Agricultural CH_4 and N_2O emissions in Switzerland

QA/QC

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Content

Important Comment:

Most findings of this QA/QC analysis refer to the Swiss National Greenhouse Gas Inventory submitted in 2009. During 2009 a major recalculation of the agricultural sector of the inventory was conducted that addressed the most important shortcomings and inconsistencies. Consequently some of the statements in this document might be obsolete. The document will be updated in the future with the new data of the Swiss National Greenhouse Gas Inventory submitted in 2010.

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, 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 standardised 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 (FOEN 2009b).

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 organisations 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 planed 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.

Most of the activity data used for the calculation of agricultural greenhouse gas emissions in Switzerland is taken from annual statistics from the Swiss Farmers Union (SBV 2008, Grüter 2007) or from the Swiss Federal Statistical Office (see Annex A). Most of the data is collected in the course of the “Agricultural Farm Census” (*Landwirtschaftliche Betriebszählung*; every 3-5 years) or more recently during the so called “Agricultural Farm Structure Census” (*Landwirtschaftliche Betriebsstrukturerhebung*; every 1-2 years). 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 “Required Standards of Ecological Performance” (REP) that are 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).

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

Assessment of livestock population data in Switzerland is considered to be very reliable. Most statistics are taken from the yearbooks of the Swiss Farmers Union (SBV 2008). Data sources used by the Swiss Farmers Union to compile their statistical yearbooks are listed in *Annex A*.

In order to prevent and combat eventual animal pests the Swiss Federal Veterinary Office (FVO) sets the framework for animal stock and traffic controls (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. Data of cattle livestock is collected by the “Animal Traffic Database” (*Tierverkehrsdatenbank*) that is updated continuously and published monthly by Identitas AG (TVD 2009). The database also comprehends owners of other animals such as sheep, goats and pigs (*Klauentiere: Rinder, Schafe, Ziegen, Schweine*) but it can be assumed, that cattle livestock data is somewhat more precise than livestock data from other animals. Livestock data is also collected during the censuses of the Swiss Federal Statistical Office (*Eidgenössische Viehzählung, Landwirtschaftliche Betriebsstrukturerhebung* and *Landwirtschaftliche Betriebszählung*) (SFSO 2009).

Seasonal fluctuation of the cattle population has been analyzed for the years 2005-2007 based on detailed information from the Swiss Farmers Union (SBV 2007). Fluctuations are usually in the order of ±3% with census data (April) always slightly above the annual mean.

The livestock activity data is generally in line with the FAO statistical data since the information source is identical (Neuhaus 2007). Yet, the Swiss Farmers Union conducts data updates in subsequent years of first publication. The FAO database does not necessarily account for these updates as does the Swiss national GHG inventory system. Consequently small differences in the order of ±2% may occur. Animal numbers in the category "Mules and Asses" are in average 70% higher than the respective FAO numbers because Switzerland additionally includes ponies and lesser horses. The total number of poultry also shows some minor discrepancies (± 2%) due to different accounting for turkeys, geese, ducks and quails.

The time series 1990–2008 are generally consistent. In 1999 the category "Mature Dairy Cattle" was split into two categories, i.e. "Mature Dairy Cattle" and "Mature non Dairy Cattle". This explains the 7.3% drop of the number of "Mature Dairy Cattle" between 1998 and 1999. The category "Mature Non Dairy Cattle" comprises mature mother cows used to produce offspring for meat and was introduced due to the increase of this more extensive production system (natura beef production). Before 1999 the respective activities were of minor importance and the category "Mature non Dairy Cattle" is reported as "included elsewhere" (IE, i.e. Mature Dairy Cattle). Furthermore, 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. Consequences for overall emissions are, however, of minor importance. While the average absolute trend for the years 1990–2005 over all animal categories was 3.2%, the average absolute trend for the years 1998-1999 was 3.9%. All livestock data was recompiled in 2006 and checked for confidence and consistency.

Calculation of CH_4 and N_2O emissions are based on slightly different livestock population break downs. The different categorizations are adapted to the availability of data on gross energy intake and nitrogen excretion in the literature (Soliva 2006; Flisch et al. 2009; Schmid et al. 2000). Nevertheless, there is no inconsistency in the total numbers of animals as they are the same both for CH_4 and N_2O emissions.

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

2. CH_4 emissions

2.1. Enteric fermentation – 4A

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 “Required Standards 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. Except for calves on milk the respective values were in the range of ± 1.5 to 3% of the animal’s body weight, satisfying the crosscheck recommended by the IPCC (1997). Furthermore, calculated estimates for total energy intake of the entire cattle livestock population can be compared with the respective data from the Swiss Farmers Union (SBV 2008). The average absolute difference in the time period 1990-2004 is ±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). The Swiss Farmers Union is currently conducting a revision of their feed energy calculation.

For all non cattle categories data on energy intake are taken 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)**).

Dairy cattle

In Switzerland dairy cattle are mainly fed with roughage and only few concentrate. 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 and the average milk production per head and day is 16 to 58% 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 2006” (UNFCCC 2008) (109 kg/head/year). Furthermore 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 (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 as a very sensitive parameter significantly affecting uncertainty in estimates of greenhouse gas emission from enteric fermentation. 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 only 3.6% respectively 0.6% to total enteric and manure methanogenesis from agricultural livestock. Consequently a more detailed methodology is not justified.

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 gross energy intake of 32MJ are more appropriate. This GE intake rate is equal to the data of the Swiss Farmers Union (SBV) used in the Swiss inventory.

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 1.2%, 5.3% and 0.8%, respectively. The gross energy intake of horses, mules and asses is higher than proposed in the emission inventory guidebook but should be realistic considering the population composition and the high feeding standards in Switzerland. The SBV provides only an aggregated estimate for digestible energy intake by animals of the horse genre. The total energy demand of the population is then distributed among the two categories used in the greenhouse gas inventory. This procedure can lead to unrealistic values for mules and asses. Total methane formation, however, is calculated correctly since energy conversion factors as well as methane conversion rates are the same for the horse- as well as the mules and asses- category. The calculated data for swine energy intake are comparable with IPCC default values (i.e. 35 – 40 MJ compared to 38 MJ).

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

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		13.5 – 15.6[c]	0.0	305 days of lactation	60%	6.0%	109.83
Mature non-dairy cattle	n.a.	550	0.00		6.8[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%	21.93
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%	10.58
Breeding cattle (4-12 months)	4-12 month	120-300	0.80	Premature race (Milk-race)	0.0	0.0	0%	60%	6.0%	35.12
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%	21.87
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%	49.03

[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 most of the individual categories is less than 365 days.

n.a. not applicable

Table 2 Comparison of methane conversion rates (Y_m) and feed digestibilities (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*

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. More recently, 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 analysed (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. If these results should be confirmed by future studies an adjustment of the values in the Swiss inventory should be considered. A methane conversion rate for cattle livestock of 6.5% as suggested in the new IPCC Guidelines (IPCC 2006) might be more suitable in this case.

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 can be seen in Table 2.

For goats, horses, mules and asses, and swine methane conversion factors are also IPCC default. The conversion rate of 2.5% for horses differs from the 3.5% suggested by Minonzio et al. (1998). However, given the relatively high feed energy intake a low value is not unrealistic. Furthermore Minonzio et al. (1998) propose a somewhat lower rate for swine (0.54 in stead 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	9.6 - 11.2	8
Goats	9.5 – 11.4	5
Horses	21.6 – 29.0	18
Mules and Asses	14.3 – 27.0	10
Swine	1.4 – 1.6	1.5
Poultry	0.02	Not estimated

2.1.3. Emission factors

Enteric fermentation emission factors for cattle have already been discussed in the previous sections. For non cattle animals implied emission factors are notably higher than IPCC default (Table 3). As explained above, this is mainly due to higher feed energy intake in Switzerland especially in the case of sheep, goats, horses and mules and asses. For sheep only Norway (14.3 kg/head/year) and Denmark (14.9 kg/head/year) reported higher values than Switzerland (10.6 kg/head/year) in 2004. New Zealand has a similar implied emission factor of 10.9 kg/head/year (UNFCCC 2008).

Methane emission from enteric fermentation and especially the methane conversion rate Y_m can be significantly influenced by animal nutrition (e.g. Hadorn and Wenk 1996; Hindrichsen et al. 2006a; Külling et al. 2002; Machmüller and Kreuzer 1999). Currently different feeding strategies are not considered in the agricultural greenhouse gas inventory. Moreover, the use of animal feed additives for the purpose of methane emission reduction is barely applied in practice and therefore also not regarded.

2.2. CH_4 emission from manure management – 4B

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 IPCC B-6 and B-7 (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 difficult for the respective categories.

Energy intake

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. The contrary is true for the respective values for sheep, goats, horses and mules and asses where values of the Swiss inventory are in most cases considerably higher. These circumstances have already been discussed in the enteric fermentation section (*2.1. Enteric fermentation – 4A*). Values for feed energy density calculated on the basis of the information in Table 4 are with two exceptions close to the 18.45 MJ/kg suggested in the IPCC Guidelines (IPCC 1997). For calves on milk 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 an even higher energy density of the feed according to the data in Table 4 (Ø 28.96 MJ/kg). In this case, the value for feed dry mass intake per day given by FAL/RAC (2001) is probably far to low. This assumption is supported by the respective data from RAP (1999) and Minonzio et al. (1998).

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	260-280	15.07 [d]	8	5.17-5.57	0.24
Mature non-dairy cattle	550	60	205.09	10.96 [d]	8	4.09	0.24
Calves on milk	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	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	1.06-1.15 [d]	8	0.40 [b]	0.19
Goats	Not determined	60	29-35	1.08-1.13 [d]	8	0.28 [b]	0.17
Horses	Not determined	70	132-177	7.12-7.94 [d]	4	1.72 [b]	0.33
Mules and Asses	Not determined	70	87-165	Not estimated	4	0.94 [b]	0.33
Swine	Not determined	75	35-40	Not estimated	2	0.50 [b]	0.45
Poultry	Not determined	Not estimated	1.6-1.9	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] FAL/RAC 2001

Feed digestibility and ash content

The digestibility of feed is of crucial importance for the calculation of volatile solids. According to the 1996 IPCC Guidelines the %DE values used should be the same as those used to implement the Tier 2 method for enteric fermentation. Such a comparison is not possible 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 analysed, 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 to 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.

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	5.37	*5.08*	*3.66*
Mature non-dairy cattle	4.09	*4.13*[a]	*2.78*
Calves on milk	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	0.97	*1.46*	*0.75*
Fattening cattle	2.48	*2.99*	*1.69*
Sheep	*0.45*	0.40	*0.30*
Goats	*0.64*	0.28	*0.43*
Horses	*2.41*	1.72	*3.77*
Mules and Asses	*1.97*	0.94	*3.07*
Swine	*0.50*	0.50	*0.41*
Poultry	*Not estimated*	0.10	*0.02*

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

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. This difference is very small for mature dairy cattle, mature non dairy cattle and for swine. These three animal categories are responsible for approximately 85% of methane emissions from animal manure. Consequently discrepancies in some of the other animal categories are of minor importance.

Calculated VS values for all young cattle categories are lower and values for sheep, goats, horses and mules and asses are higher than default. The fact that Switzerland uses IPCC default values for all non cattle categories might therefore lead to a slight underestimation of total emissions from manure management. However, a revision of theses values can only be considered when further country specific values for digestibility and ash content are available.

Minonzio et al. (1998) suggest VS excretion data that are generally lower than values in the Swiss inventory and also lower than IPCC default (

Table 5). Their estimates are based on indications of the general feeding doctrines. The results imply that the IPCC methodology overestimates the VS excretion by 20 to 60%. 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. Since bedding materials typically are associated with solid storage systems, that have low methane conversion factors, the respective contribution is probably of minor importance for overall methane production (compare also IPCC 2006).

2.2.2. Maximum CH_4 producing capacity (B_0)

No country specific values for B_0 are available. Therefore the inventory is based on the IPCC default values. 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.

2.2.3. CH_4 conversion factors (MCF_{jk})

The Swiss agricultural greenhouse gas inventory is based on default MCF's (IPCC 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; FAL/RAC 2001). Besides being a substrate for methane formation, bedding material can contribute to crust formation on slurry tanks, influencing aeration of liquid manure systems.
- The temperature dependency of the MCF was also investigated in small scale experiments. However, substrate temperature may in practice differ significantly from ambient air temperature. The share of bedding material in the substrate is 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). For solid storage in Switzerland it amounts generally 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. 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 micro organisms. 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 emphasised 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%) suggesting rather high emissions. 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.

Generally more country specific information based on field measurement is needed to increase process understanding and reduce uncertainties in this field. 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).

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 FAL/RAC (2001) 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) and Menzi et al. (1997).

The fraction of animal manure handled in different manure management systems is calculated according to Reidy and Menzi (2005) (Table 6). The specific input parameters used in the greenhouse-gas-inventory were calculated from the “Agri-Food & Agri-Environmental Economics Group” of the Swiss Federal Institute of Technology in Zürich (ETH). The underlying data was assessed in a representative survey with nearly 2000 participating farmers (Reidy et al. 2008). 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 fraction of manure dropped on pastures is calculated according to Menzi et al. (1997).

Manure management system distribution data is generally not handled consistently in the Swiss greenhouse gas inventory (compare chapter *3.1. Standard literature for the calculation of N-flows in Swiss agriculture* and chapter *3.3.3. Manure management system fractions (MS(T,S))*). Different approaches are used for CH_4 and N_2O emissions. Furthermore, all values are kept stable during the whole inventory period and reflect production conditions in 2003. However, parameters should be adapted in the case of changing management practices (Soliva 2006). Currently a revision of the calculation model for ammonia emission from Swiss agriculture is being conducted that will provide updated data for manure system distribution. The results will be checked for suitability for the greenhouse gas inventory and will be eventually adopted in order to further improve the inventory.

Table 6 Comparison of manure management systems distribution for CH_4 with IPCC default values (IPCC Guidelines 1996 Table B3-7)[a]

Type		**Manure Management Systems**			
		Liquid / Slurry	**Solid Storage**	**Pasture / Range**	**Deep Litter / Other**
	MCFs	*10%*	*1%*	*1%*	0.1% – 10%
Mature Dairy Cattle	Switzerland	71%	22%	7%	0%
	IPCC	40%	18%	19%	23%[b]
Mature Non-Dairy Cattle	Switzerland	26%	41%	33%	0%
	IPCC[c]	18%	68%	13%	1%
Young Cattle	Switzerland	38%	30%	32%	0%
	IPCC[d]	50%	0%	38%	12%
Sheep	Switzerland	0%	0%	69%	31%
	IPCC	*Not determined → MCF = 1%*			
Goats	Switzerland	0%	0%	20%	80%
	IPCC	*Not determined → MCF = 1%*			
Swine	Switzerland	51%	49%	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 summarised 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. For poultry the updated MCF of 1.5% from the 2000 IPCC Guidelines is responsible for the difference in emission factor.

Table 7 Manure management CH_4 emission factors

	Default Values (IPCC 1997) kg CH_4/head/yr	Swiss GHG Inventory kg CH_4/head/yr
Mature dairy cattle	14.00	22.26 – 24.01
Mature non-dairy cattle	6.00[a]	8.05
Calves on milk	Not determined	0.36
Pre-weaned calves	Not determined	1.11
Breeding calves	Not determined	0.26
Breeding cattle 1	Not determined	1.69
Breeding cattle 2	Not determined	4.25
Fattening calves	Not determined	0.51
Fattening cattle	Not determined	3.32
Sheep	0.19	0.35
Goats	0.12	0.39
Horses	1.39	1.39
Mules and Asses	0.76	0.76
Swine	3.00	3.08
Poultry	0.078	0.117[b]

[a] Estern Europe Dairy Cattle

[b] MCF from IPCC 2000

Methane emission factors for manure management from Switzerland were compared with the data given in the Synthesis and Assessment report 2006 (UNFCCC 2008). Values for mature dairy and non-dairy cattle were slightly higher than average and comparable to the respective values from Austria, where agricultural structures are similar. Emission factors for sheep are 50% higher than 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 50% lower than average (but still higher than IPCC default). In this case the reason lies probably in the relatively higher share of manure managed solidly.

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). 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 quality and suitability of N_2O emission factors is hard 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). 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. The separate assessment of these N-loss fractions, however, is more difficult and associated with considerable uncertainties (Werder et al. 2004). 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 are based on the same standard literature (Table 8) which is also used for the Swiss greenhouse gas inventory. 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 crop and feed 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.

While the "Principles of fertilization" 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. The ammonia models by Menzi et al. (1997) and Reidy and Menzi (2005) are widely used both by scientists and policy makers. As FAL/RAC (2001) is an updated version of Walter et al. (1994), the model by Reidy and Menzi (2005) can be understood as a revision of Menzi et al. (1997). Currently the calculation scheme for NH_3 is being reviewed. A new version based on new on farm surveys will be available soon. Its suitability for the greenhouse gas inventory will be tested and the results will be adopted eventually.

Most of the standard literature described above is used by agricultural advisory centres 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.

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. Main differences between the IULIA method and IPCC are (Schmid et al. 2000):

- IULIA estimates lower nitrogen excretion per animal; especially in the case of cattle livestock.
- The amount of excreted nitrogen that is lost to the atmosphere is more than 50% higher compared to IPCC.
- The amount of nitrogen leaching (of manure nitrogen and of synthetic fertilizers) is lower by 1/3 compared to IPCC.
- The share of manure stored solidly is more than twofold; the share of excretion on pasture, range and paddock is lower by 1/3.
- The nitrogen inputs from biological fixation are higher by 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 total N_2O emissions are quite moderate. In total IULIA estimations of the N_2O emissions from agriculture are 14% lower than the IPCC estimations (Schmid et al. 2000).

The Swiss Greenhouse Gas Inventory uses currently values from all five standard publications mentioned above (Table 8). This generates problems of consistency and transparency that will be further discussed in the respective chapters below. While the updates in FAL/RAC 2001 have relatively small consequences for the key nitrogen figures, the new parameters from Reidy and Menzi 2005 have a bigger influence (Werder et al. 2004). Although the effect on the calculated total of greenhouse gas emission might be rather small, the situation is dissatisfying and should be addressed in the future.

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 Schmid et al. 2000	Principles of fertilization Update of Walther et al. 1994 N_2O Model IULIA
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 Schmid et al. 2000	NH_3 Model Update of Menzi et al. 1997 Principles of fertilization Update of Walther et al. 1994 N_2O Model IULIA
NH_3 emission factors	Menzi et al. 1997 Reidy and Menzi 2005	NH_3 Model Update of Menzi et al. 1997
Standard fertilizer requirements	Walther et al. 1994 FAL/RAC 2001	Principles of fertilization Update of Walther et al. 1994
Standard crop yields	Walther et al. 1994 FAL/RAC 2001	Principles of fertilization Update of Walther et al. 1994
Nitrogen contents of crops and crop residues	Walther et al. 1994 FAL/RAC 2001	Principles of fertilization Update of Walther et al. 1994
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 extensified 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).

Reidy et al. (2008) concluded that about two thirds of the ammonia emission reduction from livestock production and manure management 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 (e.g. reduced mineral fertiliser use, use of low emission manure spreading techniques, increased grazing and use of low protein diets for pigs) primarily induced by new nutrient balance legislation and improved awareness of farmers. 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 programmes 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 "Required standard of Ecological Performance" (REP). This programme aims at comprising an overall scheme of measures particularly respectful to the reduction of environmental risks. Integrated production (IP) and organic farming are favoured as special voluntary efforts with direct payments, and monetary incentives are not 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 REP 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 programmes in 1993 and the REP 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. This key figures stress the importance of animal production in Switzerland, in consequence of natural conditions which favour grasslands as the major fodder source for the animal herd.

The Swiss greenhouse gas inventory reproduces very well reductions in animal population. However, many technical measures that alter nitrogen flows in agriculture are not yet reflected by the current model. Most of the parameters such as manure management system distribution (MS), ammonia and nitric oxide volatilization ($Frac_{GASM}$ and $Frac_{GASF}$) or the fraction of crop residue that is removed from the field as crop ($Frac_R$) are left constant over the whole inventory period. Considering the above mentioned changes of agricultural structures, i.e. the adoption of the "Required standard of Ecological Performance" (REP), this must be seen as a notable shortcoming of the inventory. Furthermore, 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 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” includes 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 fulfil 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. As mentioned above, the Swiss greenhouse gas inventory at its current state could reproduce the expected changes only marginally. However, it is foreseen to work on a refinement of the model to better describe the respective implications. 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. N_2O emission from manure management - 4B

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/kgN 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 ($N_{ex(T)}$)

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.

Standard values for nitrogen excretion of the individual livestock categories are taken from Walther et al. (1994) for the time series 1990 till 2000 and from FAL/RAC (2001) for the time series 2001 till 2007 (Table 8). Some figures had to be adapted to the special livestock category classification of the greenhouse gas inventory according to Schmid et al. (2000). 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 up to a certain extent the consistency between livestock related CH_4 and N_2O emissions.

Values for nitrogen excretion of most of the considered animal categories changed from Walther et al. (1994) to FAL/RAC (2001). Most of these changes are due to new experimental principles, new feeding recommendations and new evaluations of the common production techniques. Only the altered values for fattening pigs and fattening calves can be related to effective changes in animal production (Werder et al. 2004; Reidy and Menzi 2005). Consequently for all other livestock categories it would be more precise to use the revised values from 2001 for the whole time series. Furthermore the nitrogen excretion of mature dairy cows depends on milk production in order to reflect the increasing production intensity. 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 meat production schemes increases in the future (i.e. renunciation of certain feed ingredients and supplements). Therefore, values for N_{ex} should be revisited during an eventual revision of the agricultural greenhouse gas inventory model.

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)		2006		
		places	heads	places	heads	
Dairy cattle	100.0	-	105.7	-	106.6	106.1
Young cattle	70.0 [a]	-	33.0	-	30.5	41.6
Sheep	20.0	16.0	7.4	12.0	6.1	9.7
Goat	-	18.0	10.6	16.0	9.5	13.0
Horses	-	-	52.9	-	42.3	62.2
Mules and Asses	-	17.0/26.0 [b]	25.0	25.0	25.0	37.6
Swine	20.0	15.0/35.0 [c]	12.0	13.0/35.0[c]	10.5	11.1
Poultry	0.6	-	0.5	-	0.5	0.6

[a] non dairy cattle

[b] mules and asses <1year/>1year

[c] fattening pig / breeding pig

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, swine and poultry the agreement is fairly well. For the calculation of N-excretion the two categories mature dairy cattle and mature non dairy cattle (mature cows used to produce offspring for meat – mother cows) are not treated separately. This might lead to a slight overestimation of nitrogen excretion since the so called mother cows do have a lower excretion rate of approximately 80 kg N per year (Werder et al. 2004; FAL/RAC 2001). 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 guidelines. For sheep the country specific value is considerably lower than default. This is in contradiction to the rather high corresponding feed intake in Switzerland and the value is somewhat greater than suggested by the IPCC. Reasons for this difference are not yet clear.

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. Resulting values for the year 2006 are presented in Table 9. Accordance is very well for the two most important categories i.e. dairy cattle and swine. For all other livestock categories the gross energy approach yields N_{ex} values 20 to 60% higher than used at present in the inventory. As mentioned in chapter *2.1.1. Animal livestock characteristics (gross energy intake, GE)* energy intake for theses animal species is rather high. The special quality of the feed might be a reason for the discrepancy, suggesting that the conversion factor of 18.45 is too low. Furthermore the 15% for CP% as well as values for $N_{retention}$ are only rough estimates and might be inappropriate for some animal species. The results must therefore be treated with relative caution. 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. Results are more or less the same as for the GE approach with relatively higher values compared to those used in the inventory at present.

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

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

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 calculations are based on the same standard literature (Walter et al. 1994; FAL/RAC 2001) some minor differences do exist. One possible explanation might be the different levels of livestock category disaggregation. Furthermore, Spiess (1999) argues that differences between the top down and bottom up approaches 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	bottom up	139.5	132.3	128.6
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 therefore 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. FAL/RAC (2001) 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. 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 Schmid et al. (2000) who follow the methodology of Menzi et al. (1997). The estimated values rely mostly on expert guess and represent the conditions of production in the years 1990-1995. A survey in 2003 revealed, however, that a few estimates are not sufficiently realistic and should be revised (Reidy and Menzi 2005, Reidy et al. 2007). This is especially the case for the grazing period of sheep and goats, the proportion of loose housing systems of heifers and the proportion of manure management systems for fattening calves and layers.

The same fraction of manure dropped on pasture is used for calculating nitrous oxide as well as methane emissions, but different fractions are used for the allocation of the remaining manure to liquid/slurry and solid storage. This is in disagreement with the IPCC Guidelines that suggest to use the same manure management system usage data for both greenhouse gases (IPCC 2000). The inconsistency is due to the revision of the CH_4 calculation model in 2006, where new and more reliable data has been adopted from Reidy and Menzi (2005) without changing simultaneously the method for the calculation of N_2O emissions. This matter will be addressed in the future. It is noteworthy, however, that the distribution of volatile solids (VS) 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 present, the Swiss inventory yields higher amounts of nitrogen stored as solid storage and lower amounts of nitrogen excreted on pasture than when calculated with IPCC default values (Schmid et al. 2000). Menzi et al. (1997) quote that pasture is 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.

As for the calculation of CH_4 emissions all parameters on animal manure distribution are kept stable during the whole inventory time period. To reflect changing management practices the values should, however, be adapted periodically as suggested by Soliva (2006). Reidy et al. (2007) found that in dairy production a strong shift towards loose housing systems occurred during the period from 1990 to 2002. Within the same period, a substantial increase of slurry systems could be observed. Based on the works of these authors a revision of the calculation model for ammonia emissions from Swiss agriculture is being conducted. The new model will provide more reliable data based on farm surveys and a dynamic time series for manure management system distribution that can be adopted for the greenhouse gas inventory. At the same time the two approaches for CH_4 and N_2O could be harmonised.

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).

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*

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.

3.4. Direct N_2O emissions from agricultural soils - 4D1

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):

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

Data on the use of synthetic fertilizer (N_{FERT}) in Switzerland is based on annual records of inland production as well as external trade statistics and is assessed by the Swiss Farmers Union (SBV) together with an explicit trust corporation (Grüter 2007). 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 2002-2005: SBV 215'000 t N; IFIA 216'000 t N). A possible source of discrepancies could be that roughly 3% 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...) (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.

Before the year 1995 N_{FERT} comprises also nitrogen from sewage sludge and compost. No separate statistics are available for this time period. Consequently N_{FERT} drops quite abruptly by 15.3% between 1994 and 1995 when sewage sludge and compost is treated separately.

The IPCC defines the term F_{SN} as the annual amount of synthetic fertilizer nitrogen applied to the soils after adjustment to account for the amount that volatilises as NH_3 and NO_x (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 soil, 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 Schmid et al. (2000) Switzerland is setting ammonia volatilization ($Frac_{NH3}$) to 6%. Thus the correction factor $Frac_{GASF}$ (= $Frac_{NH3}$ in Switzerland) is considerably lower than IPCC default

(10%). However, practically all countries adopting country specific values for $Frac_{GASF}$ report low values. The European community also calculates with a loss of 6% (UNFCCC 2008).

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 Menzi et al. (1997). 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 losses during application in the field have been at least partially taken into account. An average ammonium emission factor of 33.4% (2006) can be calculated, considering the different contributions of the individual animal categories to overall emissions. This is considerably higher than IPCC default. It is notable, however, that nearly all countries applying country specific values report higher emissions than IPCC default, ranging from 21% (Austria) to 34% (Spain). 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). Reidy and Menzi (2005) estimate this share to be around 60% 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 that, the new IPCC Guidelines of 2006 alter the methodology in that way, that only nitrogen losses from the manure management system ($Frac_{LossMS}$) are taken into account (IPCC 2006; equation 10.34).

The model of Menzi et al. (1997) proved to be inaccurate in several aspects. The NH_3 emissions have been estimated to be 3.4% lower (Herzog and Richner 2005) compared with a new improved inventory by Reidy and Menzi (2005). Since individual errors might compensate each other the deviation of specific parameters might be higher. Furthermore, different interpretations of the same underlying data on ammonia emission may lead to considerable uncertainties. Total 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 (2005).

As is true for other parameters, changes in agricultural structures and techniques have not been considered yet and the same $Frac_{NH3T}$'s are adopted for the whole time series. Yet, agricultural ammonia emissions have declined substantially between 1990 and 2000. Roughly two third of this reduction is due to lower animal livestock numbers. The remaining decrease can be attributed to changes in production techniques. According to Reidy and Menzi (2005) the most important changes have been improved feed utilization by swine, introduction of low emission slurry preparation and increased grazing ($Frac_{PRPT}$). Working in opposite direction is a strong shift towards loose housing systems for cattle.

Currently a new model is in preparation that will come up with more detailed data and new ammonia emission factors. It will be able to reflect structural and technical changes in agriculture. The suitability of this model for the greenhouse gas inventory will be checked and, if positive, the model will be adopted.

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 (SBV 2008). Crop yield data is assessed in collaboration with several organisations 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 2006). 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 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 Walther et al. (1994) and FAL/RAC (2001). The calculated values for $Frac_{NCRBF}$ range from 0.018 to 0.041 being 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).

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

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 here. 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.

Most of the values underlying nitrogen fixation assessment are based on expert guess (see Berthoud 2004) but are comparable to indications from other authors. However, 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 nitrogen fixation of 4.15 kg N/ha/%clover instead of 3.26 kg N/ha/%clover in the Swiss greenhouse gas 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}.

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 adopted.

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	32'404	32'262	32'417	
	Spiess 1999	37'730			
	Spiess 2005		35'700		
	Peter et al. 2006			32'500	
$F_{(CR)}$	Swiss GHG Inventory	36'801	36'445	36'028	35’180
	Spiess 1999	38'000			
	Spiess 2005		34'000		
	Peter et al. 2006			36'620	
	Calculation based on IPCC 2006 Guidelines				33’630

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 form 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 Walter et al. (1994) and FAL/RAC (2001). 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 Walter et al. (1994) and FAL/RAC (2001) 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). Most of these values remain constant over the whole inventory time period except for some crop species where standard values changed from Walter et al. (1994) to FAL/RAC (2001). In the case of silage corn, yearly yield data (Y_{Cr}) from the Swiss Farmers Union (SBV 2008) are used, due to great interannual variability. Comparisons with IPCC default values show a generally fair agreement 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% 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 support the later conclusion, though 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 2007	IPCC 1996[a]	IPCC 2000[b]	Swiss GHG Inventory 2007	IPCC 2000[b]	IPCC 2006[c]	Swiss GHG Inventory 2007[d]	IPCC 1996[a]	IPCC 2000[b]	IPCC 2006[c]	Swiss GHG Inventory 2007	IPCC 1996[a]
Cereals												
Wheat	1.25	1.22	1.30	0.85	0.82-0.88	0.89	0.0060	0.0150	0.0028	0.0060	0.44	0.45
Barley	1.08	1.22	1.20	0.85	0.82-0.88	0.89	0.0052	0.0150	0.0043	0.0070	0.48	0.45
Maize	1.19	1.22	1.00	0.85	0.70-0.86	0.87	0.0071	0.0150	0.0081	0.0060	0.46	0.45
Oats	1.27	1.22	1.30	0.85	0.92	0.89	0.0059	0.0150	0.0070	0.0070	0.44	0.45
Rye	1.36	1.22	1.60	0.85	0.90	0.88	0.0060	0.0150	0.0048	0.0050	0.42	0.45
Other												
Mix of bred cereals [e]	1.25	1.22	1.30	0.85	0.82-0.88	0.88	0.0060	0.0150	0.0028	0.0060	0.44	0.45
Triticale	1.33	1.22		0.85		0.88	0.0088	0.0150			0.43	0.45
Mix of fodder cereals [f]	1.08	1.22	1.20	0.85	0.82-0.88	0.88	0.0052	0.0150	0.0043	0.0070	0.48	0.45
Spelt	1.50	1.22		0.85		0.88	0.0060	0.0150			0.40	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	1.00	1.22	1.50	0.85	0.87	0.91	0.0235	0.0300	0.0142	0.0080	0.50	0.45
Soybeans	1.00	1.22	2.10	0.85	0.84-0.89		0.0414	0.0300	0.0230	0.0080	0.50	0.45
Other												
Leguminous vegetables	4.62	1.22		0.22			0.0182	0.0300			0.18	0.45
Tubers and Roots												
Potatoes	0.48	1.22	0.40	0.14		0.22	0.0143	0.0150	0.0110	0.0190	0.68	0.45
Sugarbeet	0.77	1.22		0.15		0.22	0.0200	0.0150		0.0190	0.57	0.45
Beet	0.44	1.22	0.30	0.15		0.22	0.0233	0.0150	0.0228	0.0190	0.69	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 2007	IPCC 1996[a]	IPCC 2000[b]	Swiss GHG Inventory 2007	IPCC 2000[b]	IPCC 2006[c]	Swiss GHG Inventory 2007[d]	IPCC 1996[a]	IPCC 2000[b]	IPCC 2006[c]	Swiss GHG Inventory 2007	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		n.a.			0.0035	0.0150			0.95	0.45
Green corn	0.05	1.22		n.a.			0.0029	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			0.0089	0.0150			0.35	0.45
Non-leguminous vegetables	0.40	1.22		0.15			0.0521	0.0150			0.71	0.45
Sunflower	2.00	1.22		0.60			0.0150	0.0150			0.33	0.45
Tobacco	1.20	1.22		n.a.			0.0217	0.0150			0.45	0.45
Rape	1.86	1.22		0.85			0.0089	0.0150			0.35	0.45
Average non-leguminous	0.53	1.22		0.34			0.0122	0.0150			0.71	0.45
Average leguminous	2.51	1.22		0.59			0.0229	0.0300			0.36	0.45
Average overall	0.54	1.22		0.34			0.0123				0.71	0.45
Average without silage corn and green corn											0.56	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 Wheat

[f] 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%. Generally it is yet unclear to what extent emissions factor estimates for grasslands are also valid for cropland and vice versa.

Emission factor estimates have also been conducted in Switzerland. In general 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. 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 fertilizers 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 criticised 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 regionalised 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 fertiliser N sources applied.

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, soil 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 intensively by agriculture was estimated from historical and recent surveys (Leifeld et al 2003). The most reliable estimate was obtained by combining information from different sources after checking for consistency (Table 16). Nonetheless, the area and spatial distribution of cultivated organic soils is very uncertain (±30%, ART 2008). Estimates range from 12’000 ha to 22’000 ha, with a mean of 17’000 ha.

The total area of cultivated organic soils in Switzerland is left unchanged during the whole inventory period. 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 an 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 “Required standards of Ecological Performance” that oblige farmers to establish a share of 7% of ecological compensation area.

3.4.7. Emission factor for emissions from organic soil cultivation (EF2)

Large N_2O emissions occur as a result of cultivation of organic soils due to enhanced mineralisation 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) suggest 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 according to measurements in Europe including Switzerland as compiled by Leifeld et al. (2003, 2005) (FOEN 2009a). Subsequently a C/N ratio of 14.9 can be calculated for the concerned organic matter pool assuming a constant N_2O emission rate of 1.25%. 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 calculated areas 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. Emissions from animal production - 4D2

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

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

For further specification of the formula see chapter *3.3. N2O emission from manure management - 4B*.

Information on animal numbers ($N_{(T)}$), nitrogen excretion rates ($N_{ex(T)}$) and manure management system distribution ($MS_{(T,S)}$) have 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 analysed to assess the suitability of this value in the Swiss agricultural context.

3.6. Indirect N_2O emissions from soils - 4D3

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).

$$N_2O_{(G)} - N = \begin{bmatrix} ((N_{FERT} + N_{SSC}) * Frac_{GASF}) + \left(\sum_T \left(N_{(T)} * Nex_{(T)}\right) * Frac_{GASM}\right) \\ + \left(AA * 1.5 kgNH_3 - N / ha\right) \end{bmatrix} * EF_4$$

$N_2O_{(G)}$ = 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)

1.5 kgNH$_3$-N/ha = ammonia emitted during decomposition of organic matter in the soil

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. Other (Use of sewage sludge and compost as fertilizers) - 4D4*. $Frac_{GASF}$ 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. The NO_x emission factor is taken from the CORINAIR emission inventory guidebook. Due to its relative low importance no further quality checks have been conducted yet. Additionally, it is assumed that on all agricultural land 1.5 kg NH_3-N is emitted per ha and year from soil N mineralization.. This value is derived from a literature review of Menzi et al. 1997. However, on the vast area of alpine pasture in Switzerland mineralization processes are probably considerably slower. Consequently the respective ammonia emissions might be overestimated.

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 judgement 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. Other (Use of sewage sludge and compost as fertilizers) - 4D4*. 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, and drainage tiles). Accordingly, the IPCC emphasises 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 most countries using country specific values estimate $Frac_{LEACH}$ to be lower than 30% (UNFCCC 2008). The European Union currently uses a factor of 26 %.

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. (2005) estimate the reduction of nitrogen leaching to be as great as 30%. Herzog et al. (2005) summarize that since the introduction of the “Required standards of Ecological Performance” nitrate-leaching could be reduced by 5-20 %.

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

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 as 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 amount of sewage sludge and compost is taken from statistics of the Swiss Farmers Union (SBV). 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. Data is only available from 1995 onward. For the time series 1990-1994 emissions from sewage sludge and compost are figured up with N_2O emissions from synthetic fertilizer use. Application of sewage sludge on agricultural land is prohibited since 2008 (UVEK 2003). The steady decline of the respective nitrogen input is therefore realistic.

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.

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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		
		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	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 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 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.
Nutztier-bestand nach Alter und Nutzungsart	**Livestock animal numbers**	*Eidgenössische Viehzählungen (VIZ)*	Swiss Federal Statistical Office (1866-1993)	Full census	yearly	Canton, Switzerland		
		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	1-2% + 4.5%	

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		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	10%	
		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*	Inland production and fertilizer imports; estimation based on foreign trade statistics.	yearly	Switzerland		
	Compost	*Statistische Erhebungen und Schätzungen über Landwirtschaft und Ernährung*, available fertilizer for agriculture and para-agriculture in Switzerland.	*Schweizerischer Bauernverband (SBV)*	Estimation based on the amount of source material (Compost: Plants >100t, data from FOEN) and data on average composition.	yearly	Switzerland	5%	
	Sewage sludge	*Statistische Erhebungen und Schätzungen über Landwirtschaft und Ernährung*, available fertilizer for agriculture and para-agriculture in Switzerland.	Agroscope Liebefeld-Posieux research station (ALP)	Estimate	yearly	Switzerland		

Table	Data	Database	Responsible institution	Data assessment	Periodicity	Geog. level	Uncer-tainty	Comments
Landwirtschaftliche Nutzfläche	**Area of agricultural 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.
		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.
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	10%	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		

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%	