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Increased quality in statistics on crop residues and lime used as input to greenhouse gas inventories

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ABSTRACT

Updated and well documented agri-environmental statistics are key for the evaluation of national and international environmental goals and targets. The annual National Greenhouse Gas (GHG) Inventories according to the UNFCCC is one such example, and requires great amounts of input data. This paper focuses on methodological improvements of the statistics on crop residues and lime, which are needed to estimate the GHG emissions from the agricultural sector. Statistics Sweden conducts several surveys in the agri-environmental area and is the responsible government agency for the statistics on crop nutrients and cultivation measures in agriculture in Sweden. In a previous pilot study, coefficients for nitrogen in crop residues were reviewed, and compared with those used in the Swedish GHG calculations. Within the same project, updated official statistics were produced on the utilisation of crop residues, presented as shares of crop areas with different management in terms of crop residues. However, to make use of the new data in the GHG gas calculations, the areas need to be converted into quantities. This requires coefficients for the ratio between crop residue and yield. Stubble heights also need to be considered. A desk study was carried out to obtain updated coefficients for ratios between straw or tops and crop yield as well as for nitrogen content in the crop residues. The updated coefficients will increase comparability between the GHG inventories and other environmental reports, such as the OECD/Eurostat nutrient budget for nitrogen.

Regarding the estimation of GHG from lime used in the agricultural sector, annual sales statistics were used until the National Inventory Report for Sweden 2015 was submitted. However, indications of increased agricultural use of lime in the form of by-products that are not distributed through the ordinary market imply that sales statistics may no longer fully reflect the amount of lime applied to arable land. A test to move from sales statistics to statistics on farmers' actual use of lime has been conducted, utilising the existing sample surveys on fertiliser use and cultivation measures in agriculture. Data on farmers' application of lime to arable land were collected for the years 2010, 2012 and 2014. The questions covered type and amount of lime product and size of land area where lime had been applied. Results were compared with sales statistics for the years 2010 and 2012. It showed that for well-defined products available on the ordinary lime market, data from the sales statistics and from the sample survey were comparable and relatively similar. However, the sample survey showed larger total amounts of lime than the sales statistics. This was due to the application of lime products in the form of by-products from e.g. the paper and concrete industries, which were not completely accounted for in the sales statistics. Hence, for environmental monitoring, such as the GHG inventory, the statistics of farmers' lime application constitute a better basis for calculations, as it reflects the actual amount that is applied to soil and hence affects the natural environment.

Keywords: crop residues, nitrogen, straw, greenhouse gas, nutrient budgets, lime, sales statistics, sample survey, mixed mode

PAPER

1. Introduction

Updated and well documented agri-environmental statistics are crucial as they form the basis for several environmental reporting systems that in turn are needed for the evaluation of national and international environmental goals and targets. The annual National Greenhouse Gas (GHG) Inventories according to the United Nations Framework Convention on Climate Change (UNFCCC) is one such example, and requires great amounts of input data. Statistics Sweden conducts several surveys in the agri-environmental area and is the responsible government agency for the statistics on crop nutrients and cultivation measures in agriculture in Sweden. Statistics Sweden is also part of the consortium Swedish Environmental Emissions Data (SMED), which conducts the inventory and reporting of GHG.

This paper focuses on two of the input variables needed for the inventory of emissions from the agricultural sector, namely: estimates on the amount of crop residues that are left on the field and the amount of lime applied to soil. The specific aims are to:

- i) update the coefficients and the method to convert shares of land areas into quantities of nitrogen in crop residues

- ii) present a new methodology to collect data on the use of lime that reflects current situation in agriculture.

2. Crop residues

In a previous pilot study, coefficients for nitrogen in crop residues were reviewed (Andrist Rangel et al, 2013a; b). It was also observed that coefficients used in the Swedish calculations for the GHG inventory and for the OECD/Eurostat's nutrient budgets requested from all European Member states (MS) differed. Within the same project, updated official statistics were produced on the utilisation of crop residues, presented as shares of crop areas with different management in terms of crop residues. However, the areas need to be converted into quantities of nutrients before they can be applied in the GHG and nutrient budget calculations.

2. 1 Share of removed crop residues – definitions and source data

Crop residues are defined as dead biomass according to 2006 IPCC Guidelines (IPCC, 2006). In the model used in Sweden for estimating flows of nitrogen within the soil-plant-animal system for the GHG inventory, litter is considered to recirculate within the agricultural system as it is returned to the field mixed with the manure (Adolfsson, 2005; Swedish EPA, 2006). Hence, the litter, which constituted about two thirds of total removed crop residues in Sweden (Statistics Sweden, 1999), is therefore not included in the estimations of the removed part in the inventory. This corresponds with the estimations of nitrogen contribution from manure, since the excretion factors used in the calculations characterise freshly excreted manure and hence, stable litter is not accounted for on the input side. Hence, whether the part used for litter shall be treated as left on or removed from the field in the calculations depends on what the coefficient for applied live-stock manure describes, i.e. if it includes straw or not.

Until the reporting of 2014 year's emissions of GHG for Sweden (Swedish EPA, 2016) and until 2011 year's official Swedish nutrient balances (Statistics Sweden, 2013a) and OECD/Eurostat balances (OECD, 2012), input data on share of crop residue removal from fields originate from a survey from 1997 (Statistics Sweden, 1999). In that survey, three categories were used to describe existing management practices of crop residues on arable land at the crop level (hectares): "burnt on field", "incorporated into the soil" and "removed from the field". For the category "removed from the field", the area was further divided into four subcategories representing different uses (% of area): "fodder", "litter", "energy production" and "other uses". In 2012, a new sample survey on the utilisation of crop residues was carried out among farmers in Sweden (Andrist Rangel et al., 2013a; b; Statistics Sweden, 2013b). The results were presented and published as shares of crop areas.

2. 2 Crops harvested green

In the 2012 survey on crop residues, the category "burnt on field" was excluded since this type of land management is insignificant Sweden (Statistics Sweden, 1999). Instead, the category "harvested green" was added, which enabled new and more precise estimations of the areas from which straw and tops had been removed from the field as residues (=dead biomass) or as part of crop products harvested green (=live biomass), respectively. According to 2006 IPCC Guidelines, no above ground crop residues are generated from crop areas harvested green, except stubble. Comparisons of the results from the 1997 and 2012 surveys showed that if the area harvested green is not considered specifically in the questionnaire, there is a risk that the respondent (farmer) reports that area in the category "removed from the field" instead, and then into the subcategory "fodder". This seems to have occurred in the 1997 survey, and is notable for crops that in Sweden typically have a high share of the crop area being harvested green, such as mixed grain (Table 1).

In the interpretation of the results from the 2012 survey, the area harvested green of crop(T) should be deducted from the total crop area of crop(T), before the partition of different uses/management practices of "real" crop residues. If the area harvested green is not accounted for in the GHG inventory, the fraction of crop residues left on the field and corresponding N2O-emissions will be overestimated.

Table 1 - Crop residues from mixed grain according the 1997 and 2012 surveys on the utilisation of crop residues in Sweden.

Year	Crop area (ha)	Share of crop area (%)					Usage of crop residues from the area where residues have been removed from the field (%)			
		Harvested green[1]	Burnt on field	Ploughed into the soil	Removed from the field	⇨	Fodder	Litter	Energy prod.	Other
1997	30 200	n.a.	0	41	59		28	70	1	1
2012	15 900	19	n.a.	35	39		37	63	0	-

1) Per definition according to 2006 IPCC Guidelines, no above ground crop residues are generated from this area, except stubble.

n.a. = not analysed

Based on the categories as defined in the 2012 survey and the assumption that litter is circulating internally, the ideal estimation of above ground cereal crop residues that are left on the soil, $Above\text{-}ground_{Left}\ N_{(T)}$, that is needed for the GHG calculation, is given in equation 1:

$$Above\text{-}ground_{Left}\ N_{(T)} = (Area\ with\ grain\ harvest_{(T)} \times Grain\ yield_{(T)} \times R_{AG(T)} \times N_{AG(T)} \times (1 - Frac_{Remove(T)})) + (Area\ harvested\ green_{(T)} \times N_{Stubble(T)}), \qquad \text{(eq. 1)}$$

where

$$Frac_{Remove(T)} = (Frac_{Removed\ from\ the\ field} / (Frac_{Ploughed\ into\ the\ soil} + Frac_{Removed\ from\ the\ field})) \times (1 - Frac_{Litter})$$

Rag(t) = Ratio of above ground crop residues (including stubble) to grain yield for crop T

Nag (t) = Nitrogen content in above ground crop residues for crop T

$N_{Stubble(T)}$ = Nitrogen in stubble per hectare of area harvested green for crop T

Grain $yield_{(T)}$ = Actual annual grain yield in dry matter for crop T

Equation 1 has not been implemented in the Swedish GHG calculations yet. Areas for annual crops harvested green have been published for Sweden since at least the year 2000 (Swedish Board of Agriculture and Statistics Sweden, 2016). The use of Equation 1 would be an improvement in accuracy in the GHG inventory.

2. 3 Ratios between crop residues and yield

To make use of updated statistics on crop residues from the 2012 survey in the GHG calculations and in the nutrient balances, areas need to be converted into quantities (Equation 1). For this, data on crop grain yields combined with coefficients for the ratio between crop residues and yield (i.e. RAG) are needed. For cereals and oil seed rape, coefficients for RAG constitute the weight ratio between straw and grain. For other crops such as potato and sugar beets it is the weight ratio between tops and harvested yield.

Another factor to consider for cereals and oil seed rape is the stubble, as this is left on the field after harvest and should be included in the above ground crop residues, Above-ground N(T), according to 2006 IPCC Guidelines. Note that stubble will also be left on the field on areas where the whole crop has been harvested green, Area harvested green(T), i.e. areas not included in Area with grain harvest(T).

For the Swedish GHG inventory, coefficients for ratios between crop residues and yield (RAG) where reviewed and changed for a range of crops before the 2006 submission (Adolfsson, 2005). Adolfsson based a lot of his conclusions on a comprehensive study conducted by Mattsson (2005), who scrutinised and compiled results from previous analyses of crop material collected at Swedish field experiments from the 1950's and onwards. The coefficients are based on a total of 5 221 observations, from 536 trials and 278 different experimental sites. The coefficients from Mattsson were subsequently turned into area weighted means in terms of level of N fertilisation in Sweden (Adolfsson, 2005) using statistics on fertiliser use (Statistics Sweden, 2004). Adolfsson also suggested adding 25 percent extra on the calculated ratios to account for stubble. This was also implemented in the 2006 NIR submission (Swedish EPA, 2006).

Concerning crop residue removals in the calculations of nutrient balances, the 2013 Handbook on Nutrient Budgets (Eurostat, 2013) implies that methodology for county specific data should be coordinated with the GHG inventory. However, until the 2011 nutrient balances, the county specific data had not been harmonised in the different reporting systems. The study by Mattson (2005) is a comprehensive source of information for the cereal crops of winter wheat, spring wheat, winter rye, spring barley and oats. In addition, the suggestion by Adolfsson (2006) to account for different levels of N fertilisation is sound. However, for other crops such as sugar beets, potato and maize, further investigation was needed to obtain country specific coefficients. Therefore, an additional review was carried out in 2015, which resulted in an updated table for all crops (Table 2), which was used in the Swedish national nutrient balance calculations for 2013 (Statistics Sweden, 2015a). These are yet to be implemented in the OECD/Eurostat balances as well as in the GHG calculations.

Table 2 - Ratios of above ground crop residue to yield, RAG, dry matter/dry matter (d.m.); nitrogen content in above ground crop residues, NAG, (% of d.m.); and removed crop residues, FracRemove, (% of crop area) for crops in Sweden.

Crop	Ratio of above ground crop residue to yield (d.m./d.m.) (R_{AG})[a]	Nitrogen content, crop residue (% of d.m.) (N_{AG}*100)	Phosphorus content, crop residue (% of d.m.) (N_{AG}*100)	Removed crop residues[v] (% of crop area) ($Frac_{Remove}$*100)
Winter barley	0.70[b]	0.77[o]	0.12[l]	22
Spring barley	0.66[c]	0.77[c]	0.12[l]	10
Oats	0.71[c]	0.73[c]	0.12[l]	10
Winter wheat	0.70[c]	0.51[c]	0.12[l]	12
Spring wheat	0.77[c]	0.44[c]	0.12[l]	10
Triticale	0.78[d]	0.76[p]	0.12[l]	12
Winter rye	0.86[c]	0.59[c]	0.12[l]	22
Grain maize	1.00[e]	0.94[q]	0.21[q]	19
Mixed grain (cereals)	0.69[f]	0.75[f]	0.12[f]	27
Mixed grain (cereals and legumes)	0.76[g]	0.95[g]	0.14[g]	27
Winter rape	1.50[h]	1.07[l]	0.14[l]	5.5
Spring rape	1.13[i]	1.07[l]	0.14[l]	5.5
Winter turnip rape	1.50[j]	1.07[l]	0.14[l]	5.5
Spring turnip rape	1.13[k]	1.07[l]	0.14[l]	5.5
Peas	0.80[l]	1.18[l]	0.15[l]	1.4
Peas for conservation	0.80[m]	1.18[m]	0.15[m]	0.0
Oil flax	n.a.	1.43[r]	0.10[r]	57
Table potato	n.a	3.25[l]	0.20[l]	1.3
Potato for starch production	n.a	3.25[l]	0.20[l]	1.3
Sugar beets	n.a	2.25[l]	0.25[l]	0.7
Field beans	0.80[l]	1.18[m]	0.15[m]	2.2
Green fodder	n.a	2.0[s]	0.3[s]	0.0
Temporary grass for seed	0.84[n]	1.09[t]	0.15[t]	35
Temporary grass	n.a	2.4[u]	0.26[u]	0.0
Pasture	n.a	2.4[u]	0.26[u]	0.0

a) Not including the 25 % extra for cereals to compensate for stubble (see section 2.3); b) same as winter wheat c) Mattsson 2005 (area weighted according to Adolfsson (2006)); d) mean of winter rye and winter wheat; e) Spörndly; 2010 f) mean of spring barley and oats; g) mean of oats and peas; h) Gunnarsson 2009; i) 75% of winter rape according to Lindén in Gunnarsson (2009); j) same as winter rape; k) same as spring rape; l) Claesson and Steineck 1991; m) same as peas; n) source not identified; o) same as spring barley; p) mean of winter wheat and winter rye; q) estimated from conc. in grain and ensilage; r) S-E Andersson, pers com; s) wholecrop silage, Swedish Board of Agriculture 2015; t) assuming 80% straw from temporary grasses for seed. 20% straw from temporary leguminous crops for seed, Swedish Board of Agriculture 2015; u) Statistics Sweden 2005 and Andrist Rangel et al 2013a; v) derived from Statistics Sweden 2013b (see section 2.2)
n.a.= not analysed or not applicable

There was an overall trend with decreased ratios compared with the ones previously used in the nutrient balances, which resulted in lower amounts of crop residues compared with previous estimations (Statistics Sweden, 2015a). This can be explained by the increased use of short straw varieties. The coefficients in Table 2 were primarily compiled for use in nutrient balance calculations. Hence, they do not include the 25 percent extra for cereals to compensate for stubble, as the focus in these calculations is on the (net) removed part, and stubble is not included in the removed part in practice. Accordingly, the coefficients for cereals in Table 2 need to be adjusted when used for the GHG inventory, where the focus is on the (net) part that is left on the field, and hence, inclusion of stubble would be justified.

2. 4 Nitrogen contents in crop residues

In a previous study on P and N contents in grain and straw of winter wheat, spring barley and oats, (see Table 2 in Andrist Rangel et al (2013a; b)), it was concluded that there is a deviation between the coefficients used in the Swedish nutrient balance calculations and the GHG inventory. Hence, in connection with the review mentioned above on ratios between crop residues and yield, contents of nitrogen in straw and tops (NAG(T)) of all corresponding crops were also scrutinised to obtain a complete and updated table to use in the different statistical and policy reports (Table 2).

Nitrogen coefficients in the GHG inventory were updated for cereal straw for the 2006 submission. The new coefficients were suggested in the review by Adolfsson but originate from the compilation study by Mattsson (2005), which considers the effect of nitrogen fertilisation, and is based on more than five thousands observations (see section 3.2). During the scrutinisation it was concluded that Mattsson (2005) was the most comprehensive reference for Swedish conditions and the results were also in line with foreign studies (see for example Table VII in Appendix I in Andrist Rangel et al (2013a)). It was therefore decided that this reference could be used for the updating of N coefficients of cereal grain and straw in the national and the OECD/Eurostat balances. This increases the coherence between the nutrient balances and the GHG inventories. For other crops not included in Mattsson (2005), more investigation was carried out during 2015 and the resulting coefficients and references are listed in Table 2. The updated coefficients were used in the Swedish national nutrient balance calculations for 2013 (Statistics Sweden, 2015a) but are yet to be implemented in the OECD/Eurostat balances as well as in the GHG inventory.

3. Lime applied to arable land

Regarding the estimation of GHG from lime applied to arable land, annual sales statistics have been used until submission 2015 (Swedish EPA, 2015). However, indications of increased agricultural use of lime in the form of by-products from industry, not distributed through the ordinary market, imply that sales statistics may no longer fully reflect the amount of lime applied to arable land.

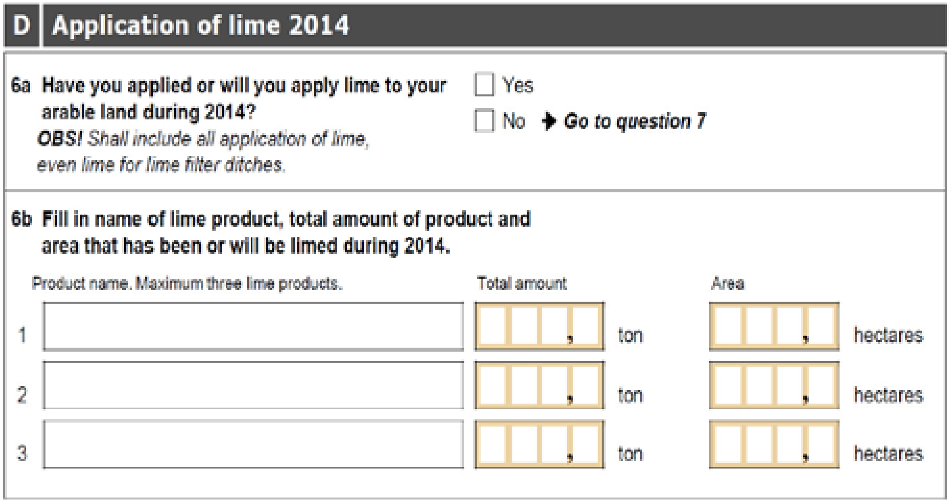
3. 1 Background

Annual statistics on sales of lime for agricultural and horticultural purposes have been produced and published since 1986 (Statistics Sweden, 2013c). Data have been collected from manufacturers, importers and retailers with the aim to cover the Swedish market. The time series published for sales of lime for agricultural purposes has been used in the GHG inventories until the reporting of the 2013 emissions (Swedish EPA, 2015). However, in the last 5 to 10 years substantial quantities of lime products have been detected that are not included in the ordinary sales records, and hence not included in the sales statistics. This is primarily lime in the form of by-products from the pulp- and paper industries. After discussions with the main users of the statistics, it was therefore decided to try changing from statistics on sales to statistics on actual use of lime in agriculture.

3. 2 Data collection from farmers on lime application

The existing sample surveys on fertiliser use and cultivation measures in agriculture were used as the frame for data collection and estimation of farmers' application of lime to arable land. Data were collected for the reference years 2010, 2012 and 2014. The sample sizes were 5 150, 3 650 and 3 000 agricultural holdings respectively for the three years. In the two first surveys, only telephone interviews were used, whereas in the survey 2014, "mixed mode" was used, using paper and web questionnaires with follow-up telephone interviews. The questions covered type and amount of lime product and size of land area where lime had been applied (Figure 1). Parallel to the new data collection, statistics on sales continued to be produced until the reference year 2012. This was to create a time period over which the two different sets of data could be compared, and also to keep the continuity in the sales statistics in case the new method did not turn out to be successful.

Figure 1 - Section on application of lime in the paper questionnaire from the sample survey "Cultivation measures in agriculture 2014" (translated from Swedish) (Statistics Sweden. 2015b).



D | Application of lime 2014

6a Have you applied or will you apply lime to your arable land during 2014?
OBS! *Shall include all application of lime, even lime for lime filter ditches.*

☐ Yes
☐ No ➜ ***Go to question 7***

6b Fill in name of lime product, total amount of product and area that has been or will be limed during 2014.

	Product name. Maximum three lime products.	Total amount		Area	
1		,	ton	,	hectares
2		,	ton	,	hectares
3		,	ton	,	hectares

3. 3 Results

One of the main outcomes of the new method of data collection, where the farmer could state and describe the type of lime, was that significant amounts of lime in the form of by-products were detected to be applied to agricultural land. Further research into the origin of these products showed that they were not always sold and/or distributed through the ordinary lime market, but could be free of charge for farmers and could for example be delivered by companies dealing with waste management. Hence, these products were not possible to detect through the sales statistics. Another obvious difference between the sales and the use statistics was that the former was a complete enumeration, whereas the latter a sample survey, and thus different in terms of estimation method. However, by using well-defined products available on the ordinary lime market such as lime produced as a co-product of the sugar manufacturing process, the two methods of estimations could be cross-checked. The outcome of the comparison was that data from the sample survey and from the sales statistics were comparable for these products.

The results from the sample surveys of 2010, 2012 and 2014 showed similar results in terms of limed area, with about 3 percent of the of arable land being limed (Statistics Sweden, 2015b). On the regional level, the corresponding value varied between 0.7 and 5.8 percent. The average application rate was also similar between the years, around 2 tonnes of CaO per hectare. However, the results showed a significant increase in the use of soil structure lime between the years 2010 and 2014. This was partly due to the introduction of subsidies for this specific type of soil management practice. The collected data were also used to estimate the amount of cadmium applied to soil via liming and the results were published in the statistical series for the first time. For 2014 it amounted to a total of ca 110 kg of cadmium, which can be compared with the amount applied via phosphorus fertilisers in Sweden, which was 82 kg in 2014/2015 (Statistics Sweden, 2016).

When data from 2010 and 2012 were compared with the sales statistics from corresponding years, the sample survey showed larger use than the sales. The difference could be explained by the quantities of by-products from e.g. the paper and concrete industries that were not accounted for in the sales statistics. This confirmed the assumption that the sales statistics no longer fully reflected the application of lime to agricultural land in Sweden. Another advantage with the sample survey was the possibility to estimate the uncertainty of the point estimate. With this as a basis, it was decided to change from sales statistics to statistics on actual use of lime. In the GHG inventory, the new estimates on lime usage available for the emission year 2010 and forward were implemented in the 2016 submission (Swedish EPA, 2016). Regarding time series consistency in the inventory, sales statistics were still used for the period 1990 - 2009, but there is no major effect as these by-products have only recently been introduced as lime products and were negligible before the turn of the century.

4. Conclusion

A review of the method of estimating the amount of crop residues has resulted in a recommendation of a more precise way to calculate amounts of straw and tops left on the field in the GHG inventory. The main suggestion for change is to include considerations of areas where crops have been harvested green. The review and updating of coefficients for ratios between crop residues and yield as well as for nitrogen contents in straw and tops is a step forward in the harmonisation process between the OECD/Eurostat nutrient budget compilation and the GHG inventory in Sweden. Using the existing sample survey on fertiliser use and cultivation measures for data collection and estimation of the application rate of lime to arable land has confirmed the hypothesis that significant quantities of lime in the form of by-products were not captured by the sales statistics. The new method has increased the quality in the statistical output compared to the sales statistics. For environmental monitoring such as the GHG inventory, statistics on farmers' application rates of lime to arable land constitute a better basis for estimation of CO2-emissions, as it reflects the actual amount that is applied to soil and hence affects the natural environment.

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