Internal Report | July 2013

Agricultural CH_4 and N_2O emissions in Switzerland

QA/QC

Author

Daniel Bretscher
Agroscope Reckenholz Tänikon Research Station (ART)

Agroscope

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Federal Department of Economic Affairs FDEA
Agroscope Reckenholz-Tänikon Research Station ART

Edition Notice

Daniel Bretscher

Agroscope Reckenholz Tänikon Research Station (ART)
Air Pollution / Climate Group

Reckenholzstrasse 191
8046 Zürich
Phone: ++41 44 377 72 50
Fax: ++41 44 377 72 01
Mail: daniel.bretscher@agroscope.admin.ch

Agricultural CH_4 and N_2O emissions in Switzerland

QA/QC

Date: March 2010

Last update: July 2013

Daniel Bretscher

Air Pollution / Climate Group

Agroscope Reckenholz Tänikon Research Station (ART)

Zürich-Reckenholz

Content

Important Comment:

Most findings of this QA/QC analysis refer to the Swiss National Greenhouse Gas Inventory submitted in 2013. However, in areas where no significant changes compared to older versions occurred, some data and conclusions might still refer to inventories of past submissions. In most cases this will be indicated in the text.

This document will be updated in regular time intervals to reflect the latest development of the Swiss National Greenhouse Gas Inventory.

Introduction

Climate change and greenhouse gas emissions are ever more in the focus of public attention. The national emission inventories have become important references in public and political debates. Accurate and reliable inventories are important tools for decisions makers when planning and implementing adaptation and mitigation strategies. Accordingly it is an important goal of the IPCC to support the development of national greenhouse gas inventories that can be readily assessed in terms of quality and completeness. To accomplish this goal it is good practice to implement quality assurance (QA) and quality control (QC) procedures. QA/QC activities should contribute to the improvement of transparency, accuracy, consistency, comparability, completeness and confidence of the inventory.

According to the IPCC Good Practice Guidance (IPCC 2000) quality control is a system of routine technical activities, to measure and control the quality of the inventory as it is being developed. Most of the QC related activities are thus covered by the inherent inventory development procedure such as standardized data file format or routine data transfers. Moreover sum checks and time series analysis are regularly conducted. Quality control activities are briefly described in a specific QC-checklist that has been designed following the requirements of Table 8.1 of the IPCC 2000 Good Practice Guidance (e.g. FOEN 2009).

Quality assurance activities include a planned system of review procedures conducted by personnel not directly involved in the inventory compilation/development process. While the underlying document has been elaborated by the inventory compilers themselves, most of the gathered information used to draw comparisons is originating from various research institutions and other organizations that can be considered independent in the above mentioned sense.

The underlying document should be understood as a working paper. It reflects the actual state of the QA/QC activities under consideration of the scientific information and temporal resources available for this purpose. It is meant to form the basis of future discussion and it is planned to elaborate updated versions in regular time intervals.

1. Activity data

Since most of the emission factors and other parameters in the Swiss greenhouse gas inventory are constant over the whole inventory time period, changes in CH_4 and N_2O emissions are mainly driven by changing activity data such as animal livestock numbers, fertilizer use or crop yields. Subsequently when analyzing temporal trends in greenhouse gas emissions quality of activity data is of crucial importance.

The assessment of agricultural statistical data in Switzerland is based on a number of different data collection procedures. The different assessment methods may be based on different methodologies and may use different livestock category definitions and disaggregation. Furthermore, different surveys may also differ in the degree of coverage of agricultural enterprises. Decisive for the in- or exclusion of farms may be the agricultural area, the presence of livestock, net production, the employment level or a combination of these criteria.

From 1866 until the end of the 20th century the Swiss Federal Statistical Office (SFSO) conducted the *Eidgenössische Viehzählung* (Federal Livestock Census). The last *Viehzählung* took place in 1993 and the program was then abandoned. Since 1905 the SFSO also conducts the *Landwirtschaftszählung* or *Landwirtschaftliche Betriebszählung (BZ S1)*, every three to five years. The BZ S1 is a comprehensive survey that incorporates all workplaces and employees of the primary economic sector. Since 1997 this survey is coordinated with the so called *Landwirtschaftliche Betriebsstrukturerhebung.* This new census program partly substitutes the *Landwirtschaftliche Betriebszählung* and is also conducted by the SFSO. It is coordinated with the Federal Office for Agriculture and the Cantonal Departments of Agriculture. Its basic population includes all agricultural farms which together generate at least 99 % of the overall agricultural production. Generally, for a farm to be included the following minimal standards are applied:

- 1 ha agricultural productive area;
- 0.3 ha specialized-crop (*Spezialkulturen*) (e.g. vines, orchards, berries, vegetables);
- 0.1 ha cultivation under protection (greenhouse, tunnel);
- 8 breeding sows;
- 80 fattening pigs;
- 80 fattening pig places;
- 300 poultry.

The *Landwirtschaftliche Betriebsstrukturerhebung* is mainly based on administrative data collected by the Cantonal Departments of Agriculture. This data serves as basis for the implementation of the agricultural policy and the evaluation of the entitlement for agricultural subsidies. Enterprises without agricultural subsidies are separately covered by an independent sampling in the course of the BZ S1. For the compilation of the respective information, the Swiss Federal Statistical Office works closely together with the Federal Office for Agriculture and the Cantonal Departments of Agriculture. The fundamental data is provided by the farmers themselves or their trustees. Farmers are obliged to report a vast set of statistical information in the context of the reporting for the “Proof of Ecological Performance” (PEP) that is linked to the payment of agricultural subsidies. In years of detailed surveys the statistical coverage is almost 100%. In years in between, various numbers are estimated based on evaluations of a subsample of approximately 1200 farms. It is noteworthy, that the used subsample is not necessarily representative for the whole of Switzerland and might therefore lead to systematic errors (Peter et al. 2006).

Most of the activity data used for the calculation of agricultural greenhouse gas emissions in Switzerland is taken from annual statistical compilations from the Swiss Farmers Union (SBV 2008, Grüter 2007) or directly from the Swiss Federal Statistical Office (SFSO 2009)(see Annex A). Most of the data relies ultimately on the different census mentioned above. The statistical yearbook of the Swiss Farmers Union is chosen because it combines the most important statistics needed for the agricultural greenhouse gas inventory in a clear and consistent compilation.

Since a couple of years some data of the Swiss Federal Statistical Office is available on an interactive web platform (SFSO 2012). Data in the greenhouse gas inventory are thus regularly cross checked with the respective data from the SFSO web platform.

Some data published by the SBV rely on preliminary estimates when reliable information is not yet available at the critical date of release. These numbers might be updated and corrected in years that follow first publication. The Swiss greenhouse gas inventory incorporates these updated values during a recalculation in order to rely on the most consistent and reliable statistical data.

1.1. Animal population data

All livestock data has been reassessed during a joint effort of the Agroscope Reckenholz-Tänikon Research Station (ART) and the School for Agriculture, Forest and Food Sciences (HAFL) in 2012 (ART/SHL 2012). Consistent and reliable time series for all major animal categories and subcategories for the time period 1990-2010 have been reconstructed as far as possible. In Switzerland scientifically data on animal characteristics (weight, feed intake, nitrogen-excretion, methane emission etc.) is mainly available from the “Principles of fertilization in arable and forage crop production” (Flisch et al. 2009). Hence, for the purpose of estimating data such as animal nitrogen excretion or greenhouse gas emissions, all livestock had to be regrouped according to the respective categories and subcategories. Different sources mainly from the Swiss Federal Statistical Office (SFSO) and the Swiss Farmers Union (SFU/SBV) have been consulted for this purpose. The newly generated time series shall form the common basis of actual and future assessments in the context of livestock husbandry in Switzerland.

For some animal categories characteristics such as nutrient excretions or feed intakes are expressed as excretion or intake per animal place. This has basically two implications: First, the yearly excretion or intake rate accounts for animal rotation when the length of stay of an animal in a specific (sub-) category is less than a year (e.g. yearly nitrogen excretion per fattening pig place lies between 12 and 17 kg N which corresponds to the nitrogen excretion of 3-3.2 fattening pigs raised from 25 to 100 kg (Flisch et al. 2009)). Second, an animal place may combine several animal sub-categories and consequently merge the respective nutrient excretions or feed intakes (e.g. the N-excretion of a goat-place includes all nitrogen excreted by a mother goat, all corresponding young and replacement animals as well as the nitrogen excreted by the corresponding share of male goats (Flisch et al. 2009)). Due to this combination the sum of all animal places within an animal category may not be equal to the total number of animals. Specifically, this is the case for sheep, goats and pigs. This procedure has led to some confusion among people that are not familiar with the respective statistics. However, the approach is necessary for statistic coherency and consistency.

1.1.1. Data sources

For the compilation of the Swiss Greenhouse Gas Inventory mainly the data published by the Swiss Farmers Union is used (e.g. SBV 2008). Data sources used by the Swiss Farmers Union to compile their statistical yearbooks are mainly the census of the SFSO and are listed in Annex A.

Despite of the large coverage of the census conducted by the SFSO there are some animals not accounted for in the official statistics (Kohler 2013). These are mostly animals held by private households as a hobby. The main categories that are affected are horses, mules and asses, sheep and goats. For horses as well as mules and asses a respective correction has been conducted (ART/SHL 2012). For all other categories differences are very small and missing data is difficult to assess. However further investigations will be conducted on this matter in the future.

In 2005 the Swiss Federal Veterinary Office (FVO) established a new framework for animal stock and traffic controls in order to prevent and combat eventual animal pests (FVO 2009). The respective regulations are defined in the “Decree on the Animal Traffic Database” from November 23rd 2005 (The Federal Authorities of the Swiss Confederation 2005). The basis of the “Animal Traffic Control” system is the registration of all farms and similar establishments where animals such as cattle, sheep, goats or swine (*Klauentiere*) are kept. Owners have to carry out stock controls and mark and identify their animals. Every cattle animal (and some other animals that are used for breeding) is provided with an individual ear mark that allows it’s monitoring from birth till slaughter. Since 2009 data of cattle livestock is exclusively collected by this “Animal Traffic Database” (*Tierverkehrsdatenbank*, TVD) that is updated continuously and published monthly by Identitas AG (TVD 2009). At present, the database also comprehends owners of other animals such as sheep, goats and pigs (*Klauentiere: Rinder, Schafe, Ziegen, Schweine*) but no further details on the numbers of animals themselves. It is planned to extend the animal traffic database to include detailed data of other livestock in the near future. In order to prevent redundancy, all data contained in the database is no more collected during the censuses of the SFSO.

1.1.2. Further quality checks and time series consistency of livestock data

The livestock population has been compared to FAO statistics. This has only been possible on an aggregated level, since FAOSTAT does not contain detailed data on a sub category level. In general all numbers are based on the same original data sources (Neuhaus 2007). Not surprisingly, differences between the recalculated data set presented here and the FAO data are rather small with a few exceptions that can be explained. In all cases the new recalculated data is considered more reliable than the FAO data. Basically for all numbers one possible explanation for differences is that the Swiss Farmers Union conducts data updates in subsequent years of first publication. The FAO database does not necessarily account for these updates. Consequently small differences in the order of ±2% may occur. Furthermore, for most animal categories there are disparities for the years 1994-1996. The data basis for these years is generally weak and differences may be due to different modes of interpolation. For horses, mules and asses disagreements are due to the different accounting of agricultural and non-agricultural animals. The Swiss inventory systems accounts for all animals no matter whether they are held on agricultural or non-agricultural enterprises. Moreover, animal numbers in the category mules and asses are in average 70% higher than the respective FAO numbers because the compilation presented here additionally encompasses ponies and lesser horses. The total number of poultry also shows some minor discrepancies due to different accounting for turkeys, ducks, geese, ostriches, pheasants, partridges and quails.

Livestock data used for the national statistics are generally available on a yearly basis and refer to the population on a reference date that is usually at the beginning of May. However, the exact number of livestock animals may vary during the year. Seasonal fluctuation of the cattle population has been analysed for the years 2005-2007 based on detailed information from the Swiss Farmers Union (SBV 2007). Fluctuations during the analysed years are usually in the order of ±3% with census data always slightly above the annual mean.

The new recalculated data according to ART/SHL (2012) has been compared to the data available on the STAT-TAB web access platform from the Swiss Federal Statistical Office (SFSO 2012). Accordance is very good with very few differences that can be readily explained in most cases. Some discrepancies for the year 1990 remain unexplained. No adjustments have been made for these numbers because the overall effect would be rather small and time series consistency might be jeopardized by adopting the STAT-TAB data.

Time series are generally considered to be consistent with two points that should be considered. First, between 1998 and 1999 the questionnaire for the collection of livestock data was modified. In some animal categories this led to minor ruptures in the time series. However, on an aggregated level the average absolute trend over all animal categories (excluding mature non-dairy cattle) for the years 1998-1999 (3.8%) was very close to the mean of the average absolute trend for the years 1990–2010 (3.3%). For some animal sub categories the effect may be more significant. However, usually this concerns shifts of animals within subcategories with very similar properties. Hence, the overall effect for emission inventories and balances is considered negligible. Second, for 2009 and 2010 cattle population statistics were not available from the censuses of the SFSO (*landwirtschaftliche Betriebszählung, Landwirtschaftliche Betriebsstrukturerhebung*). From 2009 onward cattle livestock data is exclusively assessed in the animal traffic database (TVD). Since the animal traffic database features only data of birth, translocation and death of the animals and does not include information on the animal's usage (breeding, fattening) the allocation to the categories of the "Principles of fertilization in arable and forage crop production" (Flisch et al. 2009) had to be specified independently. This has been done at the School for Agriculture, Forest and food Sciences (HAFL) based on the distribution of the respective animal categories between the years 2000 and 2008 (SHL 2010). For 2007 and 2008 data was available both for the official censuses from the Swiss Federal Statistical Office (SFSO) and the animal traffic database. This permits a comparison between the detailed animal population distribution according to the census and the estimated population distribution according to SHL (2010). The total number of cattle in the animal traffic database is slightly higher than the traditional census data from the SFSO. However, the number of mature dairy cows and mature non-dairy cows is nearly identical or slightly lower with the new assessment method. The latter is considered more robust. The highest differences occur for breeding cattle populations that tend to be slightly higher with the TVD data. Considering the overall problem of cattle livestock statistics a process has been initiated in 2011 in order to harmonize the respective data, integrating all involved authorities.

Further data on animal livestock properties is presented in chapter *2.1. 4A - Enteric fermentation* and chapter *2.2. 4B - CH4 emission from manure management*.

2. CH_4 emissions

2.1. 4A - Enteric fermentation

Methane emission from enteric fermentation is based on IPCC equation 4.14 (IPCC 2000; p. 4.26).

$$EF = \frac{GE * Y_m * 365\, days / y}{55.65\, MJ / kg\, CH_4}$$

GE = gross energy intake (MJ/head/day)

Y_m = methane conversion rate, which is the fraction of gross energy in feed converted to methane

55.65 MJ/kg = energy content of methane

Note that the number of days need not necessarily be 365. In the case of young cattle the number of days represents the length of stay in a specific category.

2.1.1. Animal livestock characteristics (gross energy intake, GE)

Detailed livestock characteristics for cattle are reported in Table 1 and Table 4 and can be compared with Table A-1 (p 4.31) and Table A-2 (p. 4.32-4.33) in section 4 of the IPCC Guidelines, Reference Manual (IPCC 1997). The information is compiled according to the methodological documentation by Soliva (2006) and based on data from the RAP feeding recommendations (RAP 1999), the Swiss Farmers Union (SBV 2008), Flisch et al. 2009 and default values from the IPCC.

For all cattle categories, gross energy intake is calculated according to the methodology developed by C. Soliva from the Swiss Federal Institute of Technology in Zürich (ETHZ, Soliva 2006). The method is based on the feeding recommendations published by the Agroscope Liebefeld-Posieux Research Station ALP (RAP 1999). The RAP energy assessment on the basis of net energy (NE) has a sound experimental basis which has been validated by numerous feeding trials. The respective recommendations are used by the Swiss farmers as basis for their cattle feeding regimen and for filling in application forms for subsidies for “Proof of Ecological Performance” and are therefore highly reliable. For the calculation of the NE-intake data, the animal’s weight, daily growth rate (weight gain), daily feed intake (DM), daily feed energy intake, and energy required for milk production and pregnancy for the respective sub-categories were considered (Soliva 2006). Category specific factors have been applied to convert NE into GE.

Dry matter intake has been calculated by dividing gross energy intake by the typical energy density of feedstuff (18.45 MJ/kg) and was then compared with animal weight. All values were in the range of ± 1.5 to 3% of the animal’s average body weight, satisfying the crosscheck recommended by the IPCC (1997). Furthermore, calculated estimates for total energy intake of the entire cattle livestock population has been compared with the respective data from the Swiss Farmers Union in 2010 (SBV 2008). The average absolute difference in the time period 1990-2004 was ±1.2%. According to the indications of the SBV, their estimates are also based on feeding requirements and the resulting figures are cross checked with total available animal feedstuff in Switzerland (Grüter 2007).

For all non-cattle categories data on energy intake are taken directly from the statistical yearbooks of the Swiss Farmers Union (SBV 2008, Annex A: Data basis of the annual statistics of the Swiss Farmers Union (SBV) (according to Grüter 2007)). Values are then corrected for feed losses and converted to gross energy. However the Swiss Farmers Union published energy requirement estimates only for the years until 2006. For subsequent years the respective data has been received directly by the responsible person from the SFU (Giuliani 2012).

Dairy cattle

In Switzerland dairy cattle are mainly fed with roughage and only few concentrate (~70-80% of dry matter; Schmid und Lanz 2013). Today, they are generally more productive than dairy cattle underlying the calculation of the IPCC default emission factor for Western Europe. They weigh on average 100 kg more (i.e. 650 kg) and the average milk production per head and day is 17 to over 60% higher. Consequently they have a greater feed energy intake and a higher emission factor than the 100 kgCH_4/head/year suggested in the emission inventory Guidelines (Table 1, IPCC 1997). The average implied emission factor for Swiss dairy cattle is comparable with the respective value of the European Community given in the “Synthesis and Assessment Report 2013” (UNFCCC 2013) (123 kg/head/year). Average fat content of milk during the inventory period has been constant and very close to 4% which is in line with the IPCC Guidelines (e.g. SBV 2008).

Mature non–dairy cattle

The category mature non-dairy cattle in the Swiss GHG inventory comprises only mature mother cows used to produce offspring for meat. Therefore the respective data cannot be compared to data from the non-dairy cattle categories of other countries. Average body weight of Swiss mature non-dairy cattle is 550 kg and average milk production is 2500 l/head/year. The feed intake is considerably lower than for dairy cows due to lower performance and a genetically based low feed intake capacity, which is typical for races used for meat production. Animals of this category can be compared with dairy cattle in Eastern Europe, as characterized in the 1997 IPCC Guidelines Table A-1 (p. 4.31). Milk production, feed energy intake and the enteric fermentation emission factor are similar to the respective default values.

Young cattle

Comparison of data from the young cattle categories in Switzerland with IPCC livestock characterization data is difficult due to the Swiss specific classification system. Generally weight gains are much higher and emission factors lower than default. A tentative calculation of energy intake following the methodology in the emission inventory Guidelines lead to much higher gross energy intake estimates than those used at present. The fact, that energy conversion factors are higher than IPCC default (i.e. more net energy per gross energy) indicates a better feed exploitation by animals in Switzerland. Therefore high feed quality together with high genetic standards of Swiss cattle i.e. higher energy use efficiency supposedly explains the above mentioned differences. Monni et al. (2007) identified feed digestibility (DE) as a very sensitive parameter significantly affecting uncertainty in estimates of greenhouse gas emission from enteric fermentation. Also the 2006 IPCC Guidelines recognize the importance of feed digestibility stating that a 10% error in estimating DE will be magnified to 12 to 20% when estimating methane emissions and even more (20 to 45%) for manure excretion (volatile solids) (IPCC 2006). Applying a rate of 70% rather than 60% in the formulas of the IPCC yields gross energy estimates that are closer to the values applied in the Swiss inventory. This is especially true for calves. High feed digestibility is not unusual in Switzerland as shown in Table 2. Another source of differences in energy intake estimates and subsequently emission factor may be that energy ingested from milk by calves is not accounted for in the country specific estimates. It is assumed that no methane is produced from milk energy (IPC 2000).

Other livestock animals

No sub-categories to calculate enteric methane formation were made for sheep and goats as in Switzerland they are mostly fed with the single purpose of meat production and no specific feeding regimes are differentiated. They contribute on average only 3.3% respectively 0.4% to total enteric and manure methanogenesis from agricultural livestock. Consequently a more detailed methodology is not justified.

Table 1 Data for estimating enteric fermentation emission factors for cattle livestock in Switzerland

Type	Age [a]	Weight[a] kg	Weight Gain [a] kg/day	Feeding Situation / Further Specification [a]	Milk [b] kg/day	Work hrs/day	Pregnant[a] %	Digestibility of Feed %[d]	CH_4 Conversion[d] %	Emission Factor kg/head/year[e]
Mature dairy cattle	n.a.	650	0.00		16.1 – 22.7[c]	0.0	305 days of lactation	60%	6.0%	123.03
Mature non-dairy cattle	n.a.	550	0.00		8.2[a]	0.0	305 days of lactation	60%	6.0%	80.71
Fattening calves	0-98 days	60-200	1.43	Rations of unskimmed milk and supplement feed when life weight exceeds 100 kg. Rations are apportioned on two servings per day.	0.0	0.0	0%	65%	0.0%	0
Pre-weaned calves	0-10 month	60-325	1.00	"Natura beef" production, milk from mother cow and additional feed.	0.0	0.0	0%	65%	6.0%	18.03
Breeding calves	0-4 month	50-120	0.80	Feeding plan for a dismission with 14 to 15 weeks. Milk, feed concentrate (100kg in total), hay (80 kg in total).	0.0	0.0	0%	65%	6.0%	26.58
Breeding cattle (4-12 months)	4-12 month	120-300	0.80	Premature race (Milk-race)	0.0	0.0	0%	60%	6.0%	
Breeding cattle (> 1 year)	12-28/30 month	300-600	0.80	Premature race (Milk-race)	0.0	0.0	0%	60%	6.0%	50.79
Fattening calves (0-4 months)	0-4 month	70-175	0.86	Diet based on milk or milk-powder and feed concentrate, hay and/or silage	0.0	0.0	0%	65%	6.0%	40.78
Fattening cattle (4-12 months)	4-12 month	175-550	1.30	Feeding recommendations for fattening steers, concentrate based	0.0	0.0	0%	60%	6.0%	

[a] data source: RAP 1999 and calculations by C. Soliva (Soliva 2006)

[b] Milk production in kg/day is calculated by dividing the average annual milk production per head by 365 days.

[c] data source: Swiss Farmers Union (SBV 2008).

[d] data source: IPCC 1997

[e] For better comparability emission factors of young cattle have been converted to kg/head/year although the time span of some of the individual categories is less than 365 days.

n.a. not applicable

Table 2 Comparison of methane conversion rates (Y_m) and feed digestibility's (DE) in studies representing Swiss feeding practices

Type in Literature	**Corresponding Type in National Inventory System**	**Feeding Regime**	**Y_m** %	**DE** %	***Reference***
9 week old calve	Breeding or fattening calf	Hay and concentrate	6.0		*Schönhusen et al. 2003*
Suckler cow together with calve	Mature non-dairy cow together with pre-weaned calve	Fresh cut grass	6.4	70.1	*Estermann et al. 2001*
Suckler cow calve	Pre-weaned calve	Free access to milk and hay	7.6		*Estermann et al. 2002*
Suckler cow	Mature non-dairy cow	Mixture of hay, grass silage and straw	7.7		*Estermann et al. 2002*
Dairy cow	Mature dairy cattle	Fresh cut grass	5.8	72.3	*Estermann et al. 2001*
Dairy cow	Mature dairy cattle	Forage and concentrate 3:2; fatty acids additives	6.4 / 6.6		*Külling et al. 2002*
Dairy cow	Mature dairy cattle	Grass supplemented with silage and concentrate	7.7		*Münger and Kreuzer 2006*
Dairy cow	Mature dairy cattle	Concentrate characterized by different carbohydrate type	7.4	64.7-71.6	*Hindrichsen et al. 2006a*
Dairy cow	Mature dairy cattle	Hay and grass silage / maize silage and grass silage	7.1 / 7.4	66.9 / 65.0	*Hindrichsen et al. 2006b*
Dairy cow	Mature dairy cattle	Hay and grass silage / maize silage and grass silage; both with concentrate (50%)	6.1 / 6.3	64.8 / 68.6	*Hindrichsen et al. 2006b*
Dairy cow	Mature dairy cattle	Hay	8.4	65.3	*Klevenhusen et al. 2008*
Dairy cow	Mature dairy cattle	Maize (grain & straw)	7.2	65.2	*Klevenhusen et al. 2008*
Dairy cow	Mature dairy cattle	Barley (grain & straw)	6.9	64.3	*Klevenhusen et al. 2008*
Adult castrate male sheep	Sheep	Diets rich in concentrate	7.4	68.8	*Machmüller and Kreuzer 2005*
Adult castrate male sheep	Sheep	Diet rich in roughage	6.4	66.3	*Machmüller and Kreuzer 2005*
Sheep	Sheep	Hay/concentrate mixture	7.5	68.5	*Machmüller and Kreuzer 1999*
Sheep	*Sheep*	*Hay, maize silage and concentrate mixture*	*4.3*	*72.8*	*Machmüller et al. 2003*

Adult sheep are considerably heavier than described in the IPCC Guidelines (60-80kg compared to 43kg). Nonetheless, Minonzio et al. (1998) argue that the IPCC default gross energy intake of 20 MJ is realistic for Switzerland. Values calculated for the Swiss inventory (21-24 MJ/day) are very close to this number. However, methane formation from enteric fermentation in sheep might be slightly overestimated, as the milk-fed lambs, included in the calculation, do actually not produce significant amounts of methane.

The data for goats cited by the IPCC (1997) are taken from Crutzen et al. (1986) and are based on a single study from India that is probably not representative for European countries. The values of Minonzio et al. (1998), i.e. a body weight of 55 kg and a daily gross energy intake of 32 MJ for and adult dairy goat are more appropriate. This GE intake rate is higher than the value of the Swiss Farmers Union (SBV) used in the Swiss inventory. The weighted mean for the whole goat population in Switzerland is 25 MJ gross energy intake per head and day. Given that goats have a rather lower body weight than sheep, the later value seems more realistic.

The horse genres, swine and poultry were also not further divided into sub categories as their contribution to total Swiss methane budget from livestock husbandry amounts to only 0.9%, 6.9% and 0.6%, respectively. The gross energy intake of horses, mules and asses has been revised during the 2012 and 2013 submissions. Values for horses are now very close to the value proposed in the IPCC Guidelines (i.e. 107 MJ per day compared to 110 MJ per day). Gross energy intake of Mules and Asses as estimated by the SFU has been questioned repeatedly by the UNFCCC expert review teams. Consequently a new assessment has been conducted in 2012 by the research institute ALP HARAS (Stricker 2012). The revised estimates are now considerably lower than before and also lower than IPCC default (i.e. 40 MJ per day compared to 60 MJ per day). The discrepancy can be explained by the fact that the population includes also light weighted ponies and asses (150 kg). All new estimates are based on solid data from Meyer and Coenen (2002). The calculated data for daily energy intake of swine are lower than IPCC default values (i.e. 26– 32 MJ compared to 38 MJ). Also this difference can be explained by the composition of the population that includes also young animals, while the IPCC default value is rather meant for adults animals.

More details on Swiss livestock characterization can be found in Minonzio et al. (1998) and Soliva (2006).

2.1.2. CH_4 conversion rate (Y_m)

The default values for the CH_4 conversion rates given by the IPCC Guidelines (IPCC 1997) are used in the Swiss inventory.

In their literature review on methane rates of cattle fed according to Swiss feeding practices Minonzio et al. (1998) conclude, that a rate of 6% corresponds well to Swiss conditions. Since then, various studies have been conducted at the ETH Zürich (Swiss Federal Institute of Technology) and in Germany in which energy turnovers of cattle and sheep have been analyzed (Table 2). Feeding schemes were comparable to those applied in Switzerland. The measured values for Y_m for cattle lie generally slightly above IPCC standards. More recent research results confirm these findings (Kreuzer 2012, Zeitz et al. 2012). A methane conversion rate for cattle livestock of 6.5% as suggested in the new IPCC Guidelines (IPCC 2006) might thus be more realistic. Currently further evaluations are conducted to implement the research findings in the national greenhouse gas inventory. A model approach is pursued that might integrate the energy and nitrogen flow through the digestive system and consider specific feed characteristics.

During the revision of the IPCC methodology for enteric fermentation in the year 2000 (IPCC 2000) the methane conversion rate for sheep has been set from 5% (also suggested by Minonzio et al. (1998)) to 7%. The later value is currently used in the Swiss inventory and is more appropriate for Swiss conditions as is also confirmed by the data in Table 2.

For goats, horses, mules and asses, and swine methane conversion factors are also IPCC default. Minonzio et al. (1998) suggested a methane conversion rate of 3.5% of the digestible energy for the horse genre. Assuming a feed digestibility of 70% this value can be translated into 2.5% of gross energy, which is the default value in the 1996 IPCC Guidelines. Furthermore Minonzio et al. (1998) propose a somewhat lower rate for swine (0.54 instead of 0.60) based on a study by Christensen et al. (1987). They argue that high values for Y_m are generally due to lower feeding intensity and untypical rations. Furthermore, they found that daily methane production increases with animal body weight. Actually, Swiss swine are fed at slightly lower intensity than suggested by the IPCC and are somewhat heavier than the 82 kg default weight. Accordingly, a high methane conversion rate of at least 0.60% seems justified.

Table 3 Comparison of enteric fermentation emission factors

Type	**EF Switzerland kg/head/year**	***EF IPCC (1997c) kg/head/year***
Sheep	9.8 - 11.0	*8*
Goats	8.1 – 9.1	*5*
Horses	17.5 – 17.7	*18*
Mules and Asses	6.4 – 6.6	*10*
Swine	1.0 – 1.3	*1.5*
Poultry	0.01 – 0.02	Not estimated

2.1.3. Emission factors

Enteric fermentation emission factors for cattle have already been discussed in the previous sections. Note that in order to calculate an annual emission factor, the categories breeding calves and breeding cattle 4-12 months are combined in the category breeding cattle 1st year. Subsequently the respective animals have two separate gross energy intake values, i.e. 26.9 MJ/head/day for the first 4 month and 89.2 MJ/head/day for the later 8 months. The same procedure is applied for fattening calves 0-4 months (GE = 55.6 MJ/head/day) and fattening cattle 4-12 months (GE = 124.6 MJ/head/day) summing up to the category fattening cattle.

For non-cattle animals implied emission factors show some differences when compared to IPCC default values (Table 3). As explained above, this is mainly due to the population composition that includes also immature animals and differing feed energy intake rates in Switzerland. For sheep only few countries reported higher values than Switzerland for 2011 (UNFCCC 2013).

Methane emission from enteric fermentation and especially the methane conversion rate Y_m can be significantly influenced by animal nutrition (e.g. Dämmgen et al. 2012a; Hadorn and Wenk 1996; Hindrichsen et al. 2006a; Külling et al. 2002; Machmüller and Kreuzer 1999). Dämmgen et al. (2012a) state that the use of a constant methane conversion rate is inadequate and that any approach to derive methane conversion rates has to reflect at least feed composition and feed properties. They evaluate a number of empirical models to predict methane emissions from enteric fermentation in dairy cows and concluded that the model of Kirchgessner et al. (1994) is still the most suitable for conditions in Germany. Currently, different feeding strategies are not considered in the agricultural greenhouse gas inventory. However, given the past development in Swiss feeding practices and the projected changes under future agricultural policies, corresponding inventory improvement possibilities are being explored. Moreover, the option to use feed additives for the purpose of methane emission reduction is explored at the moment in Switzerland. Accordingly a corresponding mechanism should also be implemented in future inventories.

2.2. 4B - CH_4 emission from manure management

Methane emission from manure management is based on IPCC equation 4.17 (IPCC 2000: p. 4.34).

$$EF = VS * 365\ days / y * B_0 * 0.67\ kg / m^3 * \sum_{jk} MCF_{jk} * MS_{jk}$$

VS = daily volatile solids excreted (kg-dm/day)

B_0 = maximum CH_4 producing capacity for manure

MCF_{jk} = CH_4 conversion factors for each manure management system *j* by climate region *k*

MS_{jk} = fraction of animal species/category's manure handled using manure system *j* in climate region *k*

Note that the number of days needs not necessarily to be 365. In the case of young cattle the number of days represents the length of stay in a specific category.

2.2.1. Volatile solids (VS)

For all cattle livestock categories excretion of volatile solids is calculated according to equation 4.16 in the IPCC Good Practice Guidance (IPCC 2000). For all other animal categories IPCC default values are used from table B-6 and B-7 in IPCC 1997.

Table 4 gives an overview over essential data for the calculation of the manure management emission factor. It can be compared with Table B-1 to B-7 in the 1996 IPCC Guidelines. Note that animal weight, feed intake, feed digestibility and ash content for non-cattle animals are not directly used in the calculation process in Switzerland, but have been included here to allow comparisons. Due to the particular cattle livestock characterization in Switzerland, comparisons with IPCC default values are problematic for the respective categories.

Energy intake and energy density of feed

In the case of cattle livestock animals the same gross energy intake data have been used for VS calculation as for enteric fermentation, assuring consistency. Energy intake and feed intake for young cattle livestock seem rather low compared to values suggested by the IPCC. Sheep and goats have higher values whereas values for swine and poultry are lower. These circumstances have already been discussed in the enteric fermentation section (*2.1. 4A - Enteric fermentation*). Values for feed energy density calculated on the basis of the information in Table 4 are with three exceptions close to the 18.45 MJ/kg suggested in the IPCC Guidelines (IPCC 1997). For fattening calves the calculated value of 23.57 MJ/kg is considerably higher, which can be explained by the content of energy rich milk in the diet and the otherwise energy rich feedstuff (milk: 24.19 MJ gross energy per kg dry matter, supplementation fodder: 22.04 MJ/kg (RAP 1999)). Goats have also a high energy density of the feed according to the data in Table 4 (Ø 21.54 MJ/kg). It has to be noted, however, that the feed dry matter intake estimates for mature cattle, sheep, goats and horses in Table 4 refer to "basal feed" only ("Grundfutter", usually roughage). In addition concentrate supplements might be fed to the respective animals relativizing the above mentioned energy density. An alleged low feed energy density is indicated for horses (13.82 MJ/kg). It is not yet clear if this low value is due to overestimation of dry matter intake in Flisch et al. (2009) or due to low feed quality.

Feed digestibility and ash content

The digestibility of feed is of crucial importance for the calculation of volatile solids. The 2006 IPCC Guidelines recognize the importance of feed digestibility stating that a 10% error in estimating DE will be magnified to 12 to 20% when estimating methane emissions and even more

(20 to 45%) for manure excretion (volatile solids) (IPCC 2006). According to the 1996 IPCC Guidelines the % DE values used for estimation of VS should be the same as those used to implement the Tier 2 method for enteric fermentation. Such a comparison is not possible here because Switzerland does follow a country specific approach to calculate enteric methanogenesis, where a conversion factor NE–GE is used rather than % DE. However, the RAP (1999) feeding guidelines used for the gross energy determination suggest a 60 % feed digestibility for ruminants which confirms the values adopted for VS calculation. Yet, various studies conducted at the ETH in Zürich and in Germany, where energy turnover of cattle and sheep held under conditions typical for Switzerland have been analyzed, found higher DE values between 64 and 73% (Table 2). As discussed in the chapter on enteric fermentation high feed quality and feed digestibility rates are not unusual in Switzerland. Therefore the low values used at present must be seen as a conservative estimate.

Values for feed energy density for the calculation of emissions from manure management are the same as for the calculation of enteric fermentation (i.e. 18.45 MJ/kg).

Minonzio et al. (1998) mention that the ash contents of the manures suggested by the IPCC and also used in the Swiss inventory are clearly too low. They state that the ash content in feed for swine is already 7% and in cow manure 14 to 20%. However, the significance of this discrepancy for the resulting VS values is relatively small.

Volatile solids

Since data for feed digestibility and ash content are IPCC default, the differences between calculated and default VS values reflect the differences in gross energy intake (Table 5). This difference is very small for mature non-dairy cattle. For mature dairy cattle the calculated value used in the inventory is higher than the default value. This is due to higher gross energy requirements as a result of high performance as described under *2.1.1. Animal livestock characteristics (gross energy intake, GE)*. Quite contrarily, the calculated value for swine is lower than IPCC default due to the inclusion of non-mature animals. Since the IPCC default value is used in the inventory in this case this might lead to some overestimation of total VS excretion. Calculated VS values for all young cattle categories and for mules and asses are lower and values for sheep and goats are higher than default. However, these discrepancies are of minor importance in the overall context.

Results by Minonzio et al. (1998) imply that the IPCC methodology overestimates the VS excretion by 20 to 60%. These authors suggest VS excretion data that are in generally lower than values in the Swiss inventory and in most cases also lower than IPCC default. Their estimates are based on indications of the general feeding doctrines. If this is true also the values in the Swiss inventory might be an overestimation. Yet, the calculations by Minonzio et al. are not beyond critics and the adoption of the more conservative IPCC default method is therefore considered to be more appropriate for Switzerland.

Another important point brought forward by Minonzio et al. (1998) is that fermentation might not only occur from volatile solids excreted by the animals but also from materials used for animal bedding. They argue that the manure management emission factor for mature dairy cows (and subsequently for all other animals with beddings) should therefore be 20% higher than generally calculated. However, the 2006 IPCC Guidelines state that since bedding materials typically are associated with solid storage systems that have low methane conversion factors, their contribution would not add significantly to overall methane production (IPCC 2006). Bedding materials are thus not included in the VS modeled under the IPCC Tier 2 method.

VS excretion values have been cross checked with the data on manure accumulation from the “Principles of Fertilization in Arable and Forage Crop Production” (Flisch et al. 2009). In this publication values for standard amounts of slurry (in m^3) and solid dung (in t) excreted per animal are provided, from which VS excretion can be estimated. A direct comparison is, however, delicate since the derivation of VS from data in Flisch et al. (2009) relies on some very rough assumptions. Especially assumptions on the use of bedding material can influence the outcome considerably. Nonetheless, values for the cattle categories agree fairly well with most discrepancies not exceeding ±10%.

Recently Staerfl et al. (2012) measured VS values under field conditions in Switzerland. The values were all in the range of 5.8 kg per mature dairy cow and day which is almost identical with the mean value in the inventory. However, given that the average milk yield of the investigated farms was above the mean milk yield of the inventory this might indicate, that the inventory currently overestimates VS excretion. This finding is also supported by the fact that the default feed digestibility of 60% used in the Swiss inventory is rather underestimated. Applying a higher feed digestibility of 65% might therefore be more realistic as already stated above.

Summarizing the results above, livestock VS excretion might be rather overestimated in the Swiss Greenhouse gas inventory. At least part of this overestimation might be compensated by the fact, that bedding material is currently not accounted for in the calculation of CH_4 emissions from manure management. Yet, adaptation of the feed digestibility for the cattle categories should be considered in the future.

2.2.2. Maximum CH_4 producing capacity (B_0)

The inventory is based on the IPCC default values for B_0. However, Minonzio et al. (1998) quote that the values for cattle are rather insecure and reported values cover a wide range due to different feeding regimes. Furthermore, they argue that the value for horses is very high, being almost one third greater than the one for mature dairy cattle. However, no alternative values are proposed. On the other hand, in a review Dämmgen et al. 2012b recommend B_0 values for Germany and Austria that are in line with IPCC default. However, the authors state that feed composition can have a strong influence on B_0. For Switzerland, Staerfl et al. (2012) also found that measured B_0 of cattle slurry varied between different feeding regimes, with values form cattle which received silage being higher than from cattle without silage. Furthermore, they found a considerable seasonal difference in B_0. Winter slurry had values slightly above the IPCC default value of 0.24 m^3*kg^{-1} while values for summer slurry were generally much lower at around 0.04 m^3*kg^{-1}. Reasons for this behavior are not yet fully explored. Different slurry age, differing VS-contents as well as temperature effects could be responsible for the encountered differences. Accordingly, Staerfl et al. (2012) recommend to further investigate CH_4 emissions with fresh slurry samples and standardized measurement protocols.

Table 4 Data for estimating manure management CH_4 emission factors in Switzerland

Type	Weight kg [a]	Digestibility of Feed % [b]	Energy Intake [c] MJ/day	Feed Intake kg/day	% Ash Dry Basis [b]	VS kg/head/day	B_0 m^3 CH_4/kg VS [b]
Mature dairy cattle	650	60	258-313	15.89 [d]	8	5.15-6.24	*0.24*
Mature non-dairy cattle	550	60	205.09	10.96 [d]	8	4.09	*0.24*
Fattening calves	60 – 200	65	47.62	2.02 [a]	8	0.83	*0.17*
Pre-weaned calves	60 – 325	65	55.73	2.98 [a]	8	0.97	*0.17*
Breeding calves	50 – 120	65	26.88	1.5 [a]	8	0.47	*0.17*
Breeding cattle 1	120 – 300	60	89.24	4.88 [a]	8	1.78	*0.17*
Breeding cattle 2	300 – 600	60	129.07	7.78 [a]	8	2.57	*0.17*
Fattening calves (0-4 months)	70 – 175	65	55.58	3.27 [a]	8	0.97	*0.17*
Fattening cattle	175 – 550	60	124.59	6.82 [a]	8	2.48	*0.17*
Sheep	Not determined	60	21-24	1.09-1.24 [d]	8	0.40 [b]	*0.19*
Goats	Not determined	60	25-28	1.21-1.25 [d]	8	0.28 [b]	*0.17*
Horses	Not determined	70	107-108	7.73-7.83 [d]	4	1.72 [b]	*0.33*
Mules and Asses	Not determined	70	39-40	Not estimated	4	0.94 [b]	*0.33*
Swine	Not determined	75	26-32	Not estimated	2	0.50 [b]	*0.45*
Poultry	Not determined	Not estimated	1.2-1.6	Not estimated	Not estimated	0.10 [b]	*0.32*

[a] *RAP 1999*

[b] *IPCC Default*

[c] *Country specific values calculated according to Soliva 2006*

[d] *Flisch et al.(2009): "basal feed" only ("Grundfutter", usually roughage)*

Table 5 Comparison of data on VS-excretion (kg/head/day)

	VS calculated according to IPCC	VS IPCC Default	VS calculated according to Minonzio et al. 1998
Mature dairy cattle	5.70	*5.08*	*3.87*
Mature non-dairy cattle	4.09	*4.13*[a]	*2.78*
Fattening calves	0.83	*1.46*	*0.65*
Pre-weaned calves	0.97	*1.46*	*0.76*
Breeding calves	0.47	*1.46*	*0.36*
Breeding cattle 1	1.78	*2.99*	*1.21*
Breeding cattle 2	2.57	*2.99*	*1.75*
Fattening calves (0-4 months)	0.97	*1.46*	*0.75*
Fattening cattle	2.48	*2.99*	*1.69*
Sheep	*0.45*	0.40	*0.30*
Goats	*0.52*	0.28	*0.36*
Horses	*1.68*	1.72	*2.62*
Mules and Asses	*0.62*	0.94	*0.96*
Swine	*0.39*	0.50	*0.31*
Poultry	*Not estimated*	0.10	*0.01*

Note: Values in italics are not used in the Swiss Greenhouse Gas Inventory
[a] Eastern Europe Dairy Cattle

2.2.3. CH_4 conversion factors (MCF_{jk})

The Swiss agricultural greenhouse gas inventory is based on default MCF's (IPCC 1997, 2000). Different values are adopted for solid storage, liquid/slurry, deep litter, pasture and poultry systems.

Both temperature and retention time play an important role in the calculation of the MCF. Manure that is managed as a liquid under warm conditions for an extended period of time promotes methane formation. In the IPCC Guidelines three climate regions are defined in terms of annual average temperature: cool (<15°C), temperate (15°C – 25°C), and warm (>25°C) (IPCC 1997, table 4-2). Switzerland has an average annual temperature below 15°C (MeteoSwiss 2009) and was therefore allocated to the cool climate region. The Swiss Farmers Union also publishes annual mean temperatures for the central plateau (SBV 2008). The long time average (1961-1990) is 8.7 °C. Seasonal, regional and diurnal temperature variation as well as storage time is not accounted for in the Swiss agricultural greenhouse gas inventory.

Different arguments have been brought forward that question the IPCC methane conversion factors and its suitability for Switzerland (Minonzio et al. 1998):

- The MCF-values have often been calculated based on small scale laboratory decomposition experiments that might not reflect conditions as found in practice (e.g. Amon et al. 2001).
- In the experiments to investigate the factors no bedding material was used which is typical for North American farming practices. However, Swiss farmers use considerable amount of bedding material when animal waste is stored solidly (1.5-2 kg litter per cow per day in stables with barriers; Flisch et al. 2009). Besides being a substrate for methane formation, bedding material can contribute to crust formation on slurry tanks, influencing aeration of liquid manure systems and leading to methane oxidation in the crust (e.g. Petersen et al. 2005).

- The temperature dependency of the MCF was also investigated in small scale experiments not necessarily representative for field conditions. Furthermore, as the processes inside the storage system are exothermic, substrate temperature may differ significantly from ambient air temperature (e.g. Dämmgen et al. 2012). The share of bedding material in the substrate can be one of the determining factors.
- Storage time is a determining factor for the MCF (Hindrichsen et al. 2006b; Külling et al. 2002; Külling et al. 2003, Zeitz et al. 2012). For solid storage in Switzerland it amounts on average 4 month which is in line with the usual time ranges used in experiments. However, manure in liquid form is stored for 4 month and more only in wintertime when temperatures are low (e.g. Staerfl et al. 2012). During summer it is applied frequently and storage time is therefore much shorter. Consequently the emission factor should be somewhat smaller.
- Animal manure is decomposed by a great number of microorganisms. The formation of methane is influenced by the composition of the population which is influenced again among others by temperature. Additionally, the amount of inoculums in slurry channels can influence methane formation significantly (Sommer et al. 2007).

The limitations of the MCF's become clear when comparing the IPCC estimates with measured values. For instance, Husted (1994) found manure values for swine to be considerably higher than IPCC default. This might be due to a large content of bedding material which led to a considerable temperature increase caused by aerobic bacteria. Accordingly, Minonzio et al. (1998) conclude that due to the extended use of bedding material in Switzerland CH_4 emissions from manure might be underestimated. On the other hand Safley et al. (1992) indicate a tendency towards lower methane production potential with increasing content of bedding material. Another factor with a strong influence on methane formation has been emphasized by Hindrichsen et al. (2006b). These authors found high variability in methane emission from stored slurry when animals were held under different milk production scenarios and feed concentrate supplementation. Furthermore, Steed and Hashimoto (1994) argue that a better estimate would take into account not only average annual storage temperature but monthly or quarterly averages. However, storage conditions may vary with respect to cover and depth below the surface, obscuring a simple relationship with ambient air temperature under practical conditions. The large influence of temperature on the MCF's has also been discussed by Sommer et al. (2007) and Møller et al. (2004). The later authors additionally emphasize the differentiation between aerobic and anaerobic processes during degradation of liquid slurry. Systems that are open to the atmosphere tend to have considerably lower emissions since there is more competition with aerobic bacteria. Subsequently ventilation, stirring, lagoon covers or natural crust covers should be taken into account when calculating CH_4 emissions from manure storage. These aspects have been included partly in the 2006 IPCC Guidelines, but are not yet considered in the Swiss inventory. According to Menzi et al. (1997) most of the liquid/slurry systems in Switzerland are covered (cattle: 80%, horses 100%, swine 65%). Finally, Amon et al. (2001) found a MCF value of 3.92% for anaerobically stacked farmyard manure in summer under conditions typical for alpine countries. They argue that most of the farmyard manure is currently stacked anaerobically and that therefore corresponding methane emissions might be underestimated by the IPCC default methodology.

For deep litter the 2000 IPCC good practice guidance suggest a MCF value of 39%. However, this would lead to a rather large overestimation of methane emissions from deep litter manure management systems in Switzerland. Since the 2000 IPCC good practice guidance state that the MCF's for cattle and swine deep litter are similar to liquid/slurry, the respective value from the 1996 IPCC Guidelines (IPCC 1997) has been adopted. This approach is supported by the following considerations:

- The national circumstances in Switzerland as an alpine country make it necessary to adopt a country specific approach since the IPCC default values are not necessarily adequate (Amon et al. 2001).
- In Switzerland long storage durations occur mainly in winter when temperatures are low.

- Most studies reporting MCF values for liquid/slurry and deep litter systems are based on swine manure. However, CH_4 emissions from cattle manure may be significantly lower than from swine manure as found by Sommer et al. (2007).
- Aerobic conditions at manure surface may lower CH_4 emissions as suggested by Amon et al. (2001) and Sommer et al. (2007). It seems therefore natural to apply a MCF factor for deep litter that is either equal or lower than for liquid/slurry.
- The following measurements of MCF values (mainly in slurry systems) support the adoption of a MCF of 10% rather than 39%: Amon et al. 2001, Külling et al. 2002, Külling et al. 2003, Moller et al. 2004, Hindrichsen et al. 2006, Park et al. 2006 and Sommer et al. 2007. Additionally the 2006 IPCC Guidelines suggest a MCF value of 17% (>1 month, ≤10°C) and 3% (<1 month) for cattle and swine deep litter. Considering the climate conditions and manure management practices in Switzerland, a mean value between 17% and 3% is reasonable.
- The assumption that all animals of the concerned (sub-) categories (i.e. calves, sheep and goats) are held under deep litter conditions is rather conservative. Recent surveys suggest that only a fraction of the manure is managed as deep litter (Agrammon 2010) while the rest would be managed as solid storage or liquid/slurry with MCF values of 1% and 10% respectively.

Generally more country specific information based on field measurement is needed to increase process understanding and reduce uncertainties for CH_4 emissions from manure management. Recently studies have been conducted to derive country specific emission factors for Switzerland (Zeitz et al. 2012, Staerfl et al. 2012), Germany and Austria (Dämmgen et al. 2012b) that take into account the specific agricultural structures and techniques. Dämmgen et al. (2012b) recommend distinguishing MCF values according to slurry type (cattle or swine) and storage conditions (coverage, crust formation). Generally they propose MCF values that are slightly above the values currently used in the Swiss inventory. On the other hand, measured MCF values under Swiss typical conditions clearly suggest that MCF values for liquid slurry and deep litter are clearly lower than the 10% currently used in the inventory (Zeitz et al. 2012). Although the contrary was true for MCF values of solid storage, Zeitz et al. (2012) conclude that overall, emissions from manure storage in Switzerland seem to be markedly overestimated when using the IPCC default values.

Since temperature, feeding regimes as well as animal and manure management practices can vary considerably between different regions in Switzerland (e.g. Alps, mountainous regions, Swiss Central Plateau), further improvement could be gained by developing regionalized MCF values and apply these to the respective cattle populations. Additionally different emission factors reflecting seasonal climatic condition could be adopted in the future (Husted 1994; Amon et al. 2001). This approach is also supported by the great seasonal differences in B_0 values found by Staerfl et al. 2012 and the conclusions of Zeitz et al. (2012).

2.2.4. Fraction of manure management systems (MS_{jk})

Two manure collection and storage systems are typical for cattle in Switzerland. The slurry system is applied in the buildings with slatted floors (tied or loose housing systems) collecting all excreta in the slurry (liquid/slurry storage), and the urine-rich slurry/farmyard manure system is typically applied in the traditional tied housing system (Menzi et al. 1997). In the later system faeces are largely retained by straw and added twice daily to a manure stack outside the building (solid storage), while the urine largely flows into an extra pit (liquid/slurry storage). According to Flisch et al. (2009) urine-rich slurry contains 90% of water and 10% of faeces, and subsequently does not pass the borderline between dry and liquid manure that can be drawn at 20% dry matter content (IPCC 2006). Calves, as well as sheep and goats, are mainly kept in deep litter systems, where dung is not removed for a long time (months). More details on housing and storage system can be found in FAL/RAC (2001), Flisch et al. (2009) and Menzi et al. (1997).

The fraction of animal’s manure handled using different manure management systems (MS) as well as the percentages of the grazing time was separately calculated for each livestock category (Table 6). The fractions are based on Flisch et al. (2009) and calculated within the Swiss ammonium model AGRAMMON (Agrammon 2010). Input data for the AGRAMMON-model for the years 1990 and 1995 is based on expert judgment and literature whereas data for 2002, 2007 and 2010 is based on extensive representative farm surveys. Values in between the assessment years have been interpolated linearly while values beyond 2010 are kept constant until new census results are available. The data clearly reflect the shift towards an increased use of pasture, range and paddocks and an associated decrease in solid storage. This is a major step forward compared to previous inventories where MS values were kept stable during the whole inventory period.

Table 6 Comparison of average manure management systems distribution for CH_4 (1990-2011) with IPCC default values (IPCC Guidelines 1996 Table B3-6)[a]

Type		***Manure Management Systems***			
		Liquid / Slurry	**Solid Storage**	**Pasture / Range**	**Other / Deep Litter**
	MCFs	*10%*	*1%*	*1%*	*0.1% – 10%*
Mature Dairy Cattle	Switzerland	66%	19%	14%	0%
	IPCC	40%	18%	19%	23%[b]
Mature Non-Dairy Cattle	Switzerland	43%	26%	31%	0%
	IPCC[c]	18%	68%	13%	1%
Young Cattle	Switzerland	46%	26%	22%	6%
	IPCC[d]	50%	0%	38%	12%
Sheep	Switzerland	0%	0%	33%	67%
	IPCC	*Not determined → MCF = 1%*			
Goats	Switzerland	0%	0%	12%	88%
	IPCC	*Not determined → MCF = 1%*			
Swine	Switzerland	100%	0%	0%	0%
	IPCC	73% [e]	21%	0%	6%

[a] *The IPCC GPG 2000 state that: "The IPCC default values for dairy cattle, non-dairy cattle, buffalo, and swine should be taken from Tables B-3 through B-6 of appendix B of Section 4.2 (livestock) of the Agriculture Chapter of the Reference Manual. The IPCC default values for all other animal species/categories should be taken from Table 4-21 of the Agriculture Chapter of the Reference Manual.*

[b] *20% Daily Spread with MCF = 0.1%*

[c] *Eastern Europe Dairy Cattle*

[d] *Non-Dairy Cattle*

[e] *Pit > 1 month*

2.2.5. Emission factors

Emission factors for CH_4 emissions from manure management in Switzerland are summarized in Table 7. Differences between IPCC default factors and country specific emission factors are mainly due to differences in the shares of manure management systems. Emission factors for mature dairy and non-dairy cattle are rather high. This can be explained by the larger share of manure that is stored in the liquid/slurry compartment which is associated with a high methane conversion factor (Table 6). In the case of mature dairy cows, the IPCC assumes in contrast to Switzerland, that 20% of the manure is managed as daily spreading with a very low MCF of 0.1%. No comparisons are possible for young cattle, as the IPCC does not offer comparable emission factors for these categories. High values for sheep and goats are due to the fact, that solid manure is handled as deep litter rather than as solid storage. Furthermore, in Switzerland manure from swine is almost exclusively managed as liquid/slurry explaining the higher emission factor. For poultry the updated MCF of 1.5% from the 2000 IPCC Guidelines is responsible for the difference in emission factor.

Methane emission factors for manure management from Switzerland were compared with the data given in the Synthesis and Assessment report 2013 (UNFCCC 2013). Values for mature dairy and non-dairy cattle were higher than average, probably due to the above mentioned reasons (high VS excretion and particular manure management system distribution). Emission factors for sheep are approximately five times the average and situated at the high end of the range. As explained above, this is probably due to the deep litter manure management system used in Switzerland. The contrary is true for swine, where the value is more than 30% lower than average but still higher than IPCC default. Main reasons are that other countries apply a higher MCF than 10% for liquid system (European Commission 2011) and the IPCC assumes a relatively high share of manure managed solidly.

Table 7 Average manure management CH_4 emission factors (1990-2011)

	Default Values (IPCC 1997) kg CH_4/head/yr	***Swiss GHG Inventory*** *kg CH_4/head/yr*
Mature dairy cattle	14.00	*23.08*
Mature non-dairy cattle	6.00[a]	*11.74*
Fattening calves	Not determined	*2.41*
Pre-weaned calves	Not determined	*1.63*
Breeding cattle 1	Not determined	*2.46*
Breeding cattle 2	Not determined	*5.42*
Fattening calves (0-4 months)	Not determined	*1.30*
Fattening cattle	Not determined	*5.38*
Sheep	0.19	*1.30*
Goats	0.12	*1.04*
Horses	1.39	*1.39*
Mules and Asses	0.76	*0.76*
Swine	3.00	*5.48*
Poultry	0.078	*0.117*[b]

[a] Eastern Europe Dairy Cattle

[b] MCF from IPCC 2000

2.3. CH_4 emission from agricultural soils

Soils are sources and sinks of atmospherical CH_4. Yet, when expressed as CO_2 equivalents, methane flows are far less important than nitrous oxide flows. N_2O emissions from agricultural soils in the European Union (EU-15) are estimated to account 327 Tg CO_2 equivalents while the CH_4 sink amounts only 6.3 Tg CO_2 equivalents (Boeckx and Van Cleemput 2001). Consequently the possible CH_4 sink of agricultural soils in Switzerland is not considered to be an important contributor to the greenhouse gas inventory.

3. N_2O emissions

Nitrous oxide emissions from agriculture are determined on one hand by the size of the nitrogen flows in the systems (N availability) and on the other hand by the relative share of nitrogen that is converted into nitrous oxide during the individual nitrification and denitrification processes (i.e. emission factors)(Figure 1). While total nitrogen inputs are fairly well known, data on the allocation to different pathways, such as specific manure management systems, leaching of nitrate or volatilization of ammonium, is less certain and the suitability and quality of N_2O emission factors is even harder to assess.

In the course of developing new environmental policies, several attempts have been undertaken to determine the total N-flows in Swiss agriculture (Peter et al. 2006; Menzi et al. 1997; Werder et al. 2004; Schmid et al. 2000; Spiess 1999; Reidy and Menzi 2005; FAL/RAC 2001, Flisch et al. 2009). Special emphasis has been put in the determination of the “nitrogen loss potential” (= N-surplus) which refers to the share of nitrogen input that is not fixed in plant materials and consequently lost for the agricultural system. The N-surplus can be determined reasonably well by building the difference between the amounts of nitrogen introduced into the system (N-fertilization) and the amount of nitrogen removed from the fields with plant biomass (N-uptake). Assuming that a substantial increase of soil nitrogen content is improbable, the remaining nitrogen is lost either as ammonia (NH_3^+ volatilization), nitrate (NO_3^- leaching) or during nitrification–denitrification as nitrous oxide (N_2O), nitric oxide (NO_x) or N_2. Additionally, some nitrogen may get lost as dissolved N. The separate assessment of these N-loss fractions, however, is more difficult and associated with considerable uncertainties (Werder et al. 2004, Amman et al. 2009). A validation of the nitrogen flow model by comparing a top-down (input minus output) with a bottom-up approach (individual N-loss- fractions) is hardly possible, since N_2 emissions due to denitrification has not been measured with sufficient precision up to now. N_2 emissions are therefore often treated as a residual factor.

Most of the calculation schemes for agricultural nitrogen flows in Switzerland are based on the same standard literature which is also used for the Swiss greenhouse gas inventory (Table 8). These publications summarize a vast range of scientific research that reflects the typical conditions of agriculture in Switzerland. Nevertheless, the outcomes of the individual N-Flow models can still be considerably different. The discrepancies are probably due to different interpretations of the literature and diverging basic assumptions. This is especially true for the share of manure that is managed as solid storage or the share of mineral fertilizer that is used outside the agricultural sector, for instance in home gardens or football fields (Peter et al. 2006).

3.1. Standard literature for the calculation of N-flows in Swiss agriculture

1994 Walter et al. published the “Principles of fertilization in arable and forage crop production” (*“Grundlagen für die Düngung im Acker- und Futterbau” GRUDAF*). It represents the basis of fertilizer management in Switzerland and contains among others data on standard crop yields, standard fertilizer requirements of different crop species, nitrogen contents of crops, crop residues and animal manure as well as data on nitrogen excretion by animals. 2001 FAL/RAC released an updated version of Walther et al. 1994. Values concerning crop production are mostly the same in both issues while values related to animal production have been updated based on new scientific findings and technical production changes. In 2009 Flisch et al. published another updated version of the “Principles of fertilization in arable and forage crop production”. Most livestock animal nitrogen excretion rates remained unchanged while crop related standard values were adapted according to new available data based on field experiments and other sources (Flisch 2010, personal communication).

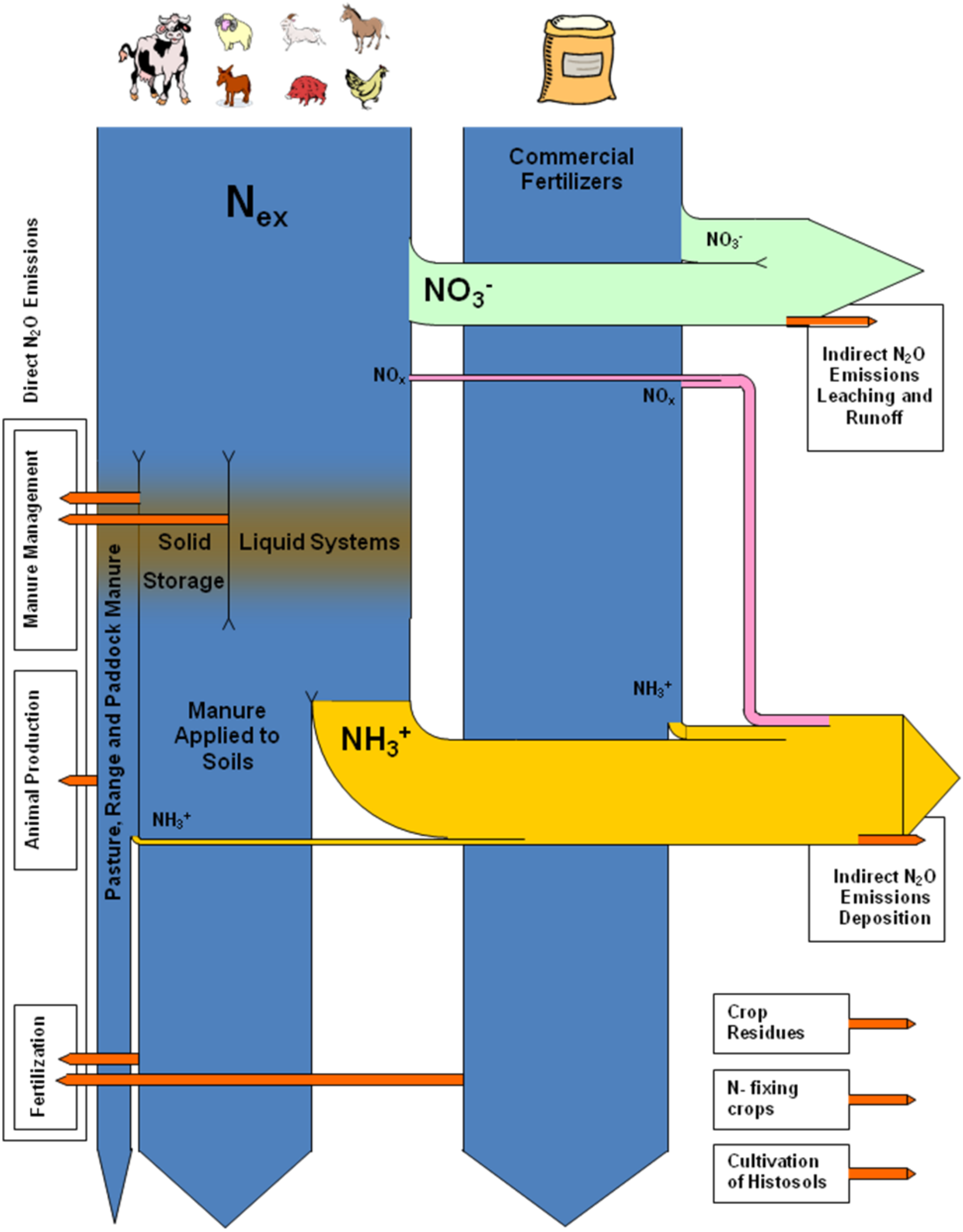

Figure 1 Nitrogen-Flow through the agricultural system and associated emissions of nitrous oxide (N_2O; red arrows). Note that the figure does not reflect mass flows nor the temporal sequence of the processes realistically but rather illustrates the nexuses within the calculation model of the Swiss agricultural greenhouse gas inventory.

While the “Principles of fertilization in arable and forage crop production” provide mainly information suitable for the calculation of nitrogen related activity data (nitrogen pools), the publications in the context of ammonia emissions can be used to model the flows of the nitrogen through the agricultural system. Formerly the ammonia models by Menzi et al. (1997) and Reidy and Menzi (2005) have been widely used both by scientists and policy makers. As FAL/RAC (2001) and Flisch et al. (2009) are updated versions of Walter et al. (1994), the model by Reidy and Menzi (2005) as well as the AGRAMMON-model can be understood as a revision of Menzi et al. (1997). The Swiss ammonia model AGRAMMON (Agrammon 2010) currently used for the Swiss greenhouse gas inventory is a publicly available web based tool for single farm assessments. Input data for national projections are available for the years 1990 and 1995 (expert judgment and literature) as well as for 2002, 2007 and 2010 (extensive surveys on approximately 3000 farms). Values in between the assessment years were interpolated linearly while values beyond 2010 are mainly kept constant until new survey results are available. Numerous plausibility checks have been conducted to assure data quality. Subsequently, the results are to a large extent independent from the personal views of individual experts and are thus more reliable than previous assessments. The model will be continually updated according to new scientific findings and changes in agricultural structures and techniques. Statistical projections of average national standard values will be done in regular intervals (Kupper et al. 2013). The most recent version and documentation should always be available from the website www.agrammon.ch .

Most of the standard literature described above is used by agricultural advisory centers and trustees. The documents serve as an orientation for planning and executing agricultural field work. This underlines the suitability of the used data as representative mean values for typical Swiss conditions. However, it is important to mention that values encountered in practice on an individual farm might differ substantially from these standards.

Once the nitrogen pools are determined and the nitrogen flow model has been established the emissions of N_2O can be assessed. Based on the works of Walter et al. (1994) and Menzi et al. (1997), Schmid et al. (2000) elaborated the IULIA model for the calculation of N_2O emissions in Switzerland. IULIA is an IPCC-derived method that basically uses the same emission factors, but adjusts the activity data to the particular situation of Switzerland. IULIA has been updated with new parameters derived from the Swiss ammonium model AGRAMMON (Kupper et al. 2013). New values for nitrogen excretion, manure system distribution and ammonium emission factors have been adopted. Furthermore the updated version of the "Principles of Fertilization in Arable and Forage Crop Production" (Flisch et al. 2009) have been used instead of obsolete data from FAL/RAC 2001 and Walther et al. 1994. Main differences between the IULIA/AGRAMMON method and IPCC are (Schmid et al. 2000: p. 74):

- IULIA/AGRAMMON estimates lower nitrogen excretion per animal category, especially due to lower excretion of young cattle.
- The amount of losses to the atmosphere from excreted nitrogen is almost 50% higher compared to IPCC.
- The amount of nitrogen leached (from manure nitrogen and of synthetic fertilizers) is lower by 1/3 compared to IPCC.
- Compared to the IPCC default method more manure is managed in liquid systems and less manure is excreted on pasture, range and paddock. Furthermore the manure management system distribution is not constant over the time series.
- The nitrogen inputs from biological fixation are higher by more than a factor of 30 since fixation on meadows and pastures are also considered. The consideration of nitrogen fixation from grassland is one of the major advantages of the method IULIA as the grassland accounts for the majority of nitrogen fixed in Swiss agriculture.
- The nitrogen inputs from crop residues are only 25% higher although emissions from plant residue on grasslands are considered. This is explained by the fact that the emissions from plant residues returned to soils on cropland are estimated 50% below the IPCC defaults.

Despite the different assumptions of the two methods, differences at the level of the N_2O emissions are quite moderate. In a comparison of the 1996 N_2O inventory, IULIA estimations of the N_2O emissions from agriculture were approximately 15% lower than the IPCC estimations (Schmid et al. 2000: p. 75). This comparison has been made with the original IULIA model in the year 2000. Since then the model has been developed further (e.g. implementation of the AGRAMMON model) and the original IULIA model has lost its validity in many aspects. A comprehensive comparison as conducted by Schmid et al. 2000 has not been made since.

Table 8 Standard literature used for the calculation of N_2O emission from agriculture in Switzerland

Data	Reference	Comment
Agricultural census data	Swiss Farmers Union (SBV) Swiss Federal Statistical Office	
Nitrogen excretion of livestock animals	Walther et al. 1994 FAL/RAC 2001 Flisch et al. 2009 Schmid et al. 2000 AGRAMMON 2010	Principles of fertilization Update of Walther et al. 1994 Update of FAL/RAC 2001 N_2O Model IULIA Current NH_3 Model
Composition and handling of animal manure (shares of manure management systems)	Menzi et al. 1997 Reidy and Menzi 2005 Walther et al. 1994 FAL/RAC 2001 Flisch et al. 2009 Schmid et al. 2000 AGRAMMON 2010	NH_3 Model Update of Menzi et al. 1997 Principles of fertilization Update of Walther et al. 1994 Update of FAL/RAC 2001 N_2O Model IULIA Current NH_3 Model
NH_3 emission factors	Menzi et al. 1997 Reidy and Menzi 2005 AGRAMMON 2010	NH_3 Model Update of Menzi et al. 1997 Current NH_3 Model
Standard fertilizer requirements / Standard crop yields / Nitrogen contents of crops and crop residues	Walther et al. 1994 FAL/RAC 2001 Flisch et al. 2009	Principles of fertilization Update of Walther et al. 1994 Update of FAL/RAC 2001
Leaching and run-off (NO_3-losses)	Braun et al. 1994 Prasuhn and Braun 1994	P- and N-Surpluses P- and N-losses to water bodies
N_2O emissions	Schmid et al. 2000	N_2O Model IULIA
Nutrient balances of Swiss agriculture	Spiess 1999	Nutrient balance of Swiss agriculture

3.2. Framework conditions and basic assumptions

In order to put the factors determining the nitrogen flows in Swiss agriculture into a broader context, agricultural structures and policies should be considered (Box 1). Ecological measures that have been implied since 1993, providing financial incentives for environmental services, have caused a sharp increase towards a more “eco-friendly” agricultural system. Namely integrated production (IP) and, to a minor extend, organic farming have shown a steady increase since the early 1990s. This has led to a significant decrease of the use of mineral nitrogen fertilizers and a more careful application of manure based fertilizers. Moreover higher production efficiency allowed a reduction of livestock population numbers while maintaining the production level of animal based food, thus reducing the total amount of animal manure nitrogen. This led to a reduction of the nitrogen loss potential (= N-surplus) and subsequently to reduced losses of environmentally relevant nitrogen components such as NH_3^+, NO_3^- and N_2O (Peter et al. 2006; Herzog and Richner 2005).

Reduction of ammonia emissions has received particular attention during the past years. Reidy et al. (2008) concluded that about two thirds of the ammonia emission reduction from livestock production and manure management between 1990 and 2000 could be attributed to reduced overall livestock numbers as a consequence of changed market conditions and technical progress. One third of the reduction was the result of improved farm and manure management primarily induced by new nutrient balance legislation and improved awareness of farmers. Specific measures that have been implemented are reduced mineral fertilizer use, use of low emission manure spreading techniques, increased grazing and use of low protein diets for pigs. Decreasing animal numbers and improved management techniques were to some extend counterbalanced by the rapid increase of loose housing and other animal welfare-friendly systems such as the introduction of hardstandings for cows and to some extend also for pigs.

Box 1:

Agricultural structures and policies in Switzerland (form Leifeld and Fuhrer 2005)

Since 1993, the Swiss federal government has given financial support to national programs applied to the agricultural sector and affecting all sectors of agricultural production, including plant production, soil and ground water protection, and animal welfare. In 1998, a new agricultural law linked all direct payments to the provision of the “Proof of Ecological Performance” (PEP). This program aims at comprising an overall scheme of measures particularly respectful to the reduction of environmental risks. Integrated production (IP) and organic farming are favored as special voluntary efforts with direct payments, and monetary incentives are no longer coupled to production. This policy contains key elements of the so called “cross compliance” mechanism of the EU, which is a major element of the fundamental reform of the European Agricultural Policy (CAP).

Key points of IP in Switzerland are a balanced use of nutrients, a diversified crop protection, a share of 7% of ecological compensation areas, and a soil protection scheme, encouraging soil covering in order to prevent erosion. A balanced use of nitrogen is chargeable when nitrogen inputs (mineral N + (manure N – NH_3 loss)*0.6%) equal standard nitrogen requirements of the cultivated crops (nitrogen outputs) ±10% on the farm level. Regarding animal husbandry, direct payments are coupled to maximum stocking densities, which in turn depend on the climatic region. Directives of PEP apply similarly to organic farming, where additional constraints, in particular, a more restrictive use of mineral fertilizer input, are to be considered. Implementation of the national programs in 1993 and the PEP in 1998 was followed by continuous increase in the share of both, IP and organic farming. In 2001, both agricultural systems together covered more than 95% of the agricultural useful area.

General indexes of Swiss agriculture (2003) are a 26% share of arable rotations, of which 30% are leys (intensively managed temporary grasslands), and 73% share of permanent grasslands, about half of it (500’000 ha) alpine meadows and pastures with comparable low productivity. Altogether 37% of the country’s area is covered by agriculture. These key figures stress the importance of animal production in Switzerland, in consequence of natural conditions which favor grasslands as the major fodder source for the animal herd.

The Swiss greenhouse gas inventory reproduces very well reductions in animal population. The most recent version also considers some of the technical measures and alteration of agriculture structures that alter nitrogen flows. Most prominent, manure management system distribution (MS) as well as ammonia volatilization ($Frac_{GASF}$, $Frac_{GASM}$) are modeled dynamically and reflect ongoing development in agricultural practices. However, some parameters, and especially some emission factors, may depend on load as stated in the IPCC Good Practice Guidance (IPCC 2000). Accordingly the extent to which standard nitrogen requirements of the crops are surpassed, determines to a certain degree the nitrogen loss rates to the environment (e.g. Schmid et al. 2001; Werder et al. 2004). At present, the scientific basis is, however, not considered sufficient to take these aspects into consideration.

Agro-political framework conditions change constantly. The government defines and adjusts agro ecological objectives and general national environmental agreements. The current “Agricultural Policy 2011” as well as the future agricultural policy for 2014-17 include the program “Sustainable use of natural resources” which includes among others an instrument to promote the nitrogen use efficiency. Furthermore Switzerland is member of various international conventions and is legally bound to fulfill the respective commitments. To reach the predefined targets agricultural policies are adapted and adjusted periodically and new measures are implemented. In order to survey the progress in the specific areas, various monitoring activities have been established. If the ecological measures are pursued systematically, a further reduction of the nitrogen flows and consequently of the nitrogen loss potential can be expected. Additionally, macro economical arrangements and technological trends have to be considered, as they influence national agricultural production. The Swiss greenhouse gas inventory, at its current state, reproduces some of the expected changes via the AGRAMMON model which is periodically improved and updated. On the other side, there are still various parameters, specifically nitrate leaching and values related to crop residues and biological nitrogen fixation that are static and will not reflect developments in agricultural practices. However these effects are considered to be rather small. Further evaluations have to determine how much effort will be assigned to the improvement of the model in this respect.

For more information about Swiss agricultural policies in the context of nitrogen related emissions, the report of Peter et al. (2006) gives a more detailed overview.

3.3. 4B - N_2O emission from manure management

Calculation of nitrous oxide emission from manure management is based on IPCC equation 4.18 (IPCC 2000: p. 4.42).

$$(N_2O-N)_{(mm)} = \sum_{(S)} \left\{ \left[\sum_{(T)} \left(N_{(T)} * Nex_{(T)} * MS_{(T,S)} \right) \right] * EF_{3(S)} \right\}$$

$(N_2O\text{-}N)_{(mm)}$ = N_2O-N emissions from manure management (kg N_2O-N/yr)

$N_{(T)}$ = number of head of livestock species/category *T*

$N_{ex(T)}$ = annual average N excretion per head of species/category *T* (kg N/animal/yr)

$MS_{(T,S)}$ = fraction of total annual excretion for each livestock species/category *T* that is managed in manure management system *S*

$EF_{3(S)}$ = N_2O emission factor for manure management system *S* (kg N_2O-N/kg N in manure management system *S*)

S = manure management system

T = species/category of livestock

3.3.1. Animal population data ($N_{(T)}$)

Assessment of livestock population data in Switzerland has been discussed in Chapter *1.1. Animal population data*.

3.3.2. Annual average nitrogen excretion ($Nex_{(T)}$)

Annual average nitrogen excretion (N_{ex}) is a key figure for N_2O emissions from manure management as well as for N_2O emissions from agricultural soils.

Estimates for nitrogen excretion of the individual livestock categories are based on Flisch et al. (2009) and calculated within AGRAMMON. All indications on the amount and composition of manure are based on calculations by means of feeding schedules with different rations. The nutrient contents of used animal feedstuff have been taken from the feeding standards of the research station Posieux (RAP). This is the same institution that also publishes the feeding standards used for the gross energy intake calculation described in Soliva (2006) (i.e. RAP 1999). This assures the consistency between livestock related CH_4 and N_2O emissions.

Nitrogen excretion for mature dairy cows is adjusted according to milk yield and animal fodder that have effects on nitrogen excretion (use of feed concentrates, corn silage, corn cubes, and hay in summer and winter rations) (Agrammon 2010, Kupper et al. 2013). N_{ex} for mature dairy cows shows a significant increase during the whole inventory time period mainly due to higher productivity. For swine, nitrogen excretion per head decreased due to breeding progresses and due to the use of protein reduced fodder. The nitrogen excretion of layers and broilers increased between 1995 and 2002 due to developments in production techniques. For all other animal categories nitrogen excretion did not change over time. Menzi et al. (1997) argue that mature dairy cows probably show the most significant changes in N_{ex} along the years. They point out that assuming constant values for all other animal categories would result in an error of only minor importance. Nevertheless, caution should be taken if the share of organic or similar alternative animal production schemes increases in the future (i.e. renunciation of certain feed ingredients and supplements). Values for N_{ex} will be periodically updated when new farm census data becomes available.

Table 9 Annual average nitrogen excretion of different livestock animals in Switzerland (kgN/year)

Type	IPCC Default	Swiss GHG Inventory				GE Approach IPCC 2006
		1990-2000 (mean)		2011		
		places	heads	places	heads	
Dairy cattle	100.0	-	98.9	-	110.4	107.6
Young cattle	70.0 [a]	-	33.2	-	33.4	34.2
Sheep	20.0	15.0/21.0[b]	7.7	15.0/21.0[b]	8.5	9.7
Goat	-	16.0	10.5	16.0	10.8	10.6
Horses	-	-	43.5	-	43.7	47.6
Mules and Asses	-	-	15.7	-	15.7	17.6
Swine	20.0	4.6-47.6	12.5	4.4-43.6	9.2	10.1
Poultry	0.6	-	0.5	-	0.5	0.39

[a] *non-dairy cattle*

[b] *fattening sheep / milksheep*

In Table 9 N_{ex} values of the Swiss greenhouse gas inventory are compared to IPCC default values. For a fair comparison the figure based on animal livestock places is more appropriate because it usually refers to adult animals, while the figure based on animal livestock heads is an average over different age classes[1]. In the case of mature dairy cattle and poultry the agreement is fairly well. For young cattle no suitable default value is provided by the IPCC. 70 kg/animal/year for non-dairy cattle could be interpreted as a reference, but this value is probably far too high for non-mature cattle as noticed in the IPCC Guidelines. For sheep two separate N_{ex} values are applied in Switzerland, i.e. 15.0 kg/place/year for fattening sheep and 21 kg/place/year for milksheep. The low value for nitrogen excretion per head is an average that includes all non-mature animals. For swine the IPCC default value presumably applies only for adult animals. In general adult swine in Switzerland (dry sows, nursing sows, boars) have nitrogen excretion rates higher than 20 kg/head/year. Nursing sows excrete even more than twice as much as suggested by IPCC default, i.e. almost 50 kg/head/year on average. As for sheep the low value for nitrogen excretion per head is an average that includes all non-mature animals.

To check for consistency of nitrogen excretion and feed intake, an alternative calculation of N_{ex} has been conducted according to equation 10.31 and equation 10.32 in the 2006 IPCC Guidelines:

$$N_{ex} = \frac{GE}{18.45} * \left(\frac{\frac{CP\%}{100}}{6.25} \right) * \left(1 - N_{retention}\right)$$

N_{ex} = annual nitrogen excretion rate (kg N/animal/year)

GE = gross energy intake of the animal (MJ/animal/day)

18.45 = conversion factor for dietary gross energy per kg of dry matter (MJ/kg)

CP% = percent crude protein in diet

6.25 = conversion from kg of dietary protein to kg of dietary N (kg feed protein/kg N)

$N_{retention}$ = fraction of annual N intake that is retained by the animal, dimensionless

Values for gross energy intake (GE) are taken from the enteric fermentation model, CP% is set at 15% according to RAP (1999) and $N_{retention}$ is taken from table 10.20 in the 2006 IPCC Guidelines except for cattle, swine and poultry where country specific values were available from Flisch et al. (2009). Resulting values for the year 2011 are presented in Table 9. For most categories agreement is very good with poultry showing the highest discrepancy with -26%. Alternatively nitrogen excretion can also be calculated with net energy data or based on animal mass according to table 10.19 in the 2006 IPCC Guidelines. Agreement is again good (discrepancies ≤12%) except for the weight-approach for non-cattle animals. In the latter case, the estimation of an average body weight representative for the whole population is very difficult and the results are therefore little informative.

Total livestock nitrogen excretion can also be computed in a top down approach as done by Spiess (1999, 2005) or Peter et al. (2006). Thereby, the total amount of nitrogen contained in animal livestock products such as meat, milk or eggs (output) is subtracted from the total amount of nitrogen in animal feedstuff produced in or imported to the country (input). Under the condition that the nitrogen pool in the animal population remains constant the result should be equal to the amount of nitrogen excreted in the manure. In Table 10 bottom up (animal numbers * specific nitrogen excretion rate) and top down (nitrogen in animal feedstuff - nitrogen contained in animal livestock products) approaches are compared for the years 1995, 2000 and 2002. Although all bottom up calculations are based on the same standard literature (Walter et al. 1994; FAL/RAC 2001, Flisch et al. 2009) some minor differences do exist. One possible explanation might be the

[1] This discrepancy also explains the partially large deviations of the Swiss N_{ex} values from other values in the “Synthesis and Assessment Reports” of the UNFCCC.

different levels of livestock category disaggregation. Most top down estimates are between 3.5 and 7.6% higher than bottom up estimates. Considering the total independence of the two approaches as well as the uncertainties in some of the basic assumptions, this can be interpreted as a good agreement. An explanation for the discrepancies between bottom up and top down estimates is provided by Spiess (1999). He argues that differences are due to the fact that species specific standard nitrogen excretion rates N_{ex} are based on optimal feeding regimes that are often not accomplished in practice.

Table 10 Annual nitrogen excretion by total livestock population in Switzerland – comparison of "top down" vs. "bottom up" approaches

Method	Approach	N-Excretion in kt N / year		
		1995	2000	2002
Swiss GHG inventory 2013	bottom up	135.8	128.1	128.4
Peter et al. 2006	bottom up	134.7	128.0	128.6
	top down	-	134.8	136.6
Spiess 1999	bottom up	143.0	-	-
	top down	140.7	-	-
Spiess 2005	top down	-	-	138.0
SBV / SFU	bottom up	138.9	128.3	131.6

In summary, data on total nitrogen excretion by animal livestock is quite reliable. The categories mature dairy cattle and swine are responsible for over 70% of the excreted nitrogen and show N_{ex} – rates that are in line with the IPCC default parameters and with the alternative GE approach. Eventual systematic errors concerning other categories are of minor importance. Moreover, top down and bottom up approaches agree fairly well.

Nitrogen originating from bedding material is neglected in the context of N_2O emissions from manure management. Flisch et al. (2009) estimates an annual contingent of 3.1 kg N per cow. Mineralization of nitrogen compounds in bedding material is, however, occurring more slowly than in manure. Furthermore, a N_2O emission of 1.25% of nitrogen input from straw is already considered in emissions from crop residues.

3.3.3. Manure management system fractions ($MS_{(T,S)}$)

Two different manure management systems are distinguished in Switzerland for the purpose of calculating N_2O emissions from storage of animal manure, namely "Liquid/Slurry" and "Solid Storage". Further details on these systems are given in chapter *2.2.4. Fraction of manure management systems (MSjk)*. Data on manure management system distribution for nitrogen related emissions as well as data on the fraction of manure dropped on pasture are based on Flisch et al. (2009) and calculated within the Swiss ammonium model AGRAMMON (Agrammon 2010). The distribution of excreted nitrogen is the same as for the excreted volatile solids (VS), assuring consistency between the calculation of N_2O and CH_4 emissions from manure management. It is noteworthy, however, that the distribution of volatile solids can be different than the distribution of nitrogen. This can be explained by the different handling of urine and dung that have different concentrations of N and VS (e.g. Külling et al. 2003). At the moment, the available data basis does not allow to resolve this shortcoming appropriately.

Total nitrogen allocation to the different manure management systems and pasture, range and paddock has been compared using the Swiss specific approach (based on AGRAMMON 2010) and default values from the IPCC (IPCC 1997:Table B3-B6; IPCC 2000: Table 4-21). In

1990 the share of nitrogen excreted on pasture, range and paddocks was significantly lower for the country specific method. This nitrogen was allocated mainly to the solid storage system but also to the liquid systems. Menzi et al. (1997) confirm this finding and quote that pasture has been of relatively low importance in Switzerland. A large share of the cattle population is grazing only during summer and remains in stables during the rest of the year where it is fed with hay, silage and other animal feeds. However, during the time series 1990-2002 a shift in the distribution can be observed, mainly from solid storage towards pasture, range and paddock. Furthermore, Reidy et al. (2007) state that in dairy production a strong shift towards loose housing systems occurred during the period from 1990 to 2002. Within the same period, but also beyond 2002, a substantial increase of the share of slurry systems for mature dairy cattle could be observed. Nevertheless the total nitrogen allocated to liquid systems did not increase due to the decreasing population of mature dairy cattle and reduced allocation of nitrogen into liquid slurry systems from swine. A comparison during the Submission 2011 revealed that for the year 2009 the share of solid storage was close to IPCC default while the share of pasture, range and paddock was still smaller and the share of liquid systems still higher than IPCC default.

3.3.4. N_2O emission factor for manure management system ($EF_{3(S)}$)

The emission factors for N_2O from manure management $EF_{3(S)}$ are IPCC default. However, ranges of measured values are very wide. Emissions depend not only on the type of manure system but also on other parameters such as duration of storage, aeration, composting, covering, temperature and nitrogen and carbon content of the manure. For instance Külling et al. (2002, 2003) found that under specific conditions N_2O formation was only promoted after extended storage duration. Moreover, many large emission peaks can dominate overall emissions as found in pig farmyard manure. Consequently measurements are associated with large uncertainties especially when non continuous measurement techniques are used and measurement periods are not sufficiently long (MAFF 2000). A compilation of European studies on N_2O emissions from animal houses and manure storage suggests that the default emission factor for liquid/slurry of 0.001 is rather too low and the emission factor for solid storage of 0.02 is rather too high (Freibauer 2003). The same conclusions can be drawn from another review of European studies conducted in 2000 (MAFF 2000). In accordance with these findings, the IPCC adopted new emission factors for both storage systems in the new IPCC Guidelines of 2006, i.e. 0.005 for liquid/slurry with natural crust cover and 0.005 for solid storage.

Studies on N_2O emissions from manure management conducted under conditions similar to those in Switzerland confirm the general findings listed above and support the new IPCC Guidelines 2006. Consequently, the emission factor for liquid/slurry systems tends to be underestimated and the emission factor for solid storage overestimated (Table 11).

N_2O emissions from animal manure management can be influenced by different feeding regimes of the animals (Machmüller et al. 2003; Klevenhusen et al. 2008; Külling et al. 2002). The crude protein content of the fodder determines to some extent the amount of nitrogen excreted in faeces. Moreover, composition of the feed as well as feed additives can influence manure composition and emission factors. Sommer et al. (2007) show that net nitrogen mineralization is related to net carbon mineralization, and that the amount of volatile solids can be a driving variable both for methane and nitrous oxide emissions. Neither such interactions nor other feeding related influences are being considered in the Swiss agricultural greenhouse gas inventory at the present time.

Table 11 Measured emission factors for N_2O emissions from manure management (EF_3) representative for Switzerland

Management System	**Animal Type and Feeding Strategy**	**$EF_{3(S)}$**	***Reference***
	Liquid System: IPCC 0.1%		
Liquid system	dairy cows, grass (low crude protein content) and hay	0.145%	*Külling et al. 2003*
Liquid system	dairy cows, hay and concentrate	0.263%	*Külling et al. 2003*
Liquid system	dairy cows, grass (high crude protein content) and hay	0.383%	*Külling et al. 2003*
Liquid system	dairy cows, hay and concentrate	0.419%	*Külling et al. 2003*
	Slurry: IPCC 0.1%		
Slurry	dairy cows, grass (low crude protein content) and hay	0.003%	*Külling et al. 2003*
Slurry	dairy cows, hay and concentrate	0.018%	*Külling et al. 2003*
Slurry	dairy cows, grass (high crude protein content) and hay	0.005%	*Külling et al. 2003*
Slurry	dairy cows, hay and concentrate	0.280%	*Külling et al. 2003*
	Solid Storage: IPCC 2.0%		
Solid Storage	dairy cows, grass (low crude protein content) and hay	1.661%	*Külling et al. 2003*
Solid Storage	dairy cows, hay and concentrate	0.690%	*Külling et al. 2003*
Solid Storage	dairy cows, grass (high crude protein content) and hay	1.303%	*Külling et al. 2003*
Solid Storage	dairy cows, hay and concentrate	0.853%	*Külling et al. 2003*
Solid Storage	Dairy cows, forage and concentrate (3:2 DM basis)	1.555%	*Külling et al. 2001*
Solid Storage	Dairy cows, feeding unknown	0.270% - 1.020	*Amon et al. 2001*
	Cattle and Swine Deep Litter: IPCC 0.005 – 0.02		
Deep Litter (Composting)	*Dairy cows, feeding unknown*	*0.1-0.3%*	*Sommer 2001*

3.4. 4D1 - Direct N_2O emissions from agricultural soils

Calculation of direct N_2O emissions from agricultural soils follows IPCC equation 4.20 (IPCC 2000).

$$N_2O_{direct} - N = \left[\left(F_{SN} + F_{AM} + F_{BN} + F_{CR}\right) * EF_1\right] + \left(F_{OS} * EF_2\right)$$

N_2O_{direct}-N = Emission of N_2O in units of nitrogen (kg N/yr)

F_{SN} = annual amount of synthetic fertilizer nitrogen applied to soils adjusted for the amount that volatilizes as NH_3 (kg N/yr)

F_{AM} = annual amount of animal manure nitrogen intentionally applied to soils adjusted for the amount that volatilizes as NH_3 (kg N/yr)

F_{BN} = amount of nitrogen fixed by N-fixing crops cultivated annually (kg N/yr)

F_{CR} = amount of nitrogen in crop residues returned to soils annually (kg N/yr)

F_{OS} = area of organic soils cultivated annually (ha)

EF_1 = emission factor for emissions from N inputs (kg N_2O-N/kg N input)

EF_2 = emission factor for emissions from organic soil cultivation (kg N_2O-N/ha/yr)

3.4.1. Synthetic fertilizer nitrogen (F_{SN})

Calculations are based on IPCC equation 4.22 (IPCC 2000):

$$F_{SN} = N_{FERT} * (1 - Frac_{NH3})$$

Data on the use of synthetic fertilizer (N_{FERT}) in Switzerland is assessed by an explicit trust corporation (Agricura 2010) and compiled within the statistical yearbooks of the Swiss Farmers Union (SBV; Grüter 2007). According to Agricura (2012) the fertilizer statistics is based on sales statistics by the compulsory storekeepers of fertilizers (Pflichtlagerhalter) and small importers. Agricura conducts plausibility checks with import statistics received by the Directorate General of Customs (Oberzolldirektion). Fertilizer production is negligible in Switzerland. Urea and other mineral fertilizers are distinguished. Cross checks with statistical data from the FAO and from the International Fertilizer Industry Association (IFIA) reveal some discrepancies. The FAO seems to account only for import and export statistics and neglects national production as well as stock changes. The IFIA obviously considers in country fertilizer production and presumably also stock changes. The values are subsequently comparable with statistics from the SBV especially for later years (cumulative amount 1990-2008: Swiss GHG inventory: 1091.5 kt N; IFIA 1080.4 kt N). A possible source of discrepancies could be that roughly 4% of the total nitrogen fertilizer is not applied on agricultural land but rather in the so called “Paralandwirtschaft” (home gardens, public green areas, recreation areas, sporting fields, traffic islands etc...) (AGRAMMON 2010, Reidy and Menzi 2005). Different nitrogen budgets might or might not include the respective amounts. In the context of the Swiss greenhouse gas inventory all fertilizers regardless of their use are accounted for. Synthetic fertilizers applied outside the agricultural sector are reported under 4D1.4 “Domestic Synthetic Fertilizers”.

The IPCC defines the term F_{SN} as the annual amount of synthetic fertilizer nitrogen applied to the soils after adjustment for NH_3- and NO_x- volatilization (IPCC 2000). However, Switzerland does not account for NO_x volatilization in the context of direct soil emissions. It is assumed that emission of NO_x occurs only after fertilizer application to soils, through similar mechanisms as emissions of N_2O (Berthoud 2004). Subsequently the emission factor for direct soil emissions relates to the amount of nitrogen reduced by ammonia volatilization but including the share that will later be lost as NO_x.

According to AGRAMMON (2010) Switzerland is setting ammonia volatilization to 15% for Urea and 2% for other mineral fertilizers (Vanderweerden and Jarvis 1997). Due to the relatively steep decline of the use of urea, the overall correction factor $Frac_{NH3}$ changes from 5.17% in 1990 to 3.80% in 2011. These values are considerably lower than IPCC default factor for $Frac_{GASF}$ (10%). However, practically all countries adopting country specific values for $Frac_{GASF}$ report values below IPCC default. Austria, which has similar agricultural structures as Switzerland, applies for the year 2011 a loss rate of 4% which is close to the respective value in the Swiss inventory (UNFCCC 2013).

Due to the specific accounting of ammonia in Switzerland the term $Frac_{GASF}$ does not correspond directly to the same term used in the IPCC Guidelines. In Switzerland the term $Frac_{GASF}$ as given in the CRF table 4.Ds2 represents the share of nitrogen of all commercial fertilizers that is lost to the atmosphere as NH_3. Commercial fertilizers include urea, other mineral fertilizers (mainly ammonia nitrate), compost, digestates and sewage sludge. As stated above

NO_x emissions are not included in this estimate. However, NO_x emissions are accounted for when calculating indirect N_2O emissions from soils. For this purpose, an additional 0.7% is added to $Frac_{GASF}$ as reported in CRF table 4.Ds2.

3.4.2. Animal manure nitrogen (F_{AM})

Calculations are based on IPCC equation 4.23 (IPCC 2000):

$$F_{AM} = \sum_T \left(N_{(T)} * Nex_{(T)}\right) * \left(1 - Frac_{NH3T}\right) * \left(1 - Frac_{PRPT}\right)$$

$N_{(T)}$ and $N_{ex(T)}$ have already been discussed in previous chapters (*1.1. Animal population data* and *3.3.2. Annual average nitrogen excretion ($Nex_{(T)}$)*). The fraction of nitrogen lost as ammonium $Frac_{NH3T}$ as well as the fraction excreted on pasture $Frac_{PRPT}$ are calculated separately for each animal category according to AGRAMMON (2010). The values are average values for livestock animals held under typical Swiss conditions. As for synthetic fertilizers, the volatilization of NO_x is not accounted for in the context of direct soil emissions (compare chapter *3.4.1. Synthetic fertilizer nitrogen (FSN)*).

For the calculation of $Frac_{NH3T}$ feeding strategies, stable systems, type of manure management systems, grazing and manure application practices in the field have been taken into account. On average weighted overall ammonium emission factors range from 33.0% to 35.0%, considering the different contributions of the individual animal categories to overall emissions. However, values reported in CRF Table 4.Ds2 are higher than this, ranging from 38.0% to 40.5%. They represent the amount of nitrogen volatilized as NH_3 from housing, manure storage and manure application divided by the manure excreted in the stable (manure excreted on pasture is not included in this consideration). The nitrogen input from manure applied to soils in CRF table 4.Ds1 can thus be calculated with the numbers given in CRF table 4.B(b) and 4.Ds2. Howsoever, ammonium emission factors are considerably higher than IPCC default. It is notable that a lot of countries applying country specific values report higher emissions than IPCC default. For the submission 2013 values ranged from 10% (New Zealand) to 40% (Switzerland) with a mean value close to IPCC default (22%; UNFCCC 2013). On the other hand the amount of ammonia subtracted should be reduced by the share that is emitted during and after manure spreading. The N_2O emission factor should be related to the total manure N applied as fertilizer, including the nitrogen that will later be lost on the field (Berthoud 2004). According to AGRAMMON (2010) this share is approximately 47% of total ammonia emission. This mechanism is not considered in the 1996 IPCC Guidelines and would lead to significantly higher direct emissions from agricultural soils. In view of this, the new IPCC Guidelines of 2006 alter the methodology in that way, that only nitrogen losses from the manure management system ($Frac_{LossMS}$) are subtracted from the excreted nitrogen (IPCC 2006; equation 10.34).

Some caution has to be applied when using data on ammonia emissions from animal livestock activities. Different interpretations of the same underlying data on ammonia emission may lead to considerable uncertainties. In an older projection, the total Swiss ammonia emissions calculated by Peter et al. (2006) with the same emission factors as proposed by Reidy and Menzi (2005) were more than 10% lower than calculated by Reidy and Menzi themselves. Furthermore, the validity of individual emission factors used in the AGRAMMON model has been put into question from different members of the research community in Switzerland (e.g. Sintermann et al. 2012). For a further discussion of NH_3 volatilization see chapter *3.6.1. Emissions from atmospheric deposition of NOx and NH3*.

3.4.3. Nitrogen fixed by N-fixing crops (F_{BN})

Calculation of the nitrogen originating from biological fixation follows the country specific approach IULIA.

Data on agricultural yields ($Crop_{BF}$) are taken form yearly statistics from the Swiss Farmers Union (e.g. SBV 2008). Crop yield data is assessed in collaboration with several organizations and institutions specialized in production, trade, processing or investigation of specific agricultural commodities. The SBV conducts cross checks with official data on area under cultivation and average crop yield (Grüter 2007). Since crop yield data from the SBV refer to fresh weight, the respective values must be converted into dry weight. The species specific dry matter contents used for this purpose are taken mainly from Flisch et al. (2009) but also from FAL/RAC (2001) and Schmid et al. (2000) and are very close to IPCC default values (Table 14). All data on agricultural yields was newly entered in 2006 and checked for consistency.

A crosscheck of yield statistics has been conducted with production data from the FAO database. The analysis revealed only minor differences (< 5%). These differences are probably due to later data-updates by the Swiss Farmers Union (compare chapter *1. Activity data*). In some cases data from several crops is aggregated differently in the Swiss GHG inventory and in the FAO database (e.g. vegetables). Straightforward comparisons are therefore not possible in these cases.

Standard values for nitrogen in main crops and crop residues of leguminous crops (dry beans, peas (Eiweisserbsen), soybeans, leguminous vegetables) are taken from Flisch et al. (2009), FAL/RAC (2001) and Walther et al. (1994). The calculated values for $Frac_{NCRBF}$ range from 0.024 to 0.041 being very close to the default value of 0.03 in the mean (Table 14). The methodology in the 1996 IPCC Guidelines suggests that all nitrogen in nitrogen fixing crops originates from biological fixation although it is mentioned that on average biological fixation supplies only 50-60% of the nitrogen harvested in grain legumes. In comparison the IULIA model used for the Swiss greenhouse gas inventory, assumes that biological fixation accounts for 60% of total crop nitrogen content (Schmid et al. 2000).

Grasslands account for more than 95% of the nitrogen fixed in Swiss agriculture. Accordingly, nitrogen fixation from clover on meadows and pasture is taken into account. A great share of grasslands in Switzerland is not used as pastures but rather mown for hay and grass silage. Hence, the argument that N_2O emissions from biological fixation on meadows and pastures are already included under emissions from animal production (4D2) does not apply. Estimates are made for the share of clover in dry matter, standard nitrogen content of dry matter of clover, and the share of nitrogen originating from biological fixation (Schmid et al. 2000)(Table 12). Clover contains a higher share of biologically fixed nitrogen than leguminous crops due to lower availability of mineral nitrogen on meadows and pastures. This is also recognized in the 1996 IPCC Guidelines who state that 70-80% of nitrogen accumulated by pasture legumes originates from biological fixation.

Table 12 Standard values for the calculation of N inputs from biological fixation and crop residues from meadows and pastures.

Type	**Share Clover**	**N Content Clover**	**N originating from Biological Fixation**	**Crop Residues**	**N Content Meadows and Pastures**
	%	**% of DM**	**%**	**% of Yield**	**% of DM**
Intensive meadows	30	3.5	80	10	2.7
Natural, extensive meadows	15	3.5	80	15	2.3
Pastures	15	3.5	80	35	1.5
Alpine and Jurassic pastures	10	3.5	80	40	1.2

Most of the values underlying nitrogen fixation assessment are based on expert guess (see Berthoud 2004) but are comparable to indications from other authors. Flisch et al. (2009) point out that under optimal conditions a nitrogen fixation of 120-240 kg $N*ha^{-1}*y^{-1}$ can be reached for pulses. Values calculated in the Swiss GHG-Inventory, i.e. 158 kg $N*ha^{-1}*y^{-1}$ on average for pulses, lie in the same range. For grassland the values diverge quite significantly, being 250 kg $N*ha^{-1}*y^{-1}$ in Flisch et al. (2009) and 104 kg $N*ha^{-1}*y^{-1}$ in the Swiss GHG-Inventory. However, the 250 kg $N*ha^{-1}*y^{-1}$ must be seen as an upper limit under optimal conditions that is presumably seldom reached. Further cross checks can be made for the total amount of nitrogen fixed in the country $F_{(BN)}$. Spiess (1999, 2005) calculates up to 16% higher annual nitrogen fixation in Swiss agriculture in his national nutrient balance. This is probably mainly because he assumes a higher nitrogen fixation rate of 4.15 kg $N*ha^{-1}*\%$ $clover^{-1}$ compared to 3.64 kg $N*ha^{-1}*\%clover^{-1}$ in the Swiss GHG-Inventory. Spiess (1999) identified nitrogen fixation as one of the factors that explains most of the divergence between different N balances. He states that early studies between 1986 and 1990 estimated a total annual nitrogen fixation of 60'000 t and more, while more recent findings suggest throughout values below 40'000 t. Table 13 summarizes more recent estimates for total $F_{(BN)}$.

Table 13 Nitrogen inputs originating from biological fixation $F_{(BN)}$ and crop residues $F_{(CR)}$ (tN / year)

		1995	2002	2000-2003	2006
$F_{(BN)}$	Swiss GHG Inventory	31'131	32'286	32'135	
	Spiess 1999	37'730			
	Spiess 2005		35'700		
	Peter et al. 2006			32'500	
$F_{(CR)}$	Swiss GHG Inventory	32'741	33'666	33'067	32'728
	Spiess 1999	38'000			
	Spiess 2005		34'000		
	Peter et al. 2006			36'620	
	Calculation based on IPCC 2006 Guidelines				33'630

Generally N_2O emissions during nitrogen fixation are widely discussed. The 2006 IPCC Guidelines state that: "Biological nitrogen fixation has been removed as a direct source of N_2O because of the lack of evidence of significant emissions arising from the fixation process itself" (Rochette and Janzen 2005). Also Freibauer and Kaltschmitt (2003) question N_2O emissions from leguminous crops based on the findings of several European studies. Meanwhile Switzerland will report N_2O emissions from biological fixation as long as the new 2006 IPCC Guidelines are not officially approved.

3.4.4. Nitrogen in crop residues returned to soils (F_{CR})

N_2O emissions due to decomposition of crop residues remaining on agricultural fields are calculated according to Schmid et al. (2000):

$$F_{CR} = \sum_{Cr} \left(\frac{E_{Cr}}{Y_{Cr}} * NR_{Cr} \right)$$

F_{CR} = Amount of nitrogen in crop residues returned to soils (tN)

E_{Cr} = Amount of crop yields for culture Cr (t)

Y_{Cr} = Standard yields for arable crops of culture Cr (t/ha)

NR_{Cr} = Standard amount of nitrogen in crop residues returned to soils (t/ha)

Data on agricultural yields (E_{Cr} also referred to as $Crop_{BF}$ and $Crop_0$) is provided by the Swiss Farmers Union and has been compared with statistical data from the FAO (for further information see chapter *3.4.3. Nitrogen fixed by N-fixing crops (FBN)*). Values for standard yields (Y_{Cr}) and standard amount of nitrogen in crop residues (NR_{Cr}) represent typical Swiss conditions and are taken from Flisch et al. (2009), FAL/RAC (2001) and Walter et al. (1994). Furthermore, Switzerland considers only above ground crop residues. Schmid et al. (2000) argue that below ground biomass should not be considered, since the respective nitrogen input is not necessarily different to what could be expected in natural ecosystems.

Additional data from Flisch et al. (2009), FAL/RAC (2001) and Walter et al. (1994) allows the calculation of $Frac_R$, $Frac_{NCRO}$, $Frac_{NCRBF}$ and $Frac_{DM}$ as well as the residue to crop product mass ratio (Res/Crop) (Table 14). All values remain constant over the whole inventory time period. Comparisons with IPCC default values show a generally fair agreement (almost 60% of all values lie within a range of ±20% of the default values) but significant discrepancies in some specific cases do exist.

Nitrogen inputs form residues of the individual crop species have been calculated using default methodologies and -values in the IPCC Guidelines and Good Practice Guidance and were then compared to values of the Swiss GHG Inventory. However, considerable differences exist between the different approaches in the 1996 and 2006 Guidelines and the 2000 Good Practice Guidance. Especially the default values for nitrogen fractions ($Frac_{NCRO}$ & $Frac_{NCRBF}$) seem to be overestimated in the 1996 Guidelines. Furthermore, the allocation of default values to specific crop types is not always straightforward. Where no suitable match could be found the 1996 default values have been applied, which probably led to great inaccuracies. The residue to crop product mass ratio seems to be a key figure that explains most of the methodological discrepancies. Especially important in this context are silage corn and residues from meadows and pastures. Switzerland assumes that almost all the plant material from these cultures is removed from the fields (95% for silage corn and ~75% for meadows and pasture). The 1996 default ratio of 45% is consequently much too low and the remaining 55% of the plant material lead to a great overestimation of nitrogen inputs.

Despite the above mentioned divergences, total nitrogen input from crop residues (F_{CR}) calculated with the methodology of the 2006 IPCC Guideline is close to the value in the Swiss GHG Inventory (Table 13). Moreover, different estimates of nitrogen inputs from crop residues (F_{CR}) by various authors agree fairly well. However, considerable discrepancies still exist for individual crop species and results must be interpreted with the respective caution.

Boeckx and Van Cleemput (2001) state that country specific input data have a great influence on N_2O emission. They mention that besides N excretion rates by animals, country specific crop dry matter contents can explain significant differences in total N_2O emissions. They conclude that at least for Western European countries the IPCC default methodology could overestimate the N_2O emission from agriculture. The results presented here do not support the later conclusion, and the methodological disagreements are rather based on the residue to crop product mass ratio as mentioned above.

Table 14 Standard values for the calculation of N inputs from crop residues

	Residue/Crop Product Ratio			Dry Matter Fraction ($Frac_{DM}$)			Nitrogen Fraction ($Frac_{NCRO}$ & $Frac_{NCRBF}$)				$Frac_R$	
	Swiss GHG Inventory 2011	IPCC 1996[a]	IPCC 2000[b]	Swiss GHG Inventory 2011	IPCC 2000[b]	IPCC 2006[c]	Swiss GHG Inventory 2011[d]	IPCC 1996[a]	IPCC 2000[b]	IPCC 2006[c]	Swiss GHG Inventory 2011	IPCC 1996[a]
Cereals												
Wheat	1.15	1.22	1.30	0.85	0.82-0.88	0.89	0.0037	0.0150	0.0028	0.0060	0.47	0.45
Barley	1.00	1.22	1.20	0.85	0.82-0.88	0.89	0.0051	0.0150	0.0043	0.0070	0.50	0.45
Maize	1.11	1.22	1.00	0.85	0.70-0.86	0.87	0.0086	0.0150	0.0081	0.0060	0.48	0.45
Oats	1.27	1.22	1.30	0.85	0.92	0.89	0.0049	0.0150	0.0070	0.0070	0.44	0.45
Rye	1.17	1.22	1.60	0.85	0.90	0.88	0.0036	0.0150	0.0048	0.0050	0.46	0.45
Other												
Mix of bred cereals	1.17	1.22	1.30	0.85	0.82-0.88	0.88	0.0037	0.0150	0.0028	0.0060	0.46	0.45
Triticale	1.25	1.22		0.85		0.88	0.0039	0.0150			0.44	0.45
Mix of fodder cereals [e]	1.00	1.22	1.20	0.85	0.82-0.88	0.88	0.0051	0.0150	0.0043	0.0070	0.50	0.45
Spelt	1.56	1.22		0.85		0.88	0.0059	0.0150			0.39	0.45
Pulses												
Dry bean	1.13	1.22	2.10	0.85	0.82-0.89	0.90	0.0353	0.0300		0.0100	0.47	0.45
Peas	1.25	1.22	1.50	0.85	0.87	0.91	0.0235	0.0300	0.0142	0.0080	0.44	0.45
Soybeans	1.00	1.22	2.10	0.85	0.84-0.89		0.0412	0.0300	0.0230	0.0080	0.50	0.45
Other												
Leguminous vegetables	3.87	1.22		0.16			0.0328	0.0300			0.21	0.45
Tubers and Roots												
Potatoes	0.47	1.22	0.40	0.14		0.22	0.0127	0.0150	0.0110	0.0190	0.68	0.45
Sugarbeet	0.67	1.22		0.15		0.22	0.0220	0.0150		0.0190	0.60	0.45
Beet	0.41	1.22	0.30	0.15		0.22	0.0233	0.0150	0.0228	0.0190	0.71	0.45

Table 14 (continued) Standard values for the calculation of N inputs from crop residues.

	Residue/Crop Product Ratio			**Dry Matter Fraction ($Frac_{DM}$)**			**Nitrogen Fraction ($Frac_{NCRO}$ & $Frac_{NCRBF}$)**				**$Frac_R$**	
	Swiss GHG Inventory 2009	**IPCC 1996[a]**	**IPCC 2000[b]**	**Swiss GHG Inventory 2009**	**IPCC 2000[b]**	**IPCC 2006[c]**	**Swiss GHG Inventory 2009[d]**	**IPCC 1996[a]**	**IPCC 2000[b]**	**IPCC 2006[c]**	**Swiss GHG Inventory 2009**	**IPCC 1996[a]**
Other												
Meadows and Pasture	0.26	1.22		n.a.		0.90	0.0215			0.0150-0.0250	0.81	0.45
Silage corn	0.05	1.22		0.32			0.0115	0.0150			0.95	0.45
Green corn	0.05	1.22		0.32			0.0091	0.0150			0.95	0.45
Fruits	n.a.	1.22		0.17			0.0040	0.0150			n.a.	0.45
Vine	n.a.	1.22		0.20			0.0060	0.0150			n.a.	0.45
Renewable energy crops	1.86	1.22		0.85			0.0083	0.0150			0.35	0.45
Non-leguminous vegetables	0.46	1.22		0.13			0.0230	0.0150			0.69	0.45
Sunflower	2.00	1.22		0.60			0.0150	0.0150			0.33	0.45
Tobacco	1.18	1.22		n.a.			0.0221	0.0150			0.46	0.45
Rape	1.86	1.22		0.85			0.0083	0.0150			0.35	0.45
Average non-leguminous	0.48	1.22		0.32			0.0143	0.0150			0.73	0.45
Average leguminous	2.62	1.22		0.48			0.0303	0.0300			0.32	0.45
Average overall	0.49	1.22		0.32			0.0144				0.73	0.45
Average without silage corn and green corn	0.77										0.58	0.45

[a] Table 4.19

[b] Table 4.16

[c] Table 11.2 ($Frac_{NCRO}$ and $Frac_{NCRBF}$: above ground residues)

[d] Nitrogen contents of crop residues

[e] same as Barley

n.a. not assessed

3.4.5. Emission factor for direct soil emission (EF_1)

For direct soil emissions the IPCC default emission factor (EF_1) is used. Various studies analyze the suitability of this emission factor for conditions in Central and Western Europe (e.g. Flechard et al. 2007; Freibauer and Kaltschmitt 2003; Roelandt et al. 2005). The findings of Freibauer and Kaltschmitt (2003) suggest that the IPCC model could underestimate emissions in mountainous regions. However, most of the intensively managed and fertilized cropland in Switzerland can be found in the central plateau. Consequently this possible error would be of minor importance. On the other hand, Flechard et al. (2007) calculated an overall emission factor of 0.75% based on three year measurement of N_2O emissions on 10 different grassland sites across Europe. This would mean that emissions on grasslands are generally overestimated by applying the default value of 1.25%. In general, it is not yet clear to what extent emission factors for grasslands and croplands are comparable. Distinguishing between these two land uses might be an important step forward in N_2O inventory compilation.

Emission factor estimates have also been conducted in Switzerland. Measured and simulated values in Switzerland support the adoption of the IPCC default emission factor of 1.25%. Flechard et al. (2005) calculated an overall emission factor of 1.1% based on quasi continuous measurement over three growing seasons on a mown grassland system in the Swiss central plateau. Rudaz et al. (1999) found N_2O emissions of 0.02 to 5.20% of the amount of N fertilizer applied to permanent pasture in the foothills of the Swiss Alps (915 m a. s. l.). Annual mean emission factors were 0.6% and 2.5% for 1993 and 1994 respectively. In an experiment with grass, clover and grass-clover mixture plots, Fischer et al. (2009) found also N_2O emissions similar to the IPCC default value ranging from 0.4 to 3.9%. The emission factor was however considerable higher when applying large amount of fertilizer to pure clover stands which is not typical for Swiss agricultural practices. Furthermore, emission factors between 1.03 and 3.79% were found for different grass-clover mixtures and fertilizer levels in the FACE experiment at Eschikon, Switzerland (Baggs et al. 2003). These estimates are based on manual chamber measurements that have been taken rather infrequently and must therefore be interpreted with caution. Emission factors were highest in pure clover stands with low fertilizer treatment. Symbiotic nitrogen fixation and possible natural background N_2O emissions have not been taken into account. Subsequently, the fraction of nitrogen that was lost from the applied fertilizer is probably smaller. Finally, Schmid et al. (2001) simulated N_2O production in grasslands caused by nitrogen inputs from different sources. They used the process-based Pasture Simulation Model PaSim 2.5 which has been tested against season-long field measurements at two different sites in Switzerland. The simulated emission factors fall well within the range of the IPCC default value for fertilizer use. However, considerable differences exist between different fertilizer types and different time scales applied in the model runs. Results suggest that especially emissions caused by nitrogen inputs from biological fixation and crop residues on grasslands may be overestimated when using the same emission factor as for mineral fertilizer N input (1.25%). On the other hand, a comparison of long-term and short-term simulation runs suggests that the IPCC emission factor, which is based on short-term measurement data, might underestimate the long-term effects of fertilizer application.

Although the IPCC Tier 1 methodology might predict overall N_2O emissions sufficiently well, it takes no account of the effect of land use, crop type, climate (temperature, precipitation), soil properties (C content, soil moisture, soil texture) or agricultural practices (e.g. tillage practices, grazing density, fertilizer type). Subsequently, temporal and spatial resolution of the emission estimates is very limited and there is no mechanism to assess the potential impact of future climate change and alterations in agricultural practices. This fact has been criticized repeatedly (e.g. Roelandt et al. 2005; Flechard et al. 2007), and several authors suggested more sophisticated models for estimating N_2O emissions (Table 15). Del Grosso et al. (2006, 2008) use the DAYCENT model to predict emission in the United States of America. In addition to N inputs, DAYCENT accounts for the influence of water, temperature, O_2 and labile C availability and plant N demand. An alternative model was used by Flynn et al. (2005) for Scotland. Their newly derived emission factors depend on crop type, daily temperature, monthly rainfall and livestock grazing practices (trampling effects). The estimated emissions were significantly higher than predicted by the IPCC methodology, almost entirely because of the increased contribution of pasture. This finding could be especially important for Switzerland considering the large share of grazing land. Also Freibauer (2003) calculated considerably higher N_2O emissions in a regionalized greenhouse gas inventory from European agriculture. At the European level, the estimates exceeded those of the official national inventories submitted under the UNFCCC by 37%. The refined model for estimating N_2O emissions considers different climate regions, crop types, soil nitrogen and soil organic carbon contents, sand content in topsoil's and annual fertilizer inputs. Yet another approach has been chosen by Roelandt et al. (2005). Theses authors developed two separate empirical models, MCROPS and MGRASS, for croplands and grasslands respectively. Both models depend on seasonal climate (precipitation and temperature) and nitrogen fertilization rates. They concluded, that their approach improved the statistical reliability of direct N_2O emissions compared with the IPCC default methodology and that the models can be used to estimate the effects of interannual variation in climate and climate change at the regional scale. Likewise, Flechard et al. (2007) suggest the use of monthly or at least seasonal emission factors that are adapted to local climate conditions in order to reproduce events such as the 2003 summer heat wave. Finally Boeckx and Van Cleemput (2001) estimated N_2O fluxes from agricultural lands in various regions in Europe and state that estimates could be improved by a greater discrimination between different moisture regimes and climates and by differentiating between N_2O emission from grassland or arable land and fertilizer N sources applied. An overall problem is that a more detailed modeling of soil N_2O emissions is only possible with reliable spatial and temporal disaggregated input data. In this context simple inference schemes as proposed by Lesschen et al. 2011 could be a possible way forward. In this approach the dataset by Stehfest and Bouwman (2006) is used to elaborate a set of modification factors for the N_2O emission factor according to nitrogen input source, soil type and land use. A great advantage of an approach with differentiated EFs is the possibility to account for the effects of additional mitigation measures, such as changes in fertilizer or manure type.

Table 15 Parameters influencing N_2O emissions from agricultural soils

Subject	**Parameter**	***Reference***
Land Use	Field history	*Flechard et al. 2007*
	Land use : Grassland vs. arable land	*Boeckx and Van Cleemput 2001; Flynn et al. 2005; Freibauer and Kaltschmitt 2003; Roelandt et al. 2005*
Climate	Temperature	*Del Grosso 2008; Flechard et al. 2007; Flynn et al. 2005; Roelandt et al. 2005*
	Rainfall ; Soil water content	*Boeckx and Van Cleemput 2001; Del Grosso 2008; Fischer 2009; Flechard et al. 2007; Flynn et al. 2005; Roelandt et al. 2005; Rudaz et al. 1999*
Soil	Soil type	*Boeckx and Van Cleemput 2001; Freibauer and Kaltschmitt 2003*
	Soil C	*Del Grosso 2008; Freibauer and Kaltschmitt 2003*
	pH	*Flechard et al. 2005*
Agricultural practices	Fertilizer type	*Boeckx and Van Cleemput 2001; FAO/IFIA 2001; Flechard et al. 2005; Freibauer and Kaltschmitt 2003; Jones et al. 2007; Schmid et al. 2001*
	Fertilizer level	*Fischer 2009*
	Crop type	*Fischer 2009; Flynn et al. 2005; Freibauer and Kaltschmitt 2003*
	Livestock grazing density	*Flechard et al. 2007; Flynn et al. 2005*
	Grass cut events	*Fischer 2009; Flechard et al. 2005; Flechard et al. 2007*

Another shortcoming not addressed by the current greenhouse gas inventory is that the relation between fertilizer application level and N_2O emissions might not be linear. The nitrous oxide emission factor can possibly depend on the absolute amount of reactive nitrogen entering the system and especially the amount of nitrogen that is not taken up directly by the crop plants. Model simulations have shown that high fertilization rates may lead to over proportional N_2O emissions (e .g. Schmid et al. 2001).

Overall uncertainties of national greenhouse gas inventories are generally dominated by uncertainties of N_2O emissions from agricultural soils. Consequently a more detailed and climate specific methodology in this area would significantly increase accuracy and reliability of national greenhouse gas inventories (Monni et al. 2007). The following parameters have been identified by Freibauer and Kaltschmitt (2003) as a minimum in future studies: position in the landscape (plane, top, slope, depression), soil type, soil texture, organic carbon and nitrogen content of the topsoil, soil pH, drainage and soil moisture changes, precipitation, crop type, N input, yields or N removed.

3.4.6. Area of cultivated organic soils (F_{OS})

The area of cultivated peatlands which to some extent is utilized by agriculture corresponds to the respective areas reported in the LULUCF sector. Both organic soils under cropland and grassland are considered. The assessment has been conducted using data of the Swiss Land Use Statistics (AREA) evaluated by the Swiss Federal Statistical Office (SFSO 2012a). For mapping the occurrence of organic soils, two datasets were used: (i) the digital soil map “BEK” (SFSO 2000) and (ii) the Inventory of Raised Bogs of National Importance (Appendix to Swiss Confederation 1991). Between 1990 and 2011 18100 ha of organic soils have been under agricultural use with only very little annual fluctuation probably due to statistical relicts. An increase of the area is unlikely since all fens and bogs are standing under some kind of protection. Objects of national significance are registered in a national inventory. On the other hand it could be assumed that some areas have been submitted to renaturation in recent years, especially in the context of the adoption of the “Proof of Ecological Performance” that oblige farmers to establish a share of 7% of ecological compensation area. However, given that agricultural area in Switzerland is limited, it is unlikely that this is a wide spread land use change.

Before submission 2013 a constant area of 17000 ha has been used. This area represents the most reliable estimate obtained by combining information from different sources according to Table 16. The number is very close to the one based on the Swiss Land Use Statistics and confirms its suitability. Nonetheless, the area and spatial distribution of cultivated organic soils remains very uncertain (±30%, ART 2008). Estimates in Table 16 range from 12’000 ha to 22’000 ha. In May 2012, the Agroscope Reckenholz-Tänikon Research Station (ART) started a three-year running research project that aims to identify (drained) fens and raised bogs under different land uses beyond the national inventories of bogs and fens in order to improve the AD estimates of drained organic soils.

3.4.7. Emission factor for emissions from organic soil cultivation (EF_2)

Large N_2O emissions occur as a result of cultivation of organic soils due to enhanced mineralization of old, N-rich organic matter. Currently the Swiss greenhouse gas inventory uses the IPCC 2000 default emission factor of 8 kg N_2O-N/ha-yr. Amman et al. (2009,) and Conant et al. (2005) state that nitrogen and carbon loss (or sequestration) in agricultural ecosystems may be strongly connected. They found that individual organic matter pools in soils show rather constant characteristic C/N ratios. A change in the N stock is therefore generally accompanied by a corresponding change in the C stock and vice versa. The annual net carbon stock change in cultivated organic soils was estimated at -9.52 t C/ha-yr for intensive use according to measurements in Europe including Switzerland as compiled by Leifeld et al. (2003, 2005) and at -5.30 t C/ha-yr for extensive use according to ART (2011)(FOEN 2013). Assuming a constant N_2O emission rate of 1.25% and applying a weighted mean carbon stock change of approximately -9 t

C/ha-yr gives a C/N ratio of 14.1. However, C/N ratios of organic soils use to be much wider. This means that N_2O emissions from cultivation of organic soils might be rather overestimated in Switzerland.

Table 16 Compilation of methods to estimate the current area (ha) of cultivated peatlands. The mean area calculated is 17'000 ha, and the lower and upper estimates are 12'000 and 22'000 ha, respectively (from Leifeld et al. 2003).

Data source	Approach	Area (ha)	Comment	Reference
Peatland inventories (fens), inventory of cultivated organic soils	Extrapolation of size distribution of peatland sites to cultivated organic soils	18'000	Considers organic soils <50 ha excluded from the inventory of organic soils	BUWAL; Presler und Gysi 1989
Inventory of cultivated organic soils, historical peatland survey	Extrapolation of distribution of organic soils to main natural regions with previous peatland distribution	15'000	Includes regions (Jura Mountains, Pre-Alps, Alps) other than Swiss Central Plateau	Presler und Gysi 1989; Früh und Schröter 1904
Historical peatland survey	Extrapolation of surveyed peatland objects (mean weighted area) to all peatland sites described	22'000	High uncertainty due to unknown ratio of surveyed peatland objects to total peatland area	Früh und Schröter 1904
Soil map (Canton of Zürich), digital soil map	Extrapolation of the proportion of organic soils in the detailed map of histosols to the digital soil map for the whole of Switzerland	12'000	Analysis shows low suitability of digital soil map for estimation of organic soils	Digital soil map, detailed soil map Canton of Zürich
Inventory of cultivated organic soils, estimate of C stock, digital soil map	Extrapolation of two crucial mapping units to the whole of Switzerland	19'000	High uncertainty due to dependence on digital soil map	Paulsen 1995; Presler und Gysi 1989; Digital soil map

Note: Previous figures for the area of cultivated peatlands ranged from 6'400 ha (Presler and Gysi 1989) to as much as 180'000 ha (Grünig 1994; based on documented melioration activities in Switzerland since 1885, as given by the Eidgenössisches Meliorationsamt Bern, 1954). The figure of 6'400 ha is considered an underestimate, since it includes only sites located on the Central Plateau with a minimum area of 50 ha, and which are used for intensive agriculture. On the other hand,180'000 ha is probably an overestimate of the actual area of cultivated peatlands, since the melioration activities on which it is based included drainage of non-organic soils, e.g. gleysols, or soils with only a shallow organic horizon. The maximum area of agricultural organic soils given by the digital soil map is 127'000 ha which is also regarded as an overestimate because it includes non-organic soils in the same soil classes.

For the references cited in Table 16 consult the original report by Leifeld et al. (2003).

3.5. 4D2 - Emissions from animal production

Emissions from animal production are calculated according to IPCC equation 4.18 (IPCC 2000: p. 4.42).

$$(N_2O-N)_{(mm)} = \sum_{(S)} \left\{ \left[\sum_{(T)} \left(N_{(T)} * Nex_{(T)} * MS_{(T,S)} \right) \right] * EF_{3(S)} \right\}$$

$(N_2O\text{-}N)_{(mm)}$ = N_2O-N emissions from manure management (kg N_2O-N/yr)

$N_{(T)}$ = number of head of livestock species/category *T*

$N_{ex(T)}$ = annual average N excretion per head of species/category *T* (kg N/animal/yr)

$MS_{(T,S)}$ = fraction of total annual excretion for each livestock species/category *T* that is managed in manure management system *S*

$EF_{3(S)}$ = N_2O emission factor for manure management system *S* (kg N_2O-N/kgN in manure management system *S*)

S = manure management system

T = species/category of livestock

Information on animal numbers ($N_{(T)}$), nitrogen excretion rates ($N_{ex(T)}$) and manure management system distribution ($MS_{(T,S)}$) has already been provided in the previous chapters (*1.1. Animal population data*; *3.3.2. Annual average nitrogen excretion (Nex$_{(T)}$)* and *3.3.3. Manure management system fractions (MS$_{(T,S)}$)*). The IPCC default value of 0.02 kg N_2O-N/kg N is used for $EF_{(3)}$. At the time being no measurement data has been analyzed to assess the suitability of this value in the Swiss agricultural context.

3.6. 4D3 - Indirect N_2O emissions from soils

3.6.1. Emissions from atmospheric deposition of NO_x and NH_3

Calculation of N_2O emissions from atmospheric deposition is based on IPCC equation 4.31 (IPCC 2000).

$$N_2O_{(G)} - N = \left[\begin{array}{l} \left(\left(N_{FERT} + N_{SSC}\right) * Frac_{GASF}\right) + \left(\sum_T \left(N_{(T)} * Nex_{(T)}\right) * Frac_{GASM}\right) \\ + \left(AA * 2kgNH_3 - N/ha\right) \end{array} \right] * EF_4$$

$N_2O_{(G)}$ = N_2O produced from atmospheric deposition of N (kg N/yr)

N_{FERT} = total amount of synthetic nitrogen fertilizer applied to soils (kg N/yr)

N_{SSC} = total amount of N from sewage sludge and compost applied to soils (kg N/yr)

$\Sigma_T(N_{(T)}*Nex_{(T)})$ = total amount of animal manure nitrogen excreted in a country (kg N/yr)

$Frac_{GASF}$ = fraction of N fertilizer that volatilizes as NH_3 and NO_x (kg NH_3-N and NO_x-N/kg of N input)

$Frac_{GASM}$ = fraction of animal manure N that volatilizes as NH_3 and NO_x (kg NH_3-N and NO_x-N/kg of N excreted)

AA = area of agricultural soils (ha)

2 kgNH$_3$-N/ha = ammonia emitted from crop canopy on agricultural land

EF_4 = emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces (kg N_2O-N/kg NH_3-N and NO_x-N emitted)

Nitrogen inputs from synthetic fertilizers (N_{FERT}) and animal manure ($N_{ex(T)}$) have already been discussed in previous chapters (*3.4.1. Synthetic fertilizer nitrogen (FSN)* and *3.3.2. Annual average nitrogen excretion (Nex$_{(T)}$)*). The amount of sewage sludge and compost will be analyzed under *3.7. 4D4 - Other (Use of sewage sludge and compost as fertilizers)*. $Frac_{GASF}$ and $Frac_{GASM}$

are the fractions of nitrogen that volatilize as NH_3 and NO_x. Ammonia emissions have already been discussed in chapter *3.4.1. Synthetic fertilizer nitrogen (FSN)* and *3.4.2. Animal manure nitrogen (FAM)* respectively. For synthetic fertilizers the relative shares of urea and other mineral fertilizers are considered. Additionally, ammonia volatilization from sewage sludge and compost are accounted for. Source specific NH_3 emission factors are taken from AGRAMMON (2010). NH_3 emissions from animal manure are also taken from AGRAMMON (2010) which takes into account the feeding strategies, stable systems, type of manure management systems, grazing and manure application practices in the field. For NO_x emissions a factor of 0.7% provided in the CORINAIR emission inventory guidebook (EEA 2007) is chosen. Due to its relative low importance no further quality checks have been conducted for this parameter. Additionally, it is assumed that on all agricultural land 2 kg NH_3-N is emitted per ha and year from the crop canopy (Schjoerring and Mattsson 2001).

Note that the terms $Frac_{GASF}$ and $Frac_{GASM}$ cannot be used as suggested in the IPCC Guidelines. For indirect N_2O emissions from soils all volatilized nitrogen is accounted for including NO_x emissions and NH_3 emissions from pasture range and paddock. In the values reported in CRF table 4.Ds2 these later two compounds are not included because the numbers are used for calculating direct soil emissions which gives them another context (compare 3.4. 4D1 - Direct N2O emissions from agricultural soils). They represent the amount of nitrogen volatilized as NH3 from housing, manure storage and manure application divided by the manure excreted in the stable. The nitrogen input from manure applied to soils in CRF table 4.Ds1 can thus be calculated with the numbers given in CRF table 4.B(b) and 4.Ds2.

The total amount of nitrogen deposited declined from 58'871 t in 1990 to 48'152 in 2004 and then increased again to 49'623 in 2011 (submission 2013). This development reflects mainly the development of the cattle population since cattle livestock is responsible for almost 70% of nitrogen lost as NH_3 or NO_x.

Estimated total atmospheric nitrogen deposition could be compared to field measurements. Verification is, however, at a preliminary stage and relies on data from relatively few monitoring sites. Model estimates were able to reproduce the monitoring results with a root mean square error of 0.75 µg m^{-3} while high NH_3 concentrations were in the order of 2 - >3 µg m^{-3} (Rihm 2000).

Due to the lack of data, no judgment is given for the quality and suitability of the emission factor for indirect N_2O emissions from agricultural soils.

3.6.2. Emissions from leaching and runoff

Calculation of N_2O emissions from leaching and runoff follows IPCC equation 4.34 (IPCC 2000).

$$N_2O_{(L)} - N = \left[N_{FERT} + N_{SSC} + \sum_T \left(N_{(T)} * Nex_{(T)}\right)\right] * Frac_{LEACH} * EF_5$$

$N_2O_{(L)}$ = N_2O produced from N lost as leaching and runoff (kg N/yr)

N_{FERT} = total amount of synthetic nitrogen fertilizer applied to soils (kg N/yr)

N_{SSC} = total amount of N from sewage sludge and compost applied to soils (kg N/yr)

$\Sigma_T(N_{(T)}*Nex_{(T)})$ = total amount of animal manure nitrogen excreted in a country (kg N/yr)

$Frac_{LEACH}$ = fraction of nitrogen lost as leaching and runoff (kg N/kg of N input)

EF_5 = emission factor for N_2O emissions from leaching and runoff (kg N_2O-N/kg N)

The terms N_{FERT} and $\Sigma_T(N_{(T)}*N_{ex(T)})$ have already been discussed earlier under *3.4.1. Synthetic fertilizer nitrogen (FSN)* and *3.3.2. Annual average nitrogen excretion ($Nex_{(T)}$)*, respectively. The amount of sewage sludge and compost will be analyzed under *3.7. 4D4 - Other (Use of sewage sludge and compost as fertilizers)*. The fraction of nitrogen lost through leaching and runoff ($Frac_{LEACH}$) can be very variable due to a vast range of differing agricultural practices (e.g. irrigation, frequency of ploughing, drainage tiles, catch crops). Accordingly, the IPCC emphasizes that caution should be used when using a country specific factor (IPCC 2000). For Switzerland $Frac_{LEACH}$ is estimated based on the works of Prasuhn and Braun (1994) and Braun et al. (1994). Average nitrate losses are estimated by multiplying cropland areas with the respective crop specific nitrate leaching-, runoff- and erosion- rates. The resulting value for $Frac_{LEACH}$ is 20% and therefore considerably lower than the respective standard value suggested by the IPCC. However, the accuracy and suitability of the IPCC default value is not beyond doubt and has been questioned (Schmid 2000). It is remarkable that nearly all countries using country specific values estimate $Frac_{LEACH}$ to be lower than 30% (UNFCCC 2013). The European Union (EU-15) currently uses a factor of 25 %.

A constant N-loss rate for the whole inventory period is probably not very realistic. Prasuhn et al. (2003) found that the N-entries into the water bodies of the canton of Bern have declined since the 1990s by 5 %. Another investigation in a catchment area in the Swiss central plateau by Decrem et al. estimate the reduction of nitrogen leaching to be as great as 30% (Decrem et al. 2005; Decrem et al. 2007). Herzog et al. (2005) summarize that since the introduction of the “Proof of Ecological Performance” nitrate-leaching could be reduced by 5-20%. This finding is consistent with measurements of nitrate in groundwater catchments that show a decreased of 18% between 1989-91 and 2002-03. The declining trend can be partly explained by the general reduction of nitrogen fertilization. However, changing shares of different crop species as well as increased use of catch crops probably contribute significantly to the overall reduction. These later factors are not yet considered in the Swiss GHG-inventory and would lead to reduced indirect N_2O emissions from leaching and runoff.

3.7. 4D4 - Other (Use of sewage sludge and compost as fertilizers)

Calculation of N_2O emissions from application of sewage sludge and compost on agricultural land follows the following equation:

$$N_2O_{SSC} - N = \left(N_{SSC} * \left(1 - Frac_{NH3}\right)\right) * EF_1$$

N_2O_{SSC} = N_2O produced from N applied from sewage sludge and compost (kg N/yr)

N_{SSC} = total amount of N from sewage sludge and compost applied to soils (kg N/yr)

$Frac_{NH3}$ = fraction of N from sewage sludge and compost that volatilizes as NH_3 (kg NH_3-N/kg of N input)

EF_1 = emission factor for emissions from N inputs (kg N_2O-N/kg N input)

Total amounts of sewage sludge, compost and liquid and solid digestates are based on Kupper et al. (2013) and have been consolidated by the responsible persons at the School of Agricultural, Forest and Food Science (HAFL, Kupper et al. 2013). Estimates are available for the years 1990, 1995, 2000, 2005, 2007 and 2010 and years in between have been interpolated linearly. Due to the small amounts of sewage sludge and compost and the great number of rather small providers, the respective data must be interpreted cautiously. Statistics of the Swiss Farmers Union (SBV) report somewhat higher values but are considered less transparent and reliable. Since 2003 the use of sewage sludge as fertilizer is prohibited in Switzerland. The steady decline of the respective nitrogen input is therefore realistic. However, a transition period applies for some areas and the individual cantons could prolong this period until 2008 in individual cases (UVEK 2003).

According to AGRAMMON (2010) the following mean ammonia emission factors are used: Sewage sludge 24.8%, compost 3.4%, digestate solid 4.0% and digestate liquid 30.0%. Due to the different development of the amounts of the different recycling fertilizers the corresponding average ammonia emission factor declined considerably over the inventory time period. Namely the amount of sewage sludge with a very high emission rate declined until the total prohibition in 2008.

It is assumed, that the IPCC default emission factor for direct soil emissions is valid also for the application of sewage sludge and compost. However, according to a report by FAO/IFIA (2001) the emission factor for organic fertilizers might be considerably lower than for mineral nitrogen. The data suggests that by using the IPCC default value emissions from organic fertilizers are eventually overestimated by more than a factor of two.

The emission source is of minor importance in the overall context of the agricultural greenhouse gas inventory.

Reference

AGRAMMON 2010: The Swiss ammonia model. Federal Office for Environment FOEN. Internet version in German, French and English: http://www.agrammon.ch/dokumente-zum-download/ [10.03.2011]
Technical description for download (updated periodically): http://www.agrammon.ch/technische-modellbeschreibung/

Agricura 2012: Geschäftsbericht 2011/2012. Agricura, Bern.

Amon, B., Amon, T., Boxberger, J., Alt, C. 2001: Emissions of NH_3, N_2O and CH_4 from dairy cows housed in a farmyard manure tying stall (housing, manure storage, manure spreading). Nutrient Cycling in Agroecosystems 60 (1-3): 103-113.

ART 2008: Uncertainty in agricultural CH_4 and N_2O emissions of Switzerland. Internal documentation by Bretscher, D. and Leifeld, J., Agroscope Reckenholz-Tänikon Research Station, Zürich.
http://www.environment-switzerland.ch/climatereporting/00545/01913/index.html?lang=en

ART 2011: First estimate on CO_2 emission factor of organic soils under unproductive wetland. Internal documentation by Leifeld, J., Agroscope Reckenholz-Tänikon Research Station, Zürich.

ART/SHL 2012: Categorization of livestock animals in Switzerland. D. Bretscher and T. Kupper. Agroscope Research Station Zürich (ART), Schweizerische Hochschule für Landwirtschaft Zollikofen (SHL). April 2012.

Baggs, E.M., Richter, M., Hartwig, U.A., Cadisch, G. 2003: Nitrous oxide emissions from grass swards during the eighth year of elevated atmospheric CO_2 (Swiss FACE). Global Change Biology 9 (8): 1214-1222.

Berthoud, F. 2004: Dokumentation der Methan- & Lachgastabelle. Eine Hilfeleistung zum Verstehen der Berechnungen und Berechnungsgrundlagen der landwirtschaftlichen Treibhausgasemissionen hin zu den Resultatwerten des Common Reporting Format des IPCC. Internal documentation. Agroscope FAL, Swiss Federal Research Station for Agroecology and Agriculture.
http://www.environment-switzerland.ch/climatereporting/00545/01913/index.html?lang=en

Boeckx, P., Van Cleemput, O. 2001: Estimates of N_2O and CH_4 fluxes from agricultural lands in various regions in Europe. Nutrient Cycling in Agroecosystems 60 (1-3): 35-47.

Braun, M., Hurni, P., Spiess, E. 1994: Phosphor- und Stickstoffüberschüsse in der Landwirtschaft und Para-Landwirtschaft : Abschätzung für die Schweiz und das Rheineinzugsgebiet der Schweiz unterhalb der Seen. [Surplus de phosphore et d'azote dans l'agriculture et la para-agriculture: estimation pour la Suisse et pour le bassin versant hydrographique suisse du Rhin en aval des lacs]. Schriftenreihe der FAC Liebefeld 18. [in German, with English and French summary]

Christensen, K., Thorbek, G. 1987: Methane excretion in the growing pig. British Journal of Nutrition 57: 355-361.

Crutzen, P.J., Aselmann, I., Seiler, W. 1986: Methane production by domestic animals, wild ruminants, other herbivorous fauna, and humans. Tellus 38 B (3-4): 271-284.

Dämmgen, U., Rösemann, C., Haenel, H.-D., Hutchings, N. J. 2012a: Enteric methane emissions from German dairy cows. Landbauforschung: vTI Agriculture and Forestry Research 62 (No. 1/2): 21-32.

Dämmgen, U., Amon, B., Hutchings, N. J., Haenel, H.-D., Rösemann, C. 2012b: Data sets to assess methane emissions from untreated cattle and pig slurry and solid manure storage systems in the German and Austrian emission inventories. Landbauforschung: vTI Agriculture and Forestry Research 62 (No. 1/2): 1-19.

Decrem, M., Herzog, F., Nievergelt, J., Richner, W., Spiess, E. 2005: Analyse von Szenarien zur Wirkung des ÖLN auf die Nitratauswaschung im Ackerbau. In: Herzog, F., Richner, W. (eds.): Evaluation der Ökomassnahmen Bereich Stickstoff und Phosphor. Schriftenreihe der FAL 57. Zürich Reckenholz: 26-31.

Decrem, M., Spiess, E., Richner, W., Herzog, F. 2007: Impact of Swiss agricultural policies on nitrate leaching from arable land. Agronomy for Sustainable Development 27 (3): 243-253.

Del Grosso, S.J., Parton, W.J., Mosier, A.R., Walsh, M.K., Ojima, D.S., Thornton, P.E. 2006: DAYCENT national-scale simulations of nitrous oxide emissions from cropped soils in the United States. Journal of Environmental Quality 35 (4): 1451-1460.

Del Grosso, S.J., Wirth, T., Ogle, S.M., Parton, W.J. 2008: Estimating agricultural nitrous oxide emissions. EOS, Transactions, American Geophysical Union. 89 (51): 529-530.

EEA 2007: EMEP/CORINAIR 2007 Emission Inventory Guidebook (December 2007). European Environment Agency. Technical Report No. 16/2007. http://www.eea.europa.eu/publications/EMEPCORINAIR5/page002.html [07.02.2011]

Estermann, B.L., Sutter, F., Schlegel, P.O., Erdin, D., Wettstein, H.-R., Kreuzer, M. 2002: Effect of calf age and dam breed on intake, energy expenditure, and excretion of nitrogen, phosphorus, and methane of beef cows with calves. Journal of Animal Science 80: 1124–1134.

Estermann, B.L., Wettstein, H.-R., Sutter, F., Kreuzer, M. 2001: Nutrient and energy conversion of grass-fed dairy and suckler beef cattle kept indoors and on high altitude pasture. Animal Research 50: 477–493.

European Commission 2011: Annual European Union greenhouse gas inventory 1990–2009 and inventory report 2011. European Commission, DG Climate Action, European Environment Agency. Brussels May 2011.

FAL/RAC 2001: Grundlagen für die Düngung im Acker- und Futterbau 2001. Eidgenössische Forschungsanstalt für Agrarökologie und Landbau / Eidgenössische Forschungsanstalt für Pflanzenbau, Agrarforschung, June 2001, Zürich-Reckenholz, Nyon. [available in German and French] http://www.environment-switzerland.ch/climatereporting/00545/01913/index.html?lang=en

FAO/IFIA 2001: Global estimates of gaseous emissions of NH_3, NO and N_2O from agricultural land. Food and Agriculture Organization of the United Nations (FAO), International Fertilizer Industry Association (IFIA). Rome, 2001.

Fischer, C., Jocher, M., Lüscher, A., Nyfeler, D., Neftel, A., Arnold, D., Conen, F. 2009: The influence of the legume fraction, nitrogen fertilization, and defoliation on N_2O emissions in grass-clover swards. Unpublished.

Flechard, C.R., Neftel, A., Jocher, M., Ammann, C., Fuhrer, J. 2005: Bi-directional soil/atmosphere N_2O exchange over two mown grassland systems with contrasting management practices. Global Change Biology 11 (12): 2114-2127.

Flechard, C.R., Ambus, P., Skiba, U., Rees, R.M., Hensen, A., van Amstel, A., Pol-van Dasselaar, A.V., Soussana, J.F., Jones, M., Clifton-Brown, J., Raschi, A., Horvath, L., Neftel, A., Jocher, M., Ammann, C., Leifeld, J., Fuhrer, J., Calanca, P., Thalman, E., Pilegaard, K., Di Marco, C., Campbell, C., Nemitz, E., Hargreaves, K.J., Levy, P.E., Ball, B.C., Jones, S.K., van de Bulk, W.C.M., Groot, T., Blom, M., Domingues, R., Kasper, G., Allard, V., Ceschia, E., Cellier, P., Laville, P., Henault, C., Bizouard, F., Abdalla, M., Williams, M., Baronti, S., Berretti, F., Grosz, B. 2007: Effects of climate and management intensity on nitrous oxide emissions in grassland systems across Europe. Agriculture Ecosystems & Environment 121 (1-2): 135-152.

Flisch, R., Sinaj, S., Charles, R., Richner, W. 2009: Grundlagen für die Düngung im Acker- und Futterbau 2009. Forschungsanstalt Agroscope Changins-Wädenswil ACW und Agroscope Reckenholz-Tänikon ART, Agrarforschung 16 (2).

Flisch 2010: Personal communication from René Flisch (ART, Zürich) to Daniel Bretscher (ART, Zürich), 12.08.2010.

Flynn, H.C., Smith, J., Smith, K.A., Wright, J., Smith, P., Massheder, J. 2005: Climate- and crop-responsive emission factors significantly alter estimates of current and future nitrous oxide emissions from fertilizer use. Global Change Biology 11 (9): 1522-1536.

FOEN 2009: Checklists (QC Tier 1) completed for the GHG Inventory submitted on 15 April 2009. Published on http://www.environment-switzerland.ch/climatereporting/00545/01913/index.html?lang=en

FOEN 2013: Switzerland's Greenhouse Gas Inventory 1990–2011: National Inventory Report, CRF tables, Kyoto Protocol LULUCF tables 2008-2011, SEF and SIAR tables from the National Registry. Submission of 15 April 2013 under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Federal Office for the Environment, Bern.

Freibauer, A. 2003: Regionalised inventory of biogenic greenhouse gas emissions from European agriculture. European Journal of Agronomy 19 (2): 135-160.

Freibauer, A., Kaltschmitt, M. 2003: Controls and models for estimating direct nitrous oxide emissions from temperate and sub-boreal agricultural mineral soils in Europe. Biogeochemistry 63 (1): 93-115.

FVO 2009: Tierverkehr. http://www.bvet.admin.ch/gesundheit_tiere/00297/00299/index.html?lang=de [09.06.2009]

Giuliani, S. 2012: Energiebedarfswerte der Nutztiere für die Periode 1990-2010. Written communication from Silvano Giuliani (SBV, Swiss Farmers Union) to Daniel Bretscher (ART, Reckenholz), 14.08.2012. http://www.bafu.admin.ch/climatereporting/00545/01913/index.html?lang=en

Grüter, R. 2007: Personal communication from Robert Grüter (Swiss Farmers Union, Brugg) to Daniel Bretscher (Agroscope Reckenholz-Tänikon, Zürich), 31.05.2007.

Hadorn, R., Wenk, C. 1996: Effect of different sources of dietary fiber on nutrient and energy utilization in broilers. 2. Energy and N-balance as well as whole body composition. Archiv für Geflügelkunde 60: 22-29.

Herzog, F., Richner, W. 2005: Evaluation der Ökomassnahmen Bereich Stickstoff und Phosphor. Schriftenreihe der FAL 57. Zürich Reckenholz.

Herzog, F., Cornaz, S., Decrem, M., Leifeld, J., Menzi, H., Muralt, R., Spiess, E., Richner, W. 2005: Wirkung der Ökomassnahmen auf die Stickstoffausträge aus der schweizerischen Landwirtschaft. In: Herzog, F., Richner, W. (eds.): Evaluation der Ökomassnahmen Bereich Stickstoff und Phosphor. Agroscope FAL Reckenholz. Zürich: 70-78.

Hindrichsen, I.K., Wettstein, H.-R., Machmüller, A., Kreuzer, M. 2006a: Digestive and metabolic utilisation of dairy cows supplemented with concentrates characterised by different carbohydrates. Animal Feed Science Technology 126: 43–61.

Hindrichsen, I.K., Wettstein, H.-R., Machmüller, A., Bach Knudsen, K.E., Madsen, J., Kreuzer, M. 2006b: Methane emission, nutrient degradation and nitrogen turnover in dairy cows and their slurry at different milk production scenarios with and without concentrate supplementation. Agricultural Ecosystems and Environment 113: 150–161.

Husted, S. 1994: Seasonal-Variation in Methane Emission from Stored Slurry and Solid Manures. Journal of Environmental Quality 23 (3): 585-592.

IPCC 1997: Greenhouse Gas Inventory Reference Manual, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Reference Manual (Volume 3). Intergovernmental

Panel on Climate Change. http://www.ipcc-nggip.iges.or.jp/public/gl/invs6.htm [10.02.2009]

IPCC 2000: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC GPG). Intergovernmental Panel on Climate Change. http://www.ipcc-nggip.iges.or.jp/public/gp/english/ [10.02.2009]

IPCC 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm [10.02.2009]

Jones, S.K., Rees, R.M., Skiba, U.M., Ball, B.C. 2007: Influence of organic and mineral N fertiliser on N_2O fluxes from a temperate grassland. Agriculture Ecosystems & Environment 121 (1-2): 74-83.

Kirchgeßner, M., Windisch, W., Müller, H.L. 1994: Methane release from dairy cows and pigs. EAAP Publ. 76: 399-402.

Klevenhusen, F., Bernasconi, S. M., Kreuzer, M., Soliva, C.R. 2008: The methanogenic potential and C-isotope fractionation of different diet types represented by either C-3 or C-4 plants as evaluated in vitro and in dairy cows. Australian Journal of Experimental Agriculture 48(1-2): 119-123.

Kohler 2013: Written communication from Florian Kohler (SFSO, Neuchâtel) to Daniel Bretscher (ART, Zürich), 18.01.2013.

Kreuzer 2012: Wissenschaftlicher Schlussbericht zuhanden des BAFU und des BLW für das Projekt: Technische Massnahmen und deren Potenzial zur Reduktion der THG CH_4 und N_2O aus der Schweizer Tierhaltung. ETH 10.2. 2012.

Külling, D. R., Dohme, F., Menzi, H., Sutter, F., Lischer, P., Kreuzer, M. 2002: Methane emissions of differently fed dairy cows and corresponding methane and nitrogen emissions from their manure during storage. Environmental Monitoring and Assessment 79 (2): 129-150.

Külling, D. R., Menzi, H., Sutter, F., Lischer, P., Kreuzer, M. 2003: Ammonia, nitrous oxide and methane emissions from differently stored dairy manure derived from grass- and hay-based rations. Nutrient Cycling in Agroecosystems 65 (1): 13-22.

Kupper, T., Bonjour, C., Achermann, B., Zaucker, F., Rihm, B., Menzi, H. 2013: Ammoniakemissionen in der Schweiz 1990-2010 und Prognose bis 2020. Hochschule für Agrar-, Forst- und Lebensmittelwissenschaften, Zollikofen. URL: http://www.agrammon.ch/dokumente-zum-download/

Leifeld, J., Bassin, S., Fuhrer, J. 2003: Carbon stocks and carbon sequestration potentials in agricultural soils in Switzerland. Schriftenreihe der FAL 44. Zürich-Reckenholz. http://www.environment-switzerland.ch/climatereporting/00545/01913/index.html?lang=en

Leifeld, J., Fuhrer, J. 2005: Greenhouse gas emissions from Swiss agriculture since 1990: Implications for environmental policies to mitigate global warming. Environmental Science & Policy 8: 410-417. http://dx.doi.org/10.1016/j.envsci.2005.04.001

Lesschen, J. P., Velthof, G. L., de Vries, W., Kros, J. 2011: Differentiation of nitrous oxide emission factors for agricultural soils. Environmental Pollution 159(11): 3215-3222.

Machmüller, A., Kreuzer, M. 1999: Methane suppression by coconut oil and associated effects on nutrient and energy balance in sheep. Canadian Journal of Animal Science 79: 65–72.

Machmüller, A., Kreuzer, M. 2005: Influence of myristic acid supplementation on energy, fatty acid and calcium metabolism of sheep as affected by dietary calcium and forage:concentrate ratio. Journal of Animal Physiology and Animal Nutrition 89: 284–296.

Machmüller, A., Soliva, C.R., Kreuzer, M. 2003: Effect of coconut oil and defaunation treatment on methanogenesis in sheep. Reproduction Nutrient Development 43: 41–55.

MAFF 2000: Improved characterization of nitrous oxide emissions from livestock buildings and animal waste stores. Ministry of Agriculture, Fisheries and Food (MAFF), Silsoe Research Institute, Silsoe. London.

Menzi, H., Frick, R., Kaufmann, R. 1997: Ammoniak-Emissionen in der Schweiz: Ausmass und technische Beurteilung des Reduktionspotenzials. [Emissions d'ammoniac en Suisse : amplitude et évaluation technique du potential de réduction]. Schriftenreihe der FAL 26. Zürich-Reckenholz. [in German, with English and French summary]

MeteoSwiss 2009: Federal Office of Meteorology and Climatology; Normwert-Tabellen 1961-1990. http://www.meteoschweiz.admin.ch/web/de/klima/klima_schweiz/tabellen.html [11.06.2009]

Meyer, H., Coenen, M., 2002: Pferdefütterung. Parey Buchverlag Berlin, 4. Auflage; ISBN 3-8263-3398-5.

Minonzio, G., Grub, A., Fuhrer, J. 1998: Methanemissionen der schweizerischen Landwirtschaft. Schriftenreihe Umwelt Nr. 298. FOEN / BUWAL, Bern.

Moller, H.B., Sommer, S.G., Ahring, B.K. 2004: Biological degradation and greenhouse gas emissions during pre-storage of liquid animal manure. Journal of Environmental Quality 33 (1): 27-36.

Monni, S., Perälä, P., Regina, K. 2007: Uncertainty in Agricultural CH4 and N2O Emissions from Finland – Possibilities to Increase Accuracy in Emission Estimates. Mitigation and Adaptation Strategies for Global Change 12 (4): 545-571.

Münger, A., Kreuzer, M. 2006: Greenhouse gases and Animal Agriculture: An Update. Soliva, C.R., Takahashi, J., Kreuzer, M., eds., Elsevier Science B.V., The Netherlands.

Neuhaus 2007: Personal communication from Ms Neuhaus (FOAG, Bern) to Daniel Bretscher (ART, Zürich), 09.07.2007.

Peter, S., Hartmann, M., Hediger, W. 2006: Entwicklung der landwirtschaftlichen Emissionen umweltrelevanter Stickstoffverbindungen. Schlussbericht, Dezember 2006. Schriftenreihe Info Agrar Wirtschaft 2006/1. ETH Zürich; Institute for Environmental Decisions IED.

Petersen, S. O., Amon, B., Gattinger, A. 2005: Methane oxidation in slurry storage crusts. Journal of Environmental Quality 34: pp. 455-461.

Prasuhn, V., Braun, M. 1994: Abschätzung der Phosphor- und Stickstoffverluste aus diffusen Quellen in die Gewässer des Kantons Bern. [Estimation des pertes en phosphore et en azote dans les eaux du canton de Berne à partir de sources diffuses]. Schriftenreihe der FAC Liebefeld 17. [in German, with English and French summary]

Prasuhn, V., Probst, T., Mohni, R. 2003: Abschätzung der Stickstoff- und Phosphoreinträge aus diffusen Quellen in die Birs. Gruppe Gewässerschutz ; Eidgenössische Forschungsanstalt für Agrarökologie und Landbau FAL. Zürich.

RAP 1999: Fütterungsempfehlungen und Nährwerttabellen für Wiederkäuer. [Apports alimentaires recommandés et tables de la valeur nutritive des aliments pour les ruminants]. Landwirtschaftliche Lehrmittelzentrale, Zollikofen. Vierte Auflage. http://www.alp.admin.ch/dokumentation/00611/00631/index.html?lang=fr [16.03.2009]

Reidy, B., Menzi, H. 2005: Ammoniakemissionen in der Schweiz: Neues Emissionsinventar 1990 bis 2000 mit Hochrechnungen bis 2003. Technischer Schlussbericht. Schweizerische Hochschule für Landwirtschaft (SHL). Zollikofen, Bern.

Reidy, B., Menzi, H. 2007: Assessment of the ammonia abatement potential of different geographical regions and altitudinal zones based on a large-scale farm and manure management survey. Biosystems Engineering 97 (4): 520-531.

Reidy, B., Rhim, B., Menzi, H. 2008: A new Swiss inventory of ammonia emissions from agriculture based on a survey on farm and manure management and farm-specific model calculations. Atmospheric Environment 42 (14): 3266-3276.

Rihm, B. 2000: Exceedance of critical loads of nitrogen in Switzerland for different ammonia emission reduction scenarios. Meteotest. Bern.

Rochette, P., Janzen, H.H. 2005: Towards a revised coefficient for estimating N_2O emissions from legumes. Nutrient Cycling in Agroecosystems 73 (2-3): 171-179.

Roelandt, C., van Wesemael, B., Rounsevell, M. 2005: Estimating annual N2O emissions from agricultural soils in temperate climates. Global Change Biology 11 (10): 1701-1711.

Rudaz, A.O., Walti, E., Kyburz, G., Lehmann, P., Fuhrer, J. 1999: Temporal variation in N_2O and N_2 fluxes from a permanent pasture in Switzerland in relation to management, soil water content and soil temperature. Agriculture Ecosystems & Environment 73 (1): 83-91.

Safley, L. M., Casada, M.E., Woodbury, J.W., Roos, K.F. 1992: Global Methane Emissions from Livestock and Poultry Manure. U. S. E. P. A. (EPA). Washington, United States Environmental Protection Agency (EPA).

SBV 2007: Landwirtschaftliche Monatszahlen – Données mensuelles sur l'agriculture. 66 (8). Schweizerischer Bauernverband, SBV Statistik, Brugg.

SBV 2008: Statistiques et évaluations concernant l'agriculture et l'alimentation, 2007. [Statistische Erhebungen und Schätzungen über Landwirtschaft und Ernährung, 2007]. Swiss Farmers Union, Brugg. [available in German and French] http://www.sbv-usp.ch/fr/shop/statistiques-et-evaluations/ [02.02.2009]

Schjoerring, J.K., Mattsson, M. 2001: Quantification of ammonia exchange between agricultural cropland and the atmosphere: Measurements over two complete growth cycles of oilseed rape, wheat, barley and pea. Plant and Soil 228 (1): 105-115.

Schmid, D., Lanz, S. 2013: Die Zusammensetzung der Futterration in der Milchviehhaltung der Schweiz. AGRARForschung Schweiz 4 (4): 184-191.

Schmid, M., Neftel, A., Fuhrer, J. 2000: Lachgasemissionen aus der Schweizer Landwirtschaft. [Emissions de protoxyde d'azote de l'agriculture Suisse]. Schriftenreihe der FAL 33. Zürich-Reckenholz. http://www.environment-switzerland.ch/climatereporting/00545/01913/index.html?lang=en

Schmid, M., Neftel, A., Riedo, M., Fuhrer, J. 2001: Process-based modelling of nitrous oxide emissions from different nitrogen sources in mown grassland. Nutrient Cycling in Agroecosystems 60 (1-3): 177-187.

Schönhusen, U., Zitnan, R., Kuhla, S., Jentsch, W., Derno, M., Voigt, J. 2003: Effects of protozoa on methane production in rumen and hindgut of calves around time of weaning. Archives of Animal Nutrition 57: 279–295.

SFSO 2000: Digital soil map 1:200'000 („Bodeneignungskarte", BEK). Swiss Federal Statistical Office, GEOSTAT, Neuchâtel.

SFSO 2009: Swiss Federal Statistical Office, Agriculture and forestry. Censuses and Sources. http://www.bfs.admin.ch/bfs/portal/de/index/themen/07/11/enq.html [09.06.2009]

SFSO 2012: STAT-TAB: Die interaktive Statistikdatenbank. Datenwürfel für Thema 07.2 – Landwirtschaft. Bundesamt für Statistik (BFS), Neuchâtel, Schweiz.

SFSO 2012a: Supply of provisional data of the AREA Land Use Statistics. Written communication from Felix Weibel and Jürg Burkhalter (SFSO, Neuchâtel) to Lukas Mathys (Sigmaplan, Bern), 03.07.2012.

SHL 2010: Bestimmung Tiere der Rindviehkategorien ab 2009 für die Berechnung des Ammoniakinventars. Schweizerische Hochschule für Landwirtschaft SHL, Zollikofen.

Sintermann, J., Neftel, A., Ammann, C., Häni, C., Hensen, A., Loubet, B., Flechard, C. R. 2012: Are ammonia emissions from field-applied slurry substantially over-estimated in European emission inventories? Biogeosciences, 9 (5): 1611–1632.

Spiess, E. 1999: Nährstoffbilanz der schweizerischen Landwirtschaft für die Jahre 1975 bis 1995. Schriftenreihe der FAL. Eidgenössische Forschungsanstalt für Agrarökologie und Landbau, Zürich-Reckenholz.

Spiess, E. 2005: Die Stickstoffbilanz der Schweiz. In: Herzog, F., Richner, W. (eds.): Evaluation der Ökomassnahmen Bereich Stickstoff und Phosphor. Schriftenreihe der FAL 57. Zürich Reckenholz: 26-31.

Soliva, C.R. 2006: Report to the attention of IPCC about the data set and calculation method used to estimate methane formation from enteric fermentation of agricultural livestock population and manure management in Swiss agriculture. On behalf of the Federal Office for the Environment, Bern. ETH Zurich, Institute of Animal Science. http://www.environment-switzerland.ch/climatereporting/00545/01913/index.html?lang=en

Sommer, S.G. 2001: Effect of composting on nutrient loss and nitrogen availability of cattle deep litter. European Journal of Agronomy 14 (2): 123-133.

Sommer, S.G., Petersen, S.O., Sorensen, P., Poulsen, H.D., Moller, H.B. 2007: Methane and carbon dioxide emissions and nitrogen turnover during liquid manure storage. Nutrient Cycling in Agroecosystems 78 (1): 27-36.

Staerfl, S., Bosshard, C., Graf, C., Zeitz, J., Kreuzer, M., Soliva, C. 2012: Einfluss von Jahreszeit und Fütterung auf die Methanemissionen aus Schweizer Milchviehgülle. AGRARForschung 3 (6): 322-329.

Steed, J., Hashimoto, A.G. 1994: Methane emissions from typical manure management systems. Bioresource Technology 50 (2): 123-130.

Stehfest, E., Bouwman, L. 2006: N2O and NO emission from agricultural fields and soils under natural vegetation: summarizing available measurement data and modeling of global annual emissions. Nutrient Cycling in Agroecosystems 74 (3): 207-228.

Stricker, B. 2012: Energiebedarfswerte der Pferde, Esel und Ponys. Written communication from Brigitte Stricker (ALP-Haras, Agroscope Liebefeld-Posieux research station) to Daniel Bretscher (ART, Reckenholz), August-October 2012.

Swiss Confederation 1991: Ordonnance du 21 janvier 1991 sur la protection des hauts-marais et des marais de transition d'importance nationale (Ordonnance sur les hauts-marais). As at 01 January 2008.

The Federal Authorities of the Swiss Confederation 2005: Verordnung über die Tierverkehr-Datenbank (TVD-Verordnung). 23. November 2005 (State of Mai 1st 2009). http://www.admin.ch/ch/d/sr/9/916.404.de.pdf [09.06.2009]

TVD 2009: Tierverkehrsdatenbank. http://www.tierverkehr.ch/de/index.htm [09.06.2009]

UNFCCC 2013: Synthesis and Assessment Report on the Greenhouse Gas Inventories Submitted in 2013. FCCC/WEB/SAI/2013.

UVEK 2003: Düngen mit Klärschlamm wird verboten, UVEK Eidgenössisches Departement für Umwelt, Verkehr, Energie, Kommunikation. http://www.admin.ch/cp/d/3e816ebe_1@presse1.admin.ch.html [16.7.2009]

Vanderweerden, T.J., Jarvis, S.C. 1997: Ammonia emission factors for N fertilizers applied to two contrasting grassland soils. Environmental Pollution 95(2): 205-211.

Walther, U., Menzi, H., Ryser, J.-P., Flisch, R., Jeangros, B., Maillard, A., Siegenthaler, A., Vuilloud, P.A. 1994: Grundlagen für die Düngung im Acker- und Futterbau. Agrarforschung 1(7): 1-40.
http://www.environment-switzerland.ch/climatereporting/00545/01913/index.html?lang=en
http://www.agrarforschung.ch/de/inh_det.php?id=724 [25.02.2009]

Werder, D., Perrin, P.-Y., Dubach, M., Gerwig, C., Hediger, W., Lehmann, B. 2004: Technischer Bericht über die Entwicklung des Stickstoff-Verlustpotenzials der Schweizer Landwirtschaft von 1994 bis 2002. Schlussbericht, April 2004. Institut für Agrarwirtschaft, Gruppe Betriebswirtschaft und Ökonomie des ländlichen Raumes, ETH Zürich.

Zeitz, J. O., Soliva, C. R., Kreuzer, M. 2012: Swiss diet types for cattle: how accurately are they reflected by the Intergovernmental Panel on Climate Change default values? Journal of Integrative Environmental Sciences, 9:sup1,199-216.

Annex A: Data basis of the annual statistics of the Swiss Farmers Union (SBV) (according to Grüter 2007)

Table	Data	Database	Responsible institution	Data assessment	Periodicity	Geog. level	Uncer-tainty	Comments
Rindvieh-bestand nach Nutzungsart und Alter	**Cattle livestock animal numbers**	*Eidgenössische Viehzählungen (VIZ)*	Swiss Federal Statistical Office (1866-1993)	Full census	yearly	Canton, Switzerland	1-2% + 4.5%	
		Tierverkehrsdatenbank (Animal Traffic Database)	Swiss Federal Veterinary Office (FVO); from December 1999 onward Identitas AG	Full census of all cattle animals (individual earmarks)	continuous	Canton, Switzerland		
		Landwirtschaftliche Betriebsstruktur-erhebung (substitutes partly earlier *Landwirtschaftliche Betriebszählung* of the SFSO)	Swiss Federal Statistical Office (since 1994), in cooperation with the Federal Office for Agriculture and the Cantonal Departments of Agriculture.	Full census through coordination of administrative data in the context of agricultural subsidies (basic population and unit: agricultural farms who together generate at least 99 % of the overall agricultural production).	yearly	Community		In the context of the coordinated full census the statistical coverage is nearly 100%. Eventually some farms with specialized activities such as silkworms, snails, fur bearing animal, etc. are missing. Data of enterprises not directly affected by agricultural policy are estimated by the SFSO.
		Landwirtschaftszählung, landwirtschaftliche Betriebszählung (BZ S1)	Swiss Federal Statistical Office (since 1905), since 1996 in cooperation with the Federal Office for Agriculture, the Swiss Federal Veterinary Office and the Cantonal Departments of Agriculture.	Full census through coordination of administrative data in the context of agricultural subsidies. Independent samples for additional information of the enterprises without agricultural subsidies (comprehensive census which encompasses all workstations and employees of the 1st economic sector) (basic population and unit: agricultural farms who together generate at least 99 % of the overall agricultural production).	every 5 years	Community		In the context of the coordinated full census the statistical coverage is nearly 100%. Eventually some farms with specialized activities such as silkworms, snails, fur bearing animal, etc. are missing. Data of enterprises not directly affected by agricultural policy are directly assessed by the SFSO. Estimates based on subsamples are not regionally differentiated.
Nutztier-bestand nach Alter und Nutzungsart	**Livestock animal numbers**	*Eidgenössische Viehzählungen (VIZ)*	Swiss Federal Statistical Office (1866-1993)	Full census	yearly	Canton, Switzerland	1-2% + 4.5%	
		Tierverkehrsdatenbank (Animal Traffic Database)	Swiss Federal Veterinary Office (FVO); from December 1999 onward Identitas AG	Registration of all owners of hoof bearing animals (cattle, sheep, goats, swine).	continuous	Canton, Switzerland		

Table	Data	Database	Responsible institution	Data assessment	Periodicity	Geog. level	Uncer-tainty	Comments
Nutztier-bestand nach Alter und Nutzungsart		*Landwirtschaftliche Betriebsstruktur-erhebung* (substitutes partly earlier *Landwirtschaftliche Betriebszählung* of the SFSO)	Swiss Federal Statistical Office (since 1994), in cooperation with the Federal Office for Agriculture and the Cantonal Departments of Agriculture.	Full census through coordination of administrative data in the context of agricultural subsidies (basic population and unit: agricultural farms who together generate at least 99 % of the overall agricultural production).	yearly	Community		In the context of the coordinated full census the statistical coverage is nearly 100%. Eventually some farms with specialized activities such as silkworms, snails, fur bearing animal, etc. are missing. Data of enterprises not directly affected by agricultural policy are estimated by the SFSO.
		Landwirtschaftszählung, landwirtschaftliche Betriebszählung (BZ S1)	Swiss Federal Statistical Office (since 1905), since 1996 in cooperation with the Federal Office for Agriculture, the Swiss Federal Veterinary Office and the Cantonal Departments of Agriculture.	Full census through coordination of administrative data in the context of agricultural subsidies. Independent samples for additional information of the enterprises without agricultural subsidies (comprehensive census which encompasses all workstations and employees of the 1st economic sector) (basic population and unit: agricultural farms who together generate at least 99 % of the overall agricultural production).	every 5 years	Community	1-2% + 4.5%	In the context of the coordinated full census the statistical coverage is nearly 100%. Eventually some farms with specialized activities such as silkworms, snails, fur bearing animal, etc. are missing. Data of enterprises not directly affected by agricultural policy are directly assessed by the SFSO. Estimates based on subsamples are not regionally differentiated.
Milchjahres-leistung	**Milk delivered**	Milk marketed (published on www.milchstatistik.ch and *Milchstatistik der Schweiz* of the SBV)	TSM GmbH (formerly *Treuhandstelle Milch GmbH*)	Full census of the milk delivered to the milk processing industries (according to article 21 of the *Milchpreisstützungs-Verordnung*: Milk-commercializing industries have to report every month the amount and utilization of milk delivered by the producers).	continuous	Switzerland	1-2%	Basic data is also available from the organization of milk-producers of Switzerland (www.swissmilk.ch).
	Utilization of the produced milk	*Zentrale Auswertung von Buchhaltungsdaten*	Agroscope Reckenholz-Tänikon Research Station (ART)	Data of 3000–4000 farms who deliver their accountancy to the central accounting evaluation. Basis for the calculation of the amount of milk for home use (own consumption, animal feed, private sales).	yearly	Production regions of Switzerland	10%	
		Statistische Erhebungen und Schätzungen über Landwirtschaft und Ernährung, yearly milk yields	*Schweizerischer Bauernverband (SBV)* (Swiss Farmers Union)	Calculation of the total milk-production based on the information mentioned above.	yearly	Switzerland		

Table	Data	Database	Responsible institution	Data assessment	Periodicity	Geog. level	Uncer-tainty	Comments
Futterbedarf des schweize-rischen Viehbestandes	**Feeding require-ments (Energy require-ments)**	Required feedstuff per animal	Agroscope Liebefeld-Posieux research station (ALP)	Investigation of feeding requirements for different animal categories.	yearly	Switzerland	10%	Requirements per animal are reviewed periodically and have been updated recently.
		Fattening pig trials	*Schweizerische Mast- und Schlachtleistungsprüfungs-anstalt*, since 1967; since 1st of January 2001 integrated in the SUISAG.	Keeping of approximately 1'800 fattening pigs with computer guided feeding regiments for the assessment of feed consumption and fat- and meat properties.	continuous	Switzerland		
		Statistische Erhebungen und Schätzungen über Landwirtschaft und Ernährung, Futterbilanz	*Schweizerischer Bauernverband (SBV)* (Swiss Farmers Union)	Estimation of feed requirements through multiplication of animal numbers with usual feed consumption rates; cross check with available feedstuff from inland production and import statistics.	yearly	Switzerland		
Verfügbarer N-Dünger für die Landwirtschaft	**Synthetic fertilizers**	*Statistische Erhebungen und Schätzungen über Landwirtschaft und Ernährung*, available fertilizer for agriculture and para-agriculture in Switzerland.	*Schweizerischer Bauernverband (SBV)* in coordination with *Treuhandstelle der Schweiz. Düngerpflichtlagerhalter TSD (AGRICURA 2012)*	Inland production and fertilizer imports; estimation based on inland sales and foreign trade statistics.	yearly	Switzerland	5%	
	Compost / Sewage sludge / digestate liquid and solid	*School for Agriculture, Forest and Food Sciences (HAFL, Kupper et al. 2013)*	*School for Agriculture, Forest and Food Sciences (HAFL, Kupper et al. 2013)*	Estimation based on the amount of source material (Compost: Plants) and data on average composition. Estimate	yearly	Switzerland		
Landwirtschaft liche Nutzfläche	**Area of agricultura l soils**	*Landwirtschaftliche Betriebsstruktur-erhebung* (substitutes partly earlier *Landwirtschaftliche Betriebszählung* of the SFSO)	Swiss Federal Statistical Office (since 1994), in cooperation with the Federal Office for Agriculture and the Cantonal Departments of Agriculture.	Full census through coordination of administrative data in the context of agricultural subsidies (basic population and unit: agricultural farms who together generate at least 99 % of the overall agricultural production).	yearly	Community	1-2%	In the context of the coordinated full census the statistical coverage is nearly 100%. Eventually some farms with specialized activities such as silkworms, snails, fur bearing animal, etc. are missing. Data of enterprises not directly affected by agricultural policy are estimated by the SFSO.

Table	Data	Database	Responsible institution	Data assessment	Periodicity	Geog. level	Uncer-tainty	Comments
		Landwirtschaftszählung, landwirtschaftliche Betriebszählung (BZ S1)	Swiss Federal Statistical Office (since 1905), since 1996 in cooperation with the Federal Office for Agriculture, the Swiss Federal Veterinary Office and the Cantonal Departments of Agriculture.	Full census through coordination of administrative data in the context of agricultural subsidies. Independent samples for additional information of the enterprises without agricultural subsidies (comprehensive census which encompasses all workstations and employees of the 1^{st} economic sector) (basic population and unit: agricultural farms who together generate at least 99 % of the overall agricultural production).	every 5 years	Community		In the context of the coordinated full census the statistical coverage is nearly 100%. Eventually some farms with specialized activities such as silkworms, snails, fur bearing animal, etc. are missing. Data of enterprises not directly affected by agricultural policy are directly assessed by the SFSO. Estimates based on subsamples are not regionally differentiated.
Verwendbare Produkte der Pflanzen-kulturen	**Cereals, Oilseeds**	*Statistische Erhebungen und Schätzungen über Landwirtschaft und Ernährung, Verwendbare Produkte der Pflanzenkulturen*	Swiss Farmers Union (SBV) in cooperation with *Swiss Granum* (*Swiss Granum* builds the common platform of the cereal-, oilseed- and protein-plants-industry)	Survey at the primary recipients, yield assessment at approximately 1000 producers, as well as central accounting evaluations of roughly 3000 farms.	yearly	Switzerland		Data source vary according to the product. The Swiss Farmers Union compares the data with calculated values of crop yields (based on cropping area and yield levels).
	Sugar beet	*Statistische Erhebungen und Schätzungen über Landwirtschaft und Ernährung, Verwendbare Produkte der Pflanzenkulturen*	Sugar-mills	Survey at the primary recipients	yearly	Switzerland		
	Green fodder	*Zentrale Auswertung von Buchhaltungsdaten*	Agroscope Reckenholz-Tänikon Research Station (ART)	Data of 3000–4000 farms who deliver their accountancy to the central accounting evaluation.	yearly	Switzerland		
	Potatoes	*Statistische Erhebungen und Schätzungen über Landwirtschaft und Ernährung, Verwendbare Produkte der Pflanzenkulturen*	swisspatat (http://www.kartoffel.ch/index.php?id=408)	Surveys at members	yearly	Switzerland	10%	

Table	Data	Database	Responsible institution	Data assessment	Periodicity	Geog. level	Uncer-tainty	Comments
Verwendbare Produkte der Pflanzen-kulturen	**Vegetables**	Vegetabel growers	*Schweizerische Zentralstelle für Gemüsebau*	Survey at the Cantonal Central for Vegetable Faming *Zentralstellen für Gemüsebau*	continuous	Switzerland	10%	
	Vines	Weinlesekontrolle	Federal Office for Agriculture	Official Grape-harvest control of the cantons	yearly	Switzerland		
	Tobacco	Delivery of Tobacco	sota (Cooperative for the purchase of inland tobacco)	Survey at the primary recipients	yearly	Switzerland		
Erträge im Obstbau	**Total of fruits without berries**	*Statistische Erhebungen und Schätzungen über Landwirtschaft und Ernährung, Erträge im Obstbau*	Swiss Farmers Union (SBV) in cooperation with the Fruits-Association (*Schweizerischen Obstverband (SOV)*) and the Federal Office for Agriculture.	Survey of the sales and stocks of fruits, the processing of fruits and the production of juices and liquors. Survey of the yields of fruit cultures.	yearly	Switzerland	10%	