	Ammonia emission slurry, kg NH3-N/ha	27.7	6.9	9.7	8.3	8.5
	Ammonia emission fertiliser, kg NH3-N/ha	0.36	0.36	0.00	0.00	0.00
	Ammonia emission total, kg NH3-N/ha	28.10	7.30	9.66	8.31	8.52
	N available in soil, kg/ha	130.9	151.7	149.3	130.9	130.9
	N applied, kg/ha	210	210	210	190.2	181.6
	Decreased leaching due to conversion from AN to NH4, kg N/ha	0	0	2.5	2.5	2.5
	Incerased yield, kg kernel/ha	0	450.0	450.0	0	0
	Incerased yield, kg straw/ha		270.0	270.0		
	Increased yield, kg N/ha	0	18.9	18.9	0	0
	Rootzone leaching, kg N/ha	69.3	69.3	66.8	60.3	57.4
	Stream leaching, kg N/ha	33.3	33.3	32.1	28.9	27.6
	Estuaries leaching, kg N/ha	24.8	24.8	23.9	21.5	20.5
GHG emission, field	Direct emission, kg N2O/ha	3.3	3.3	3.3	3.0	2.9
	Direct emission, kg CO2-eq/ha	983.4	983.4	983.4	890.7	850.5

	Indirect, ammonia, kg N2O/ha	0.44	0.11	0.15	0.13	0.13
	Indirect, ammonia, kg CO2-eq/ha	131.6	34.2	45.2	38.9	39.9
	Indirect, leaching, kg N2O/ha	0.50	0.50	0.48	0.44	0.41
	Indirect, leaching, kg CO2-eq/ha	149.1	149.1	143.7	129.6	123.6
Transport/Application	Fertilizer application, 1 appl,kg CO2/ha	4.5	4.5			
	Slurry application, 1 appl,kg CO2/ha	20.2	20.2	20.2	20.2	24.3
Liming	Changed emission, kg CO2/ha	0	98.0	98.0	98.0	81.2
Production	From mineral fert. Production, kg CO2-eq/ha (Yara Sluiskil)	129.6	129.6	107.6	54.3	109.8
	From mineral fert. Production,. kg CO2-eq/ha (European average)	170.8	170.8	121.6	61.4	124.0
	Production from mineral fert., kg CO2-eq/kg P ha. saved					-6.2
Total emission	kg CO2-eq/ha	1459.6	1460.2	1412.1	1238.8	1237.4
Increased kernel yield	kg CO2-eq/ha		1122	1122		
Total emission incl. change in yield	kg CO2-eq/ha	1459.6	686.0	637.9	1238.8	1237.4
Reduktion compared to default	kg CO2-eq/ha		773.6	821.6	220.7	222.2
Relative emission: default = 100	CO2-eq excl. bio substitution	100	100	97	85	85
Relative emission: default = 100	CO2-eq incl. bio substitution	100	47	44	85	85

The overall GHG emission estimate for the default application method is 1.459 kg CO_2-eq./ha. This amount includes only fertilizer, manure application and the related GHG emissions and not field preparation, sowing and harvesting. It can therefore as such not be compared with an average carbon footprint for what growing. The carbon footprint for wheat growing has in several investigations been estimated to app. 2000-2500 kg CO_2-eq./ha (See eg. Hillier et al. 2009).

The share of the total carbon footprint from mineral fertilizers are low in table 1 compared to the international studies where only mineral fertilizers has been used. This is because that the crop is primarily fertilized with animal manure.

Under Danish conditions an increase in the crop yield is seen. This is very likely due to the strict Danish fertilization rules where the allowed application rate is 10-20% under the economical optimum. In these cases acidification of the slurry increase the availability of nitrogen for the plants which then gives a higher yield. This effect is not included in the European estimate (Table 5).

The SyreN+ application system allows a shift from AN use to the cheaper NH_3. The difference in the GHG emission in the production facilities is 0.55 kg CO_2-eq/kg N for the optimized factories and 1.23 kg CO_2-eq/kg N for the average European factories. Because of the low application rates in Denmark with only an additional application of 40-50 kg N/ha in mineral fertilizer is the effect on the overall GHG emission limited if no correction of the plant availability is made. In this case will an increased yield be obtained. If the increased yield is taken into account the SyreN or the SyreN+ system will reduce the GHG emission with app. 800 kg CO_2-eq./ha compared to the default scenario with trailing hose. Beside the GHG effect is the ammonia emission reduced with app. 20 kg N/ha (scenario 2 and 3).

If the increased bioavailability of nitrogen is used to reduce the overall fertilization level (scenario 4 and 5) no increase in the yield is expected. In these cases a similar reduction of 20 kg ammonia/ha is expected. Because of the lower nitrogen application rate is a reduced leaching foreseen. In total this decrease the GHG emission with app. 220 kg CO_2-eq./ha or 15% lower than the default scenario. If compared to the general GHG foot print for wheat, the SyreN+ system reduce the carbon foot print with app. 10% per ha where the reference situation is trailing hose on growing crops.

Scenario 5 is optimized to plant need for phosphorous (P). If 170 kg slurry is applied a 20% over fertilization with P will take place and the application rate is therefore reduced to 141 kg N in slurry/ha combined with an increased NH_3 application. The overall effect on the GHG emission is as in Scenario 4, an reduction in the GHG emission with 220 kg CO_2-eq./ha.

The total effect on the national GHG balance on introduction of the SyreN+ system depends on the availability of slurry, future regulation on the N application rate for the system and the area which are treated with trailing hose on growing crops.

In table 2 is shown the estimated total amount of nitrogen in 2011 in Denmark in different slurry types in tonnes N. Approximately 75% of nitrogen in cattle manure is handled as liquid and for pig is 97% of the nitrogen handled as liquid.

Table 2. Total nitrogen in different types of animal manure in 2011. source: The Danish GHG inventories.

	Liquid	Solid manure	Deep Litter	Total
Cattle	75,290	1,887	21,974	99,151
Pigs	86,768	277	1,772	88,817
Poultry	159	1,468	5,489	7,116
Other	9,893	7	3,160	13,060
Sum	172,110	3,638	32,396	208,144

In table 3 is shown the share of the cattle and pig liquid manure applied in growing crops in 2011. It is known that injection in growing crops may damage the crop as well as has additional fuel costs. Introduction of SyreN and SyreN+ may therefore substitute the injection in these crops. The maximum potential of using SyreN and SyreN+ is estimated to 598,000 hectares.

Table 3. Per cent of liquid manure applied in growing crops (cereals and grass) and potential area. Source: The Danish GHG inventories.

	Pig slurry	Cattle slurry
Injected in growing crops	7	18
Trailing hose in growing crop	61	22
Total, per cent	68	40

Max. application rate (Danish rules), kg N/ha	140	170
Potential hectares	421,000	177,000

If scenario 2 and 3, with no reduction in the N application rate are implemented, no or only a very limited reduction in the GHG emission is foreseen. In scenario 3 where AN is substituted with NH_4^+ a reduction of 37 kg CO2-eq./ha is estimated. This gives an overall reduction of 0.028 mio. ton CO_2-eq./y if the full potential is utilized and that the input data are representative for all crops. If the fertilization level is reduced the overall potential is a reduction in the GHG emission of 0.133 mio. ton CO_2-eq./yr.

If the increased crop yield is taken into account in scenario 2 and 3 the total reduction/sequestration is 0.46-0.49 mio. ton CO_2-eq./yr.

For European conditions

In table 4 is shown the results for default European EF factors. For winter wheat is assumed a nitrogen fertilization level of 240 kg N/ha. Because of the relative high nitrogen application rate is not foreseen and increased crop yield. According to the EMEP/EEA guidebook evaporates 55% of TAN and acidification of the manure therefore gives a high reduction in the ammonia emission of 41 kg NH_3-N/ha in scenario 2 compared to the reference scenario. In scenario 3, 4 and 5 is the ammonia emission higher than in 2. This is due to that ammonia is applied in the mineral form by SyreN+ resulting in a higher ammonia emission. The leaching depends on local conditions and is extremely difficult to estimate. It has been estimated to 30% of N applied regardless of the nitrogen source.

The total GHG emission without basic soil treatment has been estimated to 2,298 kg CO_2-eq./ha. If AN is replaced with NH_4^+ a likely reduction in the GHG emission is 216 kg CO_2-eq./ha (scenario 2).

Because of the high fertilization level combined with acidification there is a high risk for over fertilization and the likely outcome is that the farmers reduce the application rate to plant need and scenario 4 is more likely. In this case a reduction in the GHG emission of approximately 500 kg CO_2-eq./ha is obtainable. A high share of this comes from a reduction in leached nitrogen which also will have co-benefits on the environment.

The overall reduction in the carbon footprint for a wheat crop under the default conditions could be as high as 20% but a more like percentage is 10-15 % as the default parameters often is reflecting a conservative estimate and that the estimate of the carbon footprint of app. 2,000 kg CO_2-eq./ha by Hillier et al. (2009) is reflecting a substantial lower nitrogen input.

Winter wheat, per ha	1	2	3	4	5
	Trailing hose and AN	No changes in min. Fert,	No changes in min. fert, AN replaced	Optimized min. Fert to default level,	Optimized ammonium addition to opti-

		Default	SyreN	SyreN+ with NH4+	SyreN+ reduction of NH4 to N app. rate.	SyreN+ mum P level
	N application rate (norm), kg/ha	240	240	240	240	240
	P (norm), kg/ha	22	22	22	22	22
	Cattle slurry, kg total N	170	170	170	170	141
	Cattle slurry, kg P	26.6	26.6	26.6	26.6	22.0
	TAN, %	50%	50%	50%	50%	50%
	TAN, kg/ha	85	85	85	85	70
	Utilization, %	70%	70%	70%	70%	70%
	N mineral fertiliser, kg AN/ha	121	121			
	N mineral fertiliser as NH4+/ha			121	84.7	99.3
	Ammonia emission, % of TAN	55.0%	6.8%	6.8%	6.8%	6.8%
	Ammonia emission slurry, kg NH3-N/ha	46.8	5.8	14.0	11.5	11.5
	Ammonia emission fertiliser, kg NH3-N/ha	1.09	1.09	0.00	0.00	0.00
	Ammonia emission total, kg NH3-N/ha	47.84	6.87	14.01	11.54	11.54
	N available in soil, kg/ha	158.2	199.1	192.0	158.2	158.2
	N applied, kg/ha	291	291	291	254.7	240.1
	Leaching, kg N/ha	87.3	87.3	87.3	76.4	72.0
GHG emission, field	Direct emission, kg N2O/ha	4.6	4.6	4.6	4.0	3.8
	Direct emission, kg CO2-eq/ha	1362.7	1362.7	1362.7	1192.7	1124.5
	Indirect, ammonia, kg N2O/ha	0.75	0.11	0.22	0.18	0.18
	Indirect, ammonia, kg CO2-eq/ha	224.0	32.2	65.6	54.0	54.0
	Indirect, leaching, kg N2O/ha	0.57	0.57	0.56	0.50	0.47
	Indirect, leaching, kg CO2-eq/ha	170.1	170.1	167.7	148.5	140.6
Transport/Application	Fertilizer application, 1 appl.kg CO2/ha	4.5	4.5			
	Slurry application, 1 appl.kg CO2/ha	20.2	20.2	20.2	20.2	24.3
Liming	Changed emission, kg CO2/ha	0	98.0	98.0	98.0	81.2
Production	From mineral fert. prod, kg CO2-eq/ha (Yara Sluiskil)	392.0	392.0	325.5	227.8	267.1
	From mineral fert. prod, kg CO2-eq/ha (European average)	516.7	516.7	367.8	257.5	301.9
	From mineral fert. prod, kg CO2-eq/kg P ha, saved					-6.2
Total emission	kg CO2-eq/ha	2298.2	2204.4	2082.0	1771.0	1720.4
Reduktion compared to default	kg CO2-eq/ha		93.8	216.2	527.2	577.8
Relative emission: default = 100	CO2-eq excl. bio substitution	100	96	91	77	75

Conclusions

Acidification of slurry and replacement of AN with NH_3 in the SyreN+ manure application system has been estimated to reduce both the ammonia emission and the GHG emission for wheat production. The estimated effect varies and depends very much on the local regulations, local manure application methodologies and local soils conditions. Under the current Danish environmental regulation a maximum reduction in the GHG emission of 0.028-0.133 mio. ton kg CO_2-eq./ha is obtainable under given conditions. The major effect is primarily due to a reduced ammonia emission and a reduced leaching. Under European conditions is the potential effect larger, up to twice the effect of the Danish estimate. Also here is the major effect due to a reduced leaching.

Appendix:

Reference data used for the emission estimates

Used reference values		
Nitrogen and Phosphor norm, Denmark	Wheat: 159 kg N/ha, 22 kg P/ha Spring barley: 119 kg N/ha, 22 kg P/ha Cut grass: 240 kg N/ha, 32 kg P/ha	Vejledning om Gødskning og harmoniregler, 1. August 2012-31. July 2013, Danish AgriFish Agency.
Nitrogen and Phosphor norm, Europe	Wheat: 240 kg N/ha, 22 kg P/ha	
Cattle slurry	Max. application rate: 170 kg N/ha TAN: 60% N in manure from dairy cattle: 129.3 kg N ab storage/year P in manure: 20.2 kg P ab storage/year Utilization rate of N in manure: 70% Kg N/ton slurry: 5,33	Vejledning om Gødskning og harmoniregler, 1. August 2012-31. July 2013, Danish AgriFish Agency. http://anis.au.dk/fileadmin/DJF/Anis/Normtal_2012_august_ny_2012.pdf
Ammonia emission from AN	0.9% of N applied	EMEP/EEA guidebook
Ammonia emission from slurry application, default value	28.6% of TAN for Danish conditions, 55% of TAN for European conditions	The Danish GHG emission inventories for Agriculture and EMEP/EEA guidebook
Ammonia emission from SyreN/SyreN+	75 % reduction compared to default value = 6.8% %	VERA-test and www.alfam.dk
Indirect N2O emission, Fraction of nitrogen leached from the root zone	0.330, Fraction of applied N and 0.3 for European conditions (IPCC Tier 1)	The Danish GHG emission inventories for Agriculture. Average fraction 2002-2011 and IPCC (2006)
Indirect N2O emission, Fraction of nitrogen applied leached to water sheds	0,158, Fraction of applied N and 0.3 for European conditions (IPCC Tier 1)	The Danish GHG emission inventories for Agriculture. Average fraction 2002-2011 and IPCC (2006)
Indirect N2O emission, Fraction of nitrogen applied leached to estuaries	0.118, Fraction of applied N and 0.3 for European conditions (IPCC Tier 1)	The Danish GHG emission inventories for Agriculture. Average fraction 2002-2011 and IPCC (2006)
Reduced leaching due to conversion from AN to NHH+	2,5 kg N/ha	Knudsen, L., 2013, Betydning af skift fra nitratholdig til ammoniumholdig gødning på kvælstofudvaskningen, Notat fra Videncenter for Landbrug.

Stem/Kernel ratio	0.6	The Danish GHG emission inventories for Agriculture.
N_2O emission factors	0,01 kg N_2O-N/kg N	IPCC 2006 Guidelines: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html
GWP	N_2O: 298	http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html
CO_2 emission from AN production	Yara production site, Sluiskil: 3.24 kg CO_2/kg N European average: 4.27 kg CO_2/kg N	Fertilizer Europe
CO_2 emission from NH_4^+ production	Yara production site, Sluiskil: 2.69 kg CO_2/kg N European average: 3.04 kg CO_2/kg N	Fertilizer Europe
CO_2 emission from phosphor production	1.35 kg CO_2/kg P	Fertilizer Europe, only emission from the factory
Fuel consumption for slurry application	7.6 l/ha	Håndbog til Driftsplanlægning 2009, Landbrugsforlaget, ISBN: 978-87-91566-24-0
Fuel consumption for mineral fertilizer application	1.7 l/ha	Håndbog til Driftsplanlægning 2009, Landbrugsforlaget, ISBN: 978-87-91566-24-0
CO_2 in diesel	2,654 kg CO_2/liter diesel	The Danish GHG emission inventories (www.dce.au.dk)
H_2SO_4, Molar weight	98.079 g/mol	
$CaCO_3$, Molar weight	100.0875 g/mol	
H_2SO_4, concentration	93%	
H_2SO_4, densitity	1,84 kg/liter	
H_2SO_4, application rate	4 liter/ton slurry	

References

EMEP 2009, EMEP/EEA air pollutant emission inventory guidebook — 2009,

www.eea.europa.eu/.../emep-eea-emission-inventory-guidebook-200...

IPCC 2006, Eggeston, S., et al. 2006 IPCC guidelines for national greenhouse gas inventories. www.ipcc-nggip.iges.or.jp/public/2006gl/

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