Deliverable No. 2.3

Region-specific nitrous oxide emission factors for organic and conventional crop rotations

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Summary

Nitrous oxide emissions were monitored in high and low intensity – corresponding to conventional and organic – crop rotations at five different locations across Europe. The locations included the major cattle-producing regions, as well as important climatic variations. In three countries, experimental crop rotations were used, while the other two countries conducted the measurement program on local farms. A large database of background information about the five locations was collected, including climate data, soil characteristics, and supporting information about N inputs and soil inorganic N dynamics in each crop. The sites covered a large variety of textural composition, but each site was representative for the region. Precipitation during the 12-month monitoring period was unusually high in Austria (+45%), and below normal in Finland (-29%) and Italy (-24%).

Total N inputs, including manure and mineral fertilizers, atmospheric deposition, symbiotic N fixation and excretal returns, were higher with the conventional rotations except in Finland, where inputs were similar but based on solid manure and mineral fertilizer, respectively. Annual mean values of both ammonium and nitrate showed consistently higher concentrations in the conventional compared to the organic rotation, but variability was high. Nitrous oxide emissions were quantified with comparable static chamber techniques in the five locations. The chambers consisted of a permanent base and a removable top, and between 15 and 28 samplings were carried out. An inter-comparison of N_2O analyses between the laboratories yielded recoveries of 97-106% of an unknown standard. Still, instrumental problems were discovered which made it necessary to correct measurement data from Denmark, and part of the data from Italy, for interference from CO_2.

For each site and crop rotation, average accumulated N_2O emissions were estimated which ranged from 1.9 to 6.5 kg N_2O-N ha^{-1} yr^{-1}. Emissions were higher from the conventional systems except in Austria, where emissions from the organic rotation was twice as high. When emission factors for organic (OR) and conventional (CO) crop rotations were calculated as proportions of total N inputs (fertilizer N, N fixation, N deposition and N in excretal returns), the results were: Austria, 0.038 (OR) and 0.015 (CO); Denmark, 0.038 (OR) and 0.026 (CO); Finland, 0.019 (OR) and 0.026 (CO); Italy, 0.024 (OR) and 0.018 (CO); and UK, 0.040 (OR) and 0.024 (CO). Generally, emission factors were thus higher for the organic rotations except in Finland, where the values for the two systems were similar. Across all sites, the relationship between total N inputs and N_2O emissions indicated that emissions increased with increasing inputs of N. The slope of the regression line was 0.016 with an intercept of 1.4 kg N_2O-N ha^{-1} yr^{-1}. This average emission factor is higher than the one recommended by the IPCC for fertilizer N inputs, although it should be stressed that the emission factor presented here was based on total N inputs, not just fertilizer N.

Effects of system, location and crop category on N_2O emissions were investigated with a linear mixed model. Log-transformed N_2O emissions depended significantly on the interaction Location × Input, indicating a significant difference between organic and conventional crop rotations, but of a different nature among the five locations. There was also a significant effect of crop category on N_2O indicating higher emissions from forage crops than from N fixing crops, cereals or grassland. A second model examined effects of soil conditions on N_2O emissions. Significant effects of moisture, temperature and crop category were observed. There was a highly significant effect of ammonium, but no effect of nitrate, which could reflect that an important part of N_2O emissions from arable soil are associated with ammonium oxidation.

Contents

0 Introduction

According to the European Environmental Agency (1999), agricultural production in EU15 contributes >40% to methane (CH_4) emissions and >50% to nitrous oxide (N_2O) emissions. Dairy production represents the largest source of CH_4 within agriculture and is also an important source of N_2O derived from, e.g., the turnover of manures, mineral fertilizers, crop residues and symbiotic N fixation (Table 0.1).

Table 0.1. Emissions of CH_4 and N_2O from agriculture and dairy cattle in the reference year 1990. (Freibauer and Kaltschmitt, 2000).

EU15 (1990)	CH_4 (Gg)	CO_2-eq[a] (Gg)	Agricultural contribution from dairy cattle (%)	N_2O (Gg)	CO_2-eq[a] (Gg)	Agricultural contribution from dairy cattle (%)
Enteric fermentation	6933	145600	41	-	0	
Animal houses	1367	28700	11	53	16560	12
Manure storage	1062	22300	32	35	10720	45
Manure spreading	20	420	5	Included in soils		
Droppings, grazing	0	0	-	77	23870	14
Rice cultivation	154	3230	-	Included in arable soils		
Arable soils	-42	-880	-	259	80380	> 19
Grassland	-25	-520	-	209	64790	> 19
Total agriculture	**9469**	**199000**	**35**	**633**	**196000**	**> 20**
Total EU budget[b]	**23074**	**484554**	**14**	**1261**	**390910**	**> 10**

[a] GWP 100

[b] (EEA, 1999)

Organic management differs from conventional management in several ways which may influence GHG emissions, including feeding strategy, manure handling, use of industrial fertilizers and pesticides, and choice of crop rotation. It was the basic hypothesis behind the MIDAIR project that cost-effective mitigation protocols for agriculture must be based on models that describe region and management specific differences in flows of C and N. A description of GHG emissions from dairy production did not exist at this level of resolution (Freibauer and Kaltschmitt, 2000), and the present study was therefore planned to provide such a database for N_2O emissions from representative organic and conventional crop rotations.

Long-term monitoring of N_2O emissions in all phases of organic and conventional dairy crop rotations in four geographic regions, i.e., Boreal, Temperate, Alpine/Prealpine and Mediterranean regions were conducted during 12-month periods between October 2001 and March 2003. Supporting information was compiled in order to describe total N inputs and provide a detailed characterization of each experimental site.

1 Experimental sites

1.1 Geographical locations

The monitoring program included measurements in five different locations covering the major cattle producing regions within the EU, as well as main climatic zones. The geographical locations are specified in Fig. 1.1.

In four of the five locations (Finland, Denmark, Austria and Italy), nitrous oxide (N_2O) emissions from high intensity (henceforth ‘conventional’) and low intensity (henceforth ‘organic’) arable crop rotations were investigated, while the location in the UK focused on emissions fra grazed pastures under organic and conventional management.

	Latitude	Longitude
Austria	47°40’N	13°05’E
Denmark	55°52’N	9°34’E
Finland	60°49'N	23°30'E
Italy	44°41’N	10°35’E
UK	50°42’N	4°52’W

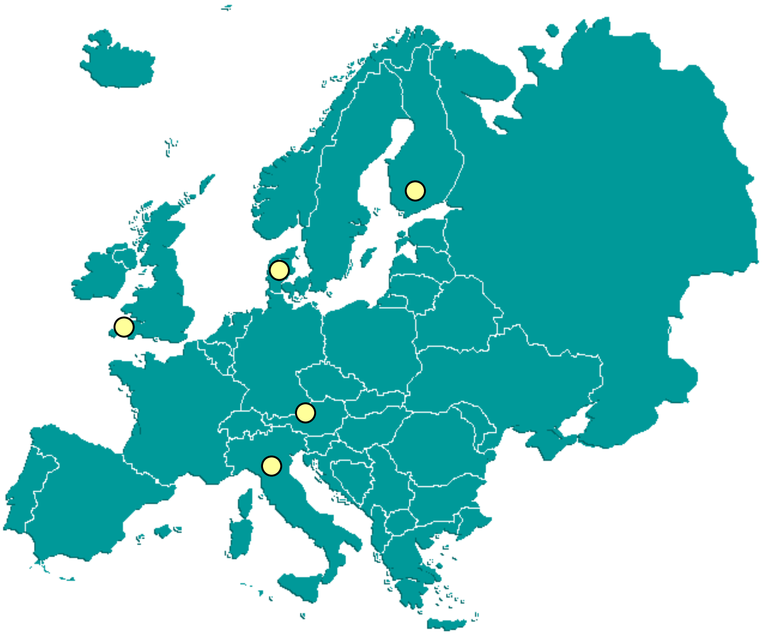

Fig. 1.1. Geographical location of the five sites of the N_2O monitoring program.

1.2 Climate

Key climate data were obtained locally as part of the monitoring programs. The data were obtained either by equipment installed on the sites for this particular project, or from already existing nearby weather stations. Air temperature and precipitation were recorded as daily means.

1.2.1 Air temperature

Monthly mean temperatures for the five locations are presented in Fig. 1.2. The periods were not identical since the 12-month monitoring periods were initiated at different times in the five countries. Still, it is evident that temperature patterns varied between countries, with the highest maximum temperature in Italy, the lowest minimum temperatures in Finland and Austria, and with much less annual variation in the Atlantic climatic conditions of Southwest UK.

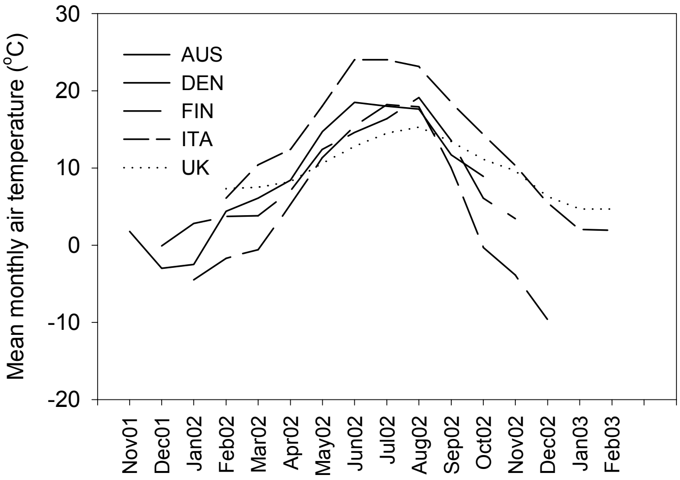

Fig. 1.2. Monthly mean temperatures of the five locations. The monitoring programs ran from December to November or from March to February. [incomplete]

In Table 1.1, the monthly mean temperatures during the monitoring periods are contrasted with long-term mean temperatures for each location. Except for relatively high summer temperatures in Italy, the temperature regimes of the monitoring periods did not deviate dramatically from long-term means.

Table 1.1. Measured and average monthly temperatures of the five N_2O monitoring locations.

	Austria		Denmark		Finland		Italy		UK	
	Monitoring	Long-term	Monitoring	Long-term	Monitoring	Long-term	Monitoring	Long-term	Monitoring	Long-term
Jan	-2,5	-1,3	2,8	-0,5	-4,5	-5,9	2,0	1,7	4,7	4,6
Feb	4,4	0,7	3,7	-0,5	-1,7	-6,5	1,9	3,5	4,7	4,6
Mar	6,1	4,7	3,8	1,8	-0,6	-2,7	10,4	6,7	7,5	6,0
Apr	8,4	8,9	7,0	5,5	5,2	2,7	12,4	10,5	8,2	7,8
May	14,7	13,3	12,4	10,5	11,3	9,5	18,0	15,3	10,6	10,8
Jun	18,5	16,4	14,6	14,2	15,4	14,1	24,0	18,8	12,8	13,5
Jul	18,0	18,3	16,4	15,4	18,2	16,1	24,0	21,7	14,5	15,5
Aug	17,6	18,0	19,1	15,1	17,9	14,5	23,1	21,3	15,3	15,4
Sep	11,7	15,0	13,6	12,1	10,1	9,3	18,5	17,1	13,4	13,5
Oct	8,9	10,0	6,1	8,5	-0,3	4,6	14,3	11,7	10,7	10,7
Nov	0,0	4,2	3,4	4,2	-3,9	-0,4	10,3	6,1	9,6	7,3
Dec	-3,0	-0,3	-0,1	1,1	-9,6	-4,1	5,4	2,4	6,3	5,5

1.2.2 Precipitation

Figure 1.3 shows precipitation (rainfall or snow) in each of the five locations. The same scale was used for all locations to facilitate a comparison between countries. Total precipitation at the sites during the 12-month monitoring periods (with percent deviation from long-term means in parentheses) were: Austria, 1698 mm (+45%); Denmark, 653 mm (+4%); Finland, 429 mm (-29%); Italy, 604 mm (-24%); and UK, 1113 mm (+6%).

Hence, Austria had extremely wet conditions, while Finland and Italy had dry conditions compared to a normal year.

Monthly means for the monitoring periods are shown, along with long-term means, in Table 1.2.

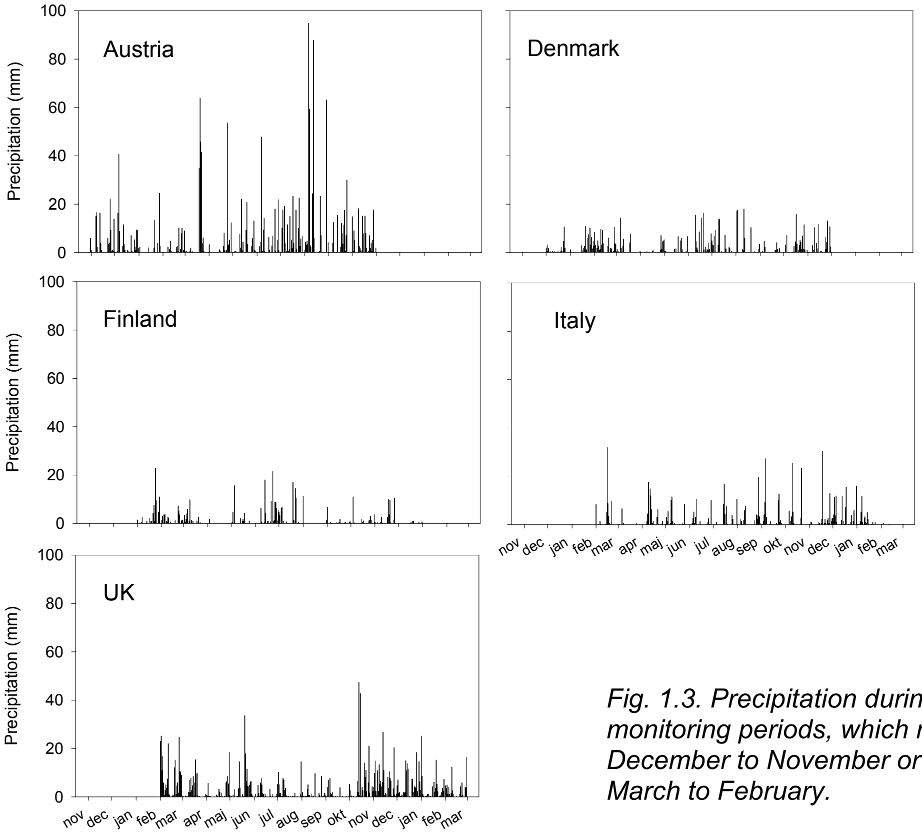

Fig. 1.3. Precipitation during the monitoring periods, which ran from December to November or from March to February.

Table 2. Measured and average monthly precipitation at the five N_2O monitoring

	Austria		Denmark		Finland		Italy		UK	
	Monitoring	Long-term	Monitoring	Long-term	Monitoring	Long-term	Monitoring	Long-term	Monitoring	Long-term
Jan	50	63	63	51	71	41	36	49	93	134
Feb	53	59	79	36	40	29	69	49	73	100
Mar	199	66	39	28	33	30	8	65	78	89
Apr	94	83	20	41	2	32	69	87	60	62
May	94	129	35	35	32	35	43	66	147	65
Jun	141	154	81	45	95	57	37	61	36	59
Jul	179	160	71	52	66	80	54	45	64	54
Aug	391	153	76	67	13	80	53	61	37	62
Sep	124	90	18	66	12	61	72	64	28	81
Oct	136	67	72	69	22	59	67	110	167	105
Nov	116	74	70	68	41	57	60	76	184	111
Dec	122	71	29	68	1	45	36	64	146	131

1.3 **Land use**

The sites used for the monitoring programs included both experimental crop rotations (Denmark, Finland and Austria) and local farms (Italy and the UK). This section gives a brief account of the prehistory of the sites used in each monitoring program.

1.3.1 Austria

The crop rotations used in Austria were established in 2000 in connection with the project ”Effects of organic manure types and quantities from different housing systems on plant yield, nutrient cycle and microbiological activities in soil, under conditions of organic farming in regions with high precipitation in West-Austria“. The project was a collaboration between the Agricultural University in Vienna and the Federal Research Institute for Agriculture in Alpine Regions, Irdning.

Fertilization of the crop rotation was adjusted to 1.0 LSU ha^{-1} (organic management), 1.8 LSU ha^{-1} (organic management) or 1.8 LSU ha^{-1} (conventional management). These three crop rotations were represented in each of four randomized blocks. The size of each plot was 4.6×12.5 m^2. The experimental site is out-lined in Appendix 1. Monitoring of N_2O emissions occurred in the two crop rotations corresponding to 1.0 LSU ha^{-1} (organic) and 1.8 LSU ha^{-1} (conventional), and was restricted to three of the four blocks. Manure management corresponded to a tie-stall system, i.e., both slurry and manure was applied.

1.3.2 Denmark

The experimental crop rotation used for the monitoring program was established in 1987, where it replaced a cereals-based rotation with straw removal and application of mineral fertilizers. From 1987 the rotation was under organic management. Until 1994, similar amounts of cattle slurry were applied within each field, depending on requirement, but in 1994 a randomized block design was established with two levels (0.7 and 1.4 LSU ha^{-1}) of cattle slurry and cattle solid manure (see Appendix 1). In the present study, the two treatments receiving slurry were used as representative for low and high intensity production.

The rotation includes six different fields, two of which are grass-clover and grazed by heifers during summer; these were not included in the monitoring program.

1.3.3 Finland

Monitoring of N_2O took place in an experimental crop rotation under organic and conventional management, which was established in 1990. Each plot is 0.5 ha, and the mangement systems are organized in randomized pairs for each crop, see Appendix 1. The organic crops are fertilized with a mixture of peat and FYM (solid cattle manure), whereas the conventional crops receive NPK.

The level of fertilization in the organic rotation corresponded to 0.5 LSU ha^{-1}, while LSU was not defined for the conventional system which received only mineral fertilizer.

1.3.4 Italy

The monitoring program in Italy was carried out near Reggio Emilia on two farms which produce milk for parma cheese production. Herd sizes at the organic and conventional farm were 42 and 60, respectively, and livestock densities were 1.5 and 2.3 LSU ha^{-1}, respectively. The areas occupied with each of the crops in the rotations ranged from 0.8 to 22.8 ha (organic rotation), and from 1.8 to 21.6 ha (conventional rotation. The organic farm was converted to this production system i 1986. More details are given in Appendix 1.

1.3.5 UK

Permanent pastures grazed by 1.0 (organic) and 2.4 LSU ha^{-1} (conventional) were used for N_2O emission measurements. On the organic farm, the field that was monitored had a size of 4.1 ha and was grazed in three-weekly intervals between mid April and the end of October. Grazing was restricted to night time. On the conventional farm, the field monitored was 7.7 ha, and it was part of a four-block grazing rotation; the grazing period was also between mid April and late October. Grazing occurred both day and night.

Both organic and conventional farms used cattle slurry, as well as FYM. The conventional farm also applied mineral fertilizer as NPK. Additional details about the production system are given in Appendix 1.

1.4 Soil characteristics

1.4.1 Soil texture

The contents of sand, silt and clay of each field of the five sites are presented in Table 1.3. The soils used for the monitoring program represented a range of soil types; i.e., silt loam (Austria), loamy sand (Denmark), clay (Finland), fine silty (Italy) and loam (UK). The Danish soil was typical for arable soils in the Western part of Denmark. The Finnish site was typical for agricultural soils in Southern Finland. For Italy, the soil type was representative for alluvial cone soils lying at the foot of a hill (as they were), whereas the lowland belt, which is more representative for the Po Valley, has relatively more clay and less silt. Soils in the region of the UK site are very variable, but mainly fine loam. The soil of both experimental sites however, was slightly coarser loam.

Sand content (% of minerals)

Code	Austria	Denmark	Finland	Italy	UK
OR1	15	83	15	13	40
OR2	12	82	15	11	-
OR3	15	83	15	13	-
OR4	15	80	15	12	-
OR5	15				
CO1	12	83	15	13	40
CO2	12	82	15	14	-
CO3	15	83	15	12	-
CO4	15	80	15	9	-
CO5	12	-	-	-	-

Clay content (% of minerals)

Code	Austria	Denmark	Finland	Italy	UK
OR1	18	8	76	19	20
OR2	24	8	76	22	-
OR3	18	8	76	20	-
OR4	18	8	76	15	-
OR5	18	-	-	-	-
CO1	24	8	76	16	20
CO2	24	8	76	29	-
CO3	18	8	76	33	-
CO4	18	8	76	28	-
CO5	24	-	-	-	-

Silt content (% of minerals)

Code	Austria	Denmark	Finland	Italy	UK
OR1	67	10	9	69	40
OR2	64	10	9	67	-
OR3	67	9	9	68	-
OR4	67	11	9	73	-
OR5	67	-	-	-	-
CO1	64	10	9	71	40
CO2	64	10	9	57	-
CO3	67	9	9	55	-
CO4	67	11	9	63	-
CO5	64	-	-	-	-

Table 1.3. Textural composition of the soils used for the N_2O monitoring program.

1.4.2 Total carbon and nitrogen

The carbon and nitrogen stocks, as well as C:N ratios, at the five sites are presented in Table 1.4. It may be noted that the sites in Austria and Italy had very similar textural composition, but differed widely in C content. The lower C stock in Italy probably reflect higher decomposition rates for soil organic matter at the higher temperatures in the Mediterranean climate zone (Townsend et al., 1997; Bol et al., 2003). The C:N ratios of the soil in Finland was markedly higher than at the other sites. Possibly there was a better protection of soil organic matter due to the very high clay content at this site (Christensen, 1992).

Soil carbon content (% of dry wt.)

Code	Austria	Denmark	Finland	Italy	UK
OR1	4	1,64	4,56	1,57	2,979
OR2	4,5	1,70	3,74	1,35	
OR3	4,2	1,66	5,35	1,65	
OR4	4,2	1,74	5,39	1,53	
CO1	3,77	1,68	3,8	1,28	4,84
CO2	4,35	1,80	4,01	1,57	
CO3	4,7	1,57	4,12	1,55	
CO4	4,35	1,72	3,98	1,37	

C/N ratio (mol basis)

Code	Austria	Denmark	Finland	Italy	UK
OR1	12,2	12,9	16,6	10,9	9,7
OR2	12,3	12,8	15,6	11,3	
OR3	12,2	12,7	16,4	13,2	
OR4	12,2	13,1	17,5	11,5	
CO1	12,1	13,3	16,4	9,3	10,8
CO2	12,3	13,6	16,1	11,4	
CO3	12,4	12,8	16,0	10,5	
CO4	12,3	12,8	16,6	12,2	

Soil nitrogen content (% of dry wt.)

Code	Austria	Denmark	Finland	Italy	UK
OR1	0,38	0,15	0,32	0,17	0,357
OR2	0,43	0,16	0,28	0,14	
OR3	0,40	0,15	0,38	0,15	
OR4	0,40	0,16	0,36	0,16	
CO1	0,36	0,15	0,27	0,16	0,521
CO2	0,41	0,16	0,29	0,16	
CO3	0,44	0,14	0,3	0,17	
CO4	0,41	0,16	0,28	0,13	

Table 1.4. Total carbon and nitrogen content, as well as C/N ratios of each crop at the five locations.

1.4.3 pH

Soil acidity is a function of parent material, state of weathering, climate and land use (Smith and Doran, 1996). Management practices such as crop sequence, use of ammoniacal fertilizers and manure application may influence pH. An important aspect of pH is that it controls the availability of minerals, which in most cases is optimal at a pH between 6 and 7.

pH has a marked effect on both nitrification and denitrification. Simek and Cooper (2002) reviewed the existing literature on denitrification response to pH and concluded that denitrifiers are often adapted to the natural pH of a given site and will express their maximum activity at that value. However, it is also generally true that the proportion of N_2O among the products of denitrification increases with decreasing pH away from neutrality. Nitrification activity is inhibited at low pH, and this is particularly true for nitrite oxidation; the accumulation of nitrite may have a direct role in the production of N_2O via nitrification (Martikainen and De Boer, 1993; Venterea and Rolston, 2000). Evidence for a role of nitrite in the production of N_2O was also obtained in WP5.1 (deliverable 5.2) of this project.

Table 1.5 shows pH_{KCl} at the five sites used in the monitoring program. All soils were neutral to slightly acidic, and there were no consistent differences between management practices.

Table 1.5. pH-values recorded in each field at a selected sampling in the autumn of 2002.

Code	Austria	Denmark	Finland	Italy	UK
OR1	6,9	6,3	6,5	7,32	5,8
OR2	7,2	6,5	7,3	7,15	-
OR3	6,6	6,4	7,3	7,22	-
OR4	6,8	6,0	7,5	7,07	-
CO1	7,5	6,3	6,7	7,33	5,4
CO2	7,5	6,6	7,0	7,21	-
CO3	7,5	6,2	7,3	7,44	-
CO4	6,7	6,1	7,6	6,87	-

1.4.4 Electrical conductivity

The electrical conductivity (*EC*) of a soil is related to the sum of cations and anions in the soil and may serve as an indicator for nutrient availability (Smith and Doran, 1996). In arable soils, *EC* is often correlated with soil nitrate content. Non-saline soils are within an *EC* range of 0-1.1 dS m^{-1} for sandy loams and 0-1.4 for silty clay loams and clay. *EC* is directly proportional to osmotic potential, and values as low as 0.6 dS m^{-1} may interfere with microbial processes, including nitrification and denitrification. A possible consequence is an increase in the proportion of total gaseous N losses emitted as N_2O.

Inputs of mineral fertilizers will increase *EC*, but the effect may vary with amount and type of fertilizer (Grewal et al., 1999). Smith and Doran (1996) recalculated data from Weier et al. (1993) and found that addition of KNO_3 at increasing rates changed *EC* of four different soils from 0.02-0.74 to 1-1.5 dS m^{-1}. At the same time, the proportion of N losses emitted as N_2O increased from 2-14% to 20-63%.

In the present study, *EC* was recorded for the soils used in the monitoring program at a selected sampling during autumn 2002, i.e., there had not been any recent inputs of fertilizer (Table 1.6). The soils were all non-saline, but some of the crops at the Italian location had *EC* values at a level that may have stimulated losses of N_2O.

Table 1.6. Electrical conductivity (dS m^{-1}) at a selected sampling in the autumn 2002.

Code	Austria	Denmark	Finland	Italy	UK
OR1	0,183	0,036	0,175	0,47	0,026
OR2	0,190	0,026	0,173	0,41	-
OR3	0,126	0,046	0,246	0,49	-
OR4	0,163	0,076	0,149	0,64	-
CO1	0,186	0,040	0,174	0,43	0,053
CO2	0,221	0,027	0,239	0,82	-
CO3	0,191	0,025	0,271	0,58	-
CO4	0,158	0,070	0,190	0,70	-

2 Crop rotations

2.1 Crops

Nitrous oxide was monitored within six- (Austria, Denmark) or four-crop rotations (Finland, Italy) under high intensity (conventional) and low intensity (organic) management. In the UK, organic and conventional pasture systems with rotational grazing were studied.

In Austria, the rotation consisted of spring barley, winter wheat, grass-clover (1st and 2nd yr), spring wheat and potatoes. The monitoring included spring barley, grass-clover, winter wheat and potatoes, as well as a permanent meadow outside the crop rotation. In Denmark, the monitoring program included a barley-pea wholecrop undersown with ryegrass, spring barley undersown with ryegrass, beet roots and oat undersown with ryegrass. The crops grown in 2001 on the fields/plots to be monitored are shown in the upper part of Table 2.1, and the crops of 2002 in the bottom part of Table 2.1. All crop rotations contained grass, small-grain crops, and N fixing crops, except that in Italy where there was only grass and alfalfa in the conventional rotation in 2001.

Table 2.1. Crop rotations at the five monitoring sites in 2001, the year preceeding the monitoring program, and in 2002.

Crops in 2001. Crops after '/' were undersown.

Code	Austria [a]	Denmark [b]	Finland	Italy	UK
OR1	potatoes	grass-clover, 2nd yr	grass	grass	grass
OR2	spring wheat/clover-grass	beet roots	rye	maize	-
OR3	grass-clover	oat/grass	pea+oat	wheat	-
OR4	winter wheat	barley-pea/grass	barley	alfalfa/grass	-
OR5	permanent meadow				
CO1	potatoes	grass-clover, 2nd yr	grass	grass	grass
CO2	spring wheat/clover-grass	beet roots	rye	alfalfa	-
CO3	grass-clover	oat/grass	pea+oat	alfalfa	-
CO4	winter wheat	barley-pea/grass	barley	grass	-
CO5	permanent meadow				

Crops in 2002. Crops after '/' were undersown.

Code	Austria [a]	Denmark [b]	Finland	Italy	UK
OR1	spring barley	barley-pea/grass	rye	grass	grass
OR2	grass-clover	barley/grass	pea+oat	wheat	-
OR3	winter wheat	beet roots	barley	alfalfa	-
OR4	potatoes	oat/grass	grass	maize	-
OR5	permanent meadow				
CO1	spring barley	barley-pea/grass	rye	grass	grass
CO2	grass-clover	barley/grass	pea+oat	wheat	-
CO3	winter wheat	beet roots	barley	alfalfa	-
CO4	potatoes	oat/grass	grass	maize	-
CO5	permanent meadow				

[a] Crops 1-4 were part of a six-crop rotation with: spring barley - winter wheat - grass-clover, 1st yr - grass clover, 2nd yr - spring wheat - potatoes

[b] Crops 1-4 were part of a six-crop rotation with: grass-clover, 1st yr - grass-clover 2nd yr - barley/grass - beet roots - oat/grass - barley-pea/grass

2.2 Fertilization

Strategies for N fertilization varied considerably between the five locations (Table 2.2). In Austria, a combination of solid manure (FYM) and slurry was applied, supplemented with mineral fertilizer in the high intensity, or conventional, rotation. In Denmark only cattle slurry was applied, but at two different rates. In Finland with the heavy clay soil a solid manure including peat was applied to the organic crop rotations, whereas the conventional rotation received only mineral fertilizer. This was also reflected in the generally higher level of soil C in the organic rotation. In Italy both solid manure and slurry was applied, and in the conventional farm also mineral fertilizer. Finally, the grassland in UK received either slurry (organic farm) or solid manure+mineral fertilizer (conventional farm).

The application rates corresponded to the following number of livestock units per hectare (OR/CO, LSU ha^{-1}): Austria – 1.0/1.8; Denmark – 0.7/1.4; Finland – 0.5/NA; Italy – 1.5/2.3; and UK – 1/ 2.4 (NA = not applicable).

Table 2.2. Detailed information about N fertilizer application in 2002. For each application the type of fertilizer, the amount (kg N ha^{-1}) and the date (in italics) is given.

Code	Austria	Denmark	Finland	Italy	UK
OR1	FYM - 24.4 *03-04-02* Slurry - 8.2 *03-04-02* Slurry - 8.2 *06-06-02*		FYM/peat - 280 *23-08-01*	Slurry - 32 *24-05-02*	Slurry - 41 *03-05-02*
OR2	FYM - 13.5 *03-04-02* Slurry - 5.3 *03-04-02* FYM - 72.4 *17-09-02*	Slurry - 50 *03-04-02*			
OR3	FYM - 33.8 *03-04-02* Slurry - 11.4 *03-04-02* Slurry - 11.4 *06-06-02*	Slurry - 125 *04-04-02*	FYM/peat - 160 *14-05-02*		
OR4	FYM - 67.5 *03-04-02* Slurry - 3.3 *03-04-02* Slurry - 3.3 *06-06-02*	Slurry - 73 *04-04-02*		Slurry - 30 *04-03-02* Slurry - 57 *03-05-02* FYM - 330 *06-05-02* FYM - 160 *17-09-02*	
OR5	Slurry - 55.5 *09-04-02* Slurry - 53.6 *11-06-02* Slurry - 52.6 *22-07-02*				
CO1	FYM - 24.4 *03-04-02* Slurry - 8.2 *03-04-02* Slurry - 8.2 *06-06-02* NPK - 32.4 *06-06-02*	Slurry - 60 *03-04-02*	NPK - 40 *31-08-01* NPK - 78 *29-04-02*	Slurry - 95 *23-03-02* Slurry - 85 *08-05-02*	AN - 31 *13-03-02* FYM - 74 *25-04-02* AN - 31 *27-04-02* AN - 31 *11-06-02* AN - 16 *10-09-02*
CO2	FYM - 13.5 *03-04-02* Slurry - 5.3 *03-04-02* NPK - 18.1 *06-06-02* FYM - 72.4 *17-09-02*	Slurry - 100 *03-04-02*	NPK - 52 *15-05-02*	NPK - 25.7 *10-03-02* FYM - 160 *17-07-02* FYM - 150 *08-08-02*	
CO3	FYM - 33.8 *03-04-02* Slurry - 11.4 *03-04-02* Slurry - 11.4 *06-06-02* NPK - 42.3 *06-06-02*	Slurry - 250 *04-04-02*	NPK - 80 *15-05-02*	NPK - 8.5 *10-03-02* NPK - 18 *29-05-02*	
CO4	FYM - 67.5 *03-04-02* Slurry - 3.3 *03-04-02* Slurry - 3.3 *06-06-02* NPK - 59.4 *06-06-02*	Slurry - 146 *04-04-02*	NPK - 78 *29-04-02* NPK - 50 *24-06-02*	Slurry - 90 *23-03-02* Pig! slurry - 97 *24-05-02* Urea - 138 *20-06-02* FYM - 249 *08-10-02*	
CO5	NPK - 53.0 *09-04-02* NPK - 53.0 *11-06-02*				

2.3 Nitrogen deposition

In an account of total N inputs, atmospheric deposition of NH_x and NO_x must be included. Total deposition is composed of wet and dry deposition, the latter being particularly important near point sources (Asman, 1998). In an agricultural area there will be a multitude of on-farm point sources and, at times of fertilization, emissions from larger areas. At the European level, wet and dry deposition is modelled by EMEP (http://www.emep.int/areas/index.html).

Four of the five locations used in this study had access to local measurements of N deposition, and these results are shown as 'Reported' in Table 2.3. For comparison, the sum of NO_x and NH_x given by EMEP for the respective areas, as judged from visual inspection of regional maps, are presented. There was a good agreement between the two different estimates.

Table 2.3. Nitrogen deposition at the five locations.

	Austria	Denmark	Finland	Italy	UK
Reported	18	20	6	16[a]	
EMEP	21-27	17-20	6-7,5	27-35	13-16

[a] Wet deposition only.

2.4 Nitrogen fixation

The inputs of symbiotically fixed nitrogen to the cropping rotations in the 2002-growing season were estimated from measured dry matter yields.

2.4.1 Method

An empirical model described by Høgh-Jensen *et al.* (1998; 2002) was used for determination of the total amount of fixed N_2 during a defined growth period, either at maturity of the crop or over the full growing season. This model can be applied whenever the dry matter accumulation of a leguminous crop can be measured or estimated.

The model distinguishes between legume species, and between legumes in pure stands and legumes in mixtures. Further, in the case of grassland the model distinguishes between younger and older grassland. The model is constructed so that the part of fixed N_2 in the shoot mass of a legume is corrected for (i) the amount of fixed N_2 below defoliation height at the end of the growing season or at maturity, (ii) fixed N_2 transferred to other species in the mixture via the soil or via grazing animals, and (iii) fixed N_2 immobilised in the soil in partly decomposed organic matter.

2.4.2 The model

Nitrogen fixation was estimated by the equation:

$$N_{fix} = DM_{legume} \times N\% \times P_{fix} \times (1 + P_{root+stubble} + P_{trans\ soil} + P_{trans\ animal} + P_{immobile})$$

where

- DM_{legume} = amount of harvested legume dry matter during the growing season;
- N% = concentration of N in the dry matter of the legume (kg kg^{-1});
- P_{fix} = fixed N_2 as proportion of total N in the shoot mass of the legume;
- $P_{root+stubble}$ = fixed N_2 in the root and stubble as proportion of fixed shoot N at the end of the growing season or at maturity;
- $P_{trans\ soil}$ = below-ground transfer of fixed legume N_2 located in the grass in mixtures as proportion of fixed shoot N at the end of the growing season or at maturity;
- $P_{trans\ animal}$ = above-ground transfer (by grazing animals) of fixed legume N_2 located in the grass in mixtures as proportion of fixed shoot N at the end of the growing season or at maturity; and
- $P_{immobile}$ = fixed N_2 immobilised in an organic soil pool at the end of the growing season as proportion of fixed shoot N at the end of the growing season or at maturity.

Model parameters for calculation of N_2 fixation from individual leguminous crops are given in Appendix 2. The amount of fixed N_2 removed from the field was estimated as $DM_{legume} \times$ %N in legume $\times P_{fix}$, and fixed N_2 left in the field as the difference between total N_2 fixation and N removed with harvest.

Estimated N_2 fixation for the five locations in 2002 are shown in Table 2.4. Details of the calculations are given in Appendix 2. For the Austrian and Italian site this source of N was evidently of great importance in an evaluation of the total N balance for the crop rotations.

Table 2.4. Symbiotic nitrogen fixation (kg N ha^{-1}) by leguminous crops in the crop rotations.

Code	Austria	Denmark	Finland	Italy	UK
OR1	-	10	-	-	-
OR2	68	-	1	-	-
OR3	-	-	-	115	-
OR5	23	-	-	-	-
OR4	-	-	-	-	-
CO1	-	9	-	-	-
CO2	88	-	2	-	-
CO3	-	-	-	195	-
CO4	-	-	-	-	-
CO5	27	-	-	-	-

2.4.3 Excretal returns

The fraction of excretal returns to the grazed pastures was estimated as described by Yamulki et al. (1998). The estimates were based on an assumption of daily deposition per cow of 2 kg dung and 2 kg urine on each of 10 occasions (5 occasions for the organic farm due to night-time grazing only) and 180 grazing days per year. This corresponded to excretal returns of 23 kg N for the organic farm with 1 LSU ha^{-1}, and of 114 kg N for the conventional farm with 2.5 LSU ha^{-1}.

2.5 Total N inputs

The total inputs of N to the organic and conventional crop rotations are shown in Fig. 2.1. Symbiotic N_2 fixation represented a significant part of total N inputs in Austria and Italy. In Finland, fertilizer inputs were the only significant source of N. The importance of atmospheric deposition was higher in Italy and Denmark than in the other countries. At the UK site, excretal returns were four-fold higher in the conventional system, partly due to the higher livestock density.

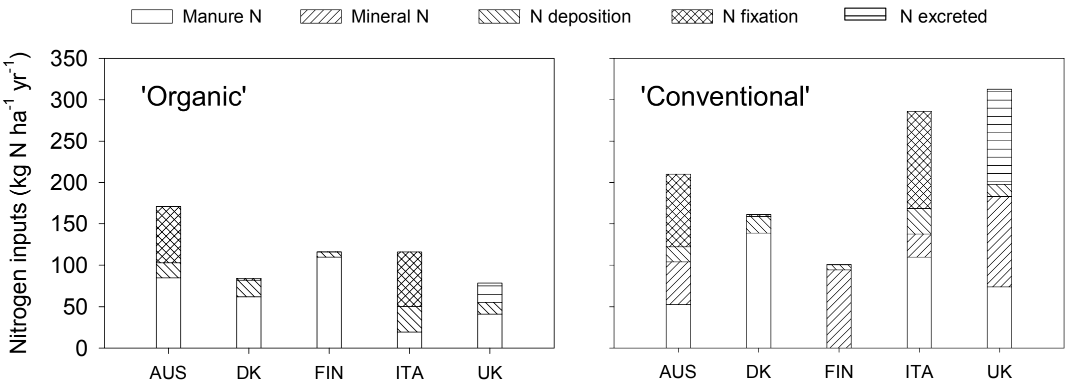

Fig. 2.1. Nitrogen inputs to organic and conventional systems at the five monitoring sites.

3 Dynamics of inorganic nitrogen

3.1 Methodology

Soil inorganic N (NH_4^+ and NO_3^-) for each crop was determined approximately monthly, but always in connection with a N_2O sampling occasion. For each crop at least four individual subsamples were pooled. The level of subsampling was selected after a preliminary test of field-scale variability conducted by P2 (see Appendix 3). In this test, ten soil samples were taken in each of four field plots in October 2001 and analyzed individually. The distribution of the results was examined with a test for normality (Shapiro and Wilk, 1965) and found to normally distributed. Based on the variability of NH_4^+ and NO_3^- it was then estimated that a precision of 30-40% or better could in most cases be obtained with four subsamples (Wollum, 1994).

The soil was sieved, mixed and subsampled for determination of gravimetric soil moisture (24 h at 105°C) and inorganic N (10 g soil extracted for 30 min in 1 *M* KCl, centrifuged, and the supernatant filtered (0.7 µm) and frozen until analyzed by standard colorimetric methods or ion chromatography (Keeney and Nelson, 1982).

Table 3.1. Annual means (with range in parentheses) of ammonium and nitrate (mg N kg^{-1}) for the organic and conventional crop rotations. On average monthly samplings of soil were included except in the UK, where soil was sampled on every sampling occasion.

Location	Ammonium		Nitrate	
	Organic	Conventional	Organic	Conventional
Austria	4.1 (0-20)	4.4 (1.3-19)	15.2 (0-49)	16.0 (0.4-118)
Denmark	1.7 (0-12)	2.8 (0-29)	9.0 (0-61)	11.5 (0-80)
Finland	5.2 (0.9-18)	6.7 (1.5-25)	4.7 (0.8-12)	8.0 (1.0-41)
Italy	5.4 (3.2-13)	6.3 (2.8-12)	20.6 (9.8-40)	23.2 (5.5-44)
UK	8.9 (0-97)	13.6 (0-132)	7.2 (0-101)	13.5 (0-141)

3.2 Measurement results

Details of soil inoganic N for individual crops, or the temporal dynamics for each crop, are not presented. Table 3.1 shows annual means and the range of concentrations encountered at each site. The inorganic N status of conventional crop rotations was consistently higher than that of the organic crop rotation, whereas this was not always the case for the range of concentrations measured. This was also true for Finland despite higher total N inputs in the organic crop rotation.

3.3 **Discussion**

The monitoring program conducted for soil inorganic N as support for the interpretation of N_2O emission results was limited to approximately monthly measurements. It would of course have been best to include soil N sampling on every gas sampling occasion, but the resources available made this impossible. However, soil N sampling coincided with gas samplings so that relationships could at least be explored for this limited data set.

The variability observed in the preliminary test of inorganic N distribution was similar to what was observed by Stenger et al. (1998) in a study of spatial variability in several fields. They pooled four subsamples from within 50 × 50 m grid cells and found that the variability among grid cells was in the order 30-40% in most cases.

Application of mineral fertilizer should lead to immediate increases in soil N in subsequent soil N analyses, at least for some weeks. Such an increase was not always evident in the present study (data not shown), suggesting that more intensive sampling would have improved the precision of soil N analyses. Still, a statistically significant relationship between N_2O emissions and soil inorganic N was observed after all (cf. section 4.3.2).

4 Nitrous oxide emissions

4.1 Methodology

The measurement of N_2O fluxes was based on manually operated static chambers. Compared to alternative methodologies this approach is characterized by low cost and high sensitivity, but a significant limitation is that only point measurements (in space and time) can be obtained (Freibauer and Kaltschmitt, 2000). The aim of this monitoring program was to compare entire crop rotations rather than individual fields or treatments, and this set a limit to the number of samplings that could be included. However, measurements in the high intensity system (conventional) and the low intensity system (organic) were always synchronous and therefore should reveal systems effects even at the relatively low temporal resolution employed.

4.1.1 Chamber design

In arable crop rotations, chambers with a base area of 0.36-0.56 m^2 were used. The number of replicates was 3 or 4. During measurement, the chambers were placed on permanently installed frames which were only removed temporarily for cultivation or seeding. In Austria, Finland and Italy the measurement units were constructed as described by Nykänen et al. (1995), except that chamber bases were made of stainless steel. In Italy, elongated chambers with the same base area were constructed for inter-row measurements in the maize field. In Denmark the chambers were made of PVC covered by a reflecting and insulating material (Petersen, 1999). At the grassland site in the UK, circular chambers with a base area of 0.13 m^2 was used (Yamulki et al., 1998), and the number of replicates was 6. Intersections were used as required to enable measurements without damaging the crop.

An overview of measurement conditions at the five sites is given in Appendix 4. The use of a vent for equilibration of pressure differences between headspace and the atmosphere has been advocated (Livingston and Hutchinson, 1995), but this aspect is subject to debate (e.g., Conen and Smith, 1998). In the present study, a vent was included in the chambers used at three of the five locations. The chamber headspace was mixed either during chamber deployment or immediately prior to sampling.

4.1.2 Sampling strategy

Gas samples were taken via a septum in the chamber wall. The samples were taken either in N_2 flushed and evacuated containers via a double needle and pressurized prior to analysis (longer storage/shipping required), or samples were pressurized at the time of sampling (short storage).

Duplicate gas samples were taken at the time of chamber deployment and typically after 60 min. Based on the change in N_2O over time, and assuming linearity in the rate of change, fluxes were calculated.

Samplings were carried out between mid-morning and mid-afternoon. In order to cover all crops, samplings in Denmark were spread over two days with two crops per day, i.e., organic and conventional treatments were always sampled in parallel. In Austria, the conventional rotation was always sampled before noon and the organic rotation in the early afternoon. In Italy, two teams sampled simultaneously at the two farms, and in the UK the two farms were sampled consecutively, but both before noon.

As stated above, chamber bases were permanently installed, and the fluxes recorded across the 12-month periods therefore represented fixed points within fields or plots. The position of sampling points was systematic relative to the invidual sampling plot or the edge of a field.

4.1.3 Nitrous oxide analyses

In all laboratories, N_2O was analyzed by gas chromatography. Column material was Porapak Q, Hayesep Q or Porapak T, the carrier gas was either Ar/CH_4 or N_2, oven temperature varied between 35 and 50°C, and detector temperature between 300 and 350°C.

An intercomparison of N_2O analyses in six different laboratories was conducted in the spring of 2002, in which the laboratories involved in WP2.2 had a recovery of 97-106% of an unknown standard circulated (see Appendix 5). Nevertheless, analytical problems were discovered in the lab of P2 during autumn 2002, where it turned out that N_2O results were contaminated by CO_2. Measurement results from Denmark, and part of the measurement results from Italy, have therefore been corrected for soil CO_2 fluxes by the model FASSET (Jacobsen et al., 1998), and for crop dark respiration as described by Søgaard et al. (2003). The principles behind the correction are outlined in Appendix 6; basically it is assumed that initial concentrations of N_2O and CO_2 corresponded to atmospheric background concentrations, and that changes during chamber deployment were linear. Modelled CO_2 data were not available for all periods or crops, in these cases correction values were selected on the basis of soil conditions (soil temperature, precipitation), crop category and growth stage.

4.1.4 Data compilation

Measurement results from the five locations of the monitoring program were compiled for estimation of monthly N_2O emissions and annual emission factors. Nitrous oxide emissions are not only derived from recent inputs of N, but also contain a background emission derived from turnover of different pools of soil organic matter (Bouwman, 1996). The background emission will vary depending on position in the crop rotation, and its relative importance will vary with the level of N fertilization. This complicates the interpretation of emission data at the level of individual crops, and emission factors were therefore calculated for crop rotations rather than individual fields.

4.2 Measurement results

4.2.1 Temporal dynamics of N_2O emissions

The Figs. 4.1 through 4.5 present the temporal dynamics of N_2O emissions observed at the five monitoring sites. The number of samplings conducted at the five locations varied between 15 and 28. Obviously, this limited number of point measurements will not give a true picture of emission patterns across the year, but should be able to reflect systematic differences between organic (low intensity) and conventional (high intensity) crop rotations.

In Austria (Fig. 4.1), high emissions were mainly observed in the late summer and autumn. Occasional negative fluxes were observed. In all crops there were several instances where emissions from the organic rotation were higher than from the conventional system.

Fluxes at the Danish site (Fig. 4.2) showed peak emissions during June in all crops, but also some elevated emission during autumn. The relatively strong and synchronous fluctuations in the fluxes could indicate that the CO_2 correction values did not correspond precisely with the actual soil conditions in the sampling locations. However, this should not result in any bias in the comparison between systems, or in the analysis of relationships between N_2O emissions and soil properties.

In Finland (Fig. 4.3), N_2O fluxes were generally low, except in periods shortly after fertilization. The peak emissions in crops 1, 3 and 4 all coincided with recent inputs of fertilizer N.

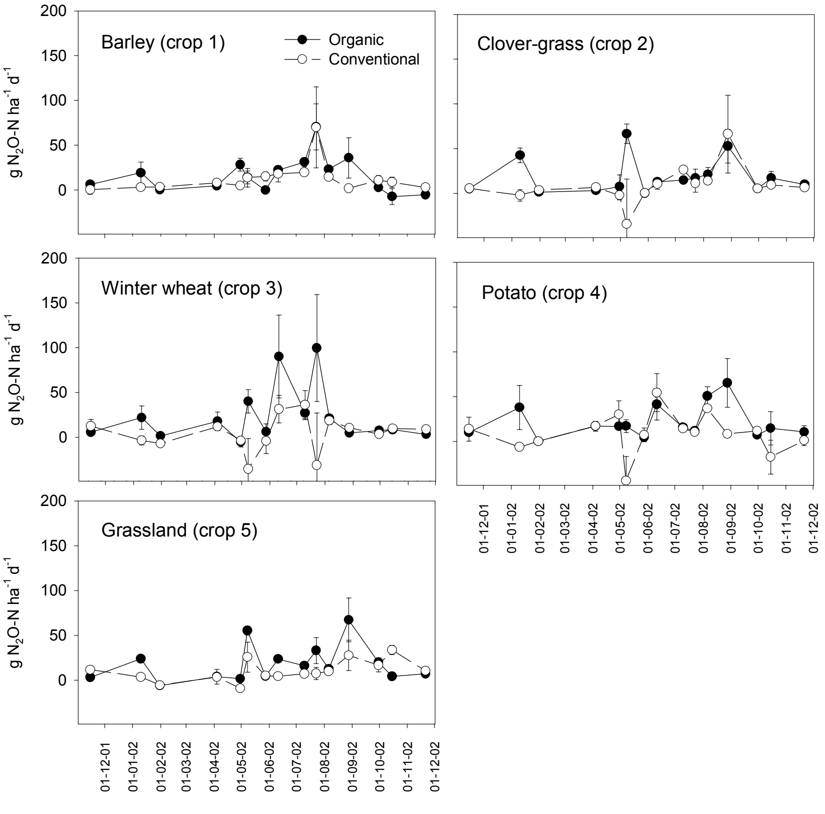

Fig. 4.1. Nitrous oxide fluxes at the site in Austria. Error bars represent standard errors. The crop numbers refer to the notation in Table 2.1.

In Italy (Fig. 4.4), the monitoring data also showed distinct peaks, but these were not well correlated with fertilizer inputs of N. The high emissions from grassland (conventional) in August 2002, and from alfalfa (conventional) in September 2002, are notable, as are the sustained high emissions from wheat (organic) in January to March 2003.

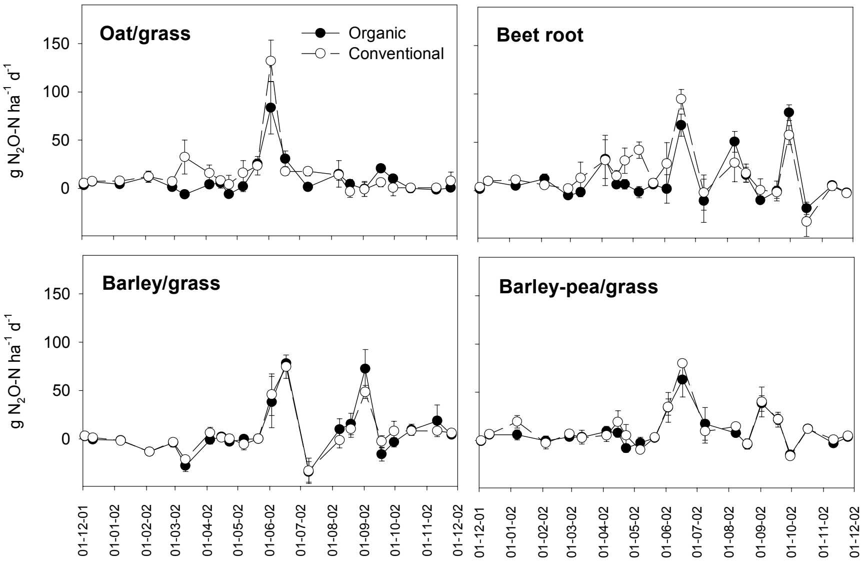

Fig. 4.2. Nitrous oxide fluxes at the site in Denmark. Error bars represent standard errors. The crop numbers refer to the notation in Table 2.1.

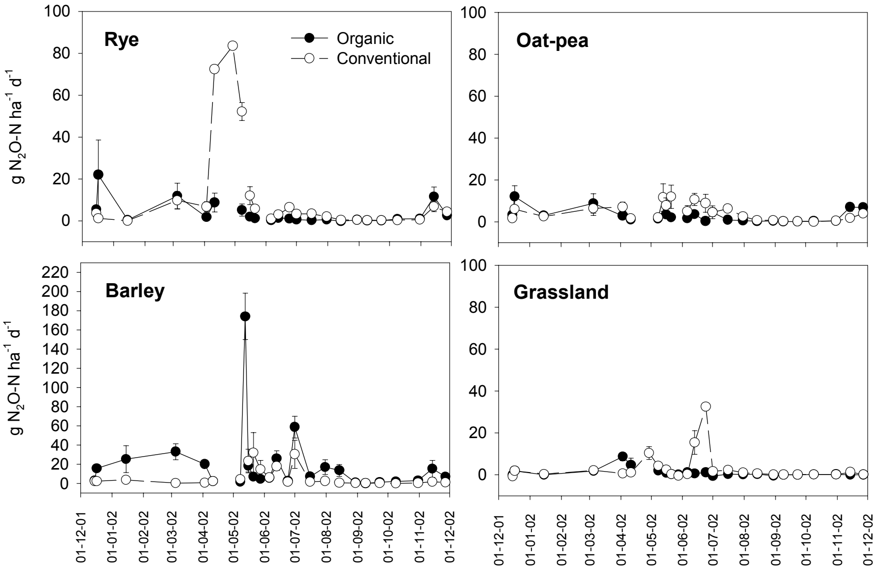

Fig. 4.3. Nitrous oxide fluxes at the site in Finland. Error bars represent standard errors. The crop numbers refer to the notation in Table 2.1.

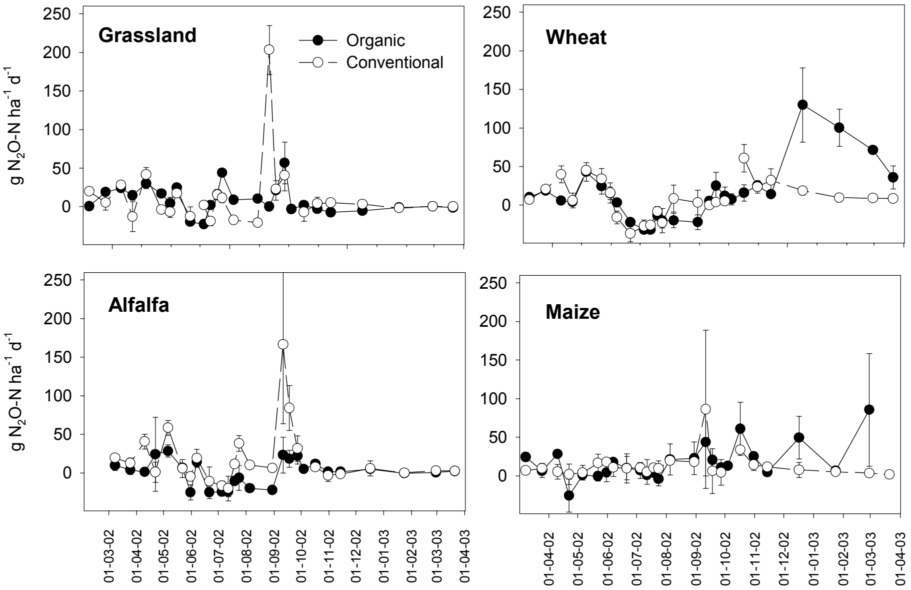

Fig. 4.4. Nitrous oxide fluxes at the site in Italy. Error bars represent standard errors. The crop numbers refer to the notation in Table 2.1.

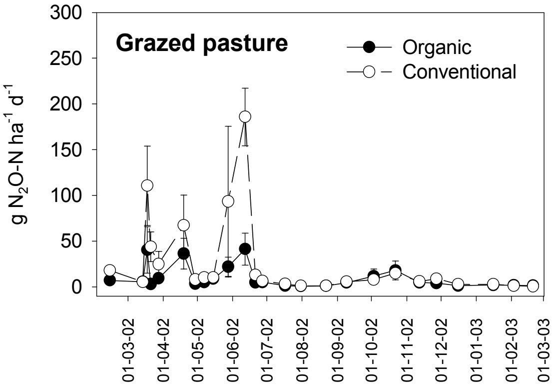

Fig. 4.5. Nitrous oxide fluxes at the site in the UK. Error bars represent standard errors. The crop numbers refer to the notation in Table 2.1.

Finally, in the UK (Fig. 4.5), high emissions of N_2O were mainly observed during spring. In the conventional pasture this followed repeated applications of ammonium nitrate.

4.2.2 Annual emissions

Total annual emissions of N_2O for the five measurement sites were calculated by the trapezoid method despite the fact that sampling intervals were very large. Fluxes for individual crops are given in Table 4.1, while average emissions for the crop rotations are presented in Fig. 4.6. In numbers, the average emissions (kg N_2O-N ha^{-1} yr^{-1}) per site and system were: Austria, 6.5 (OR) and 3.2 (CO); Denmark, 3.2 (OR) and 4.2 (CO); Finland, 2.1 (OR) and 1.9 (CO); Italy, 2.7 (OR) and 4.9 (CO); and UK, 3.6 (OR) and 5.9 (CO). The statistical significance of differences between systems is addressed in section 4.3.

For Denmark, Finland, Italy and UK emissions from the conventional system were similar to or greater than from the organic system, whereas in Austria total emissions from the organic system were twice as high as from the conventional system. A solid cattle manure with a relatively high C:N ratio was used at the Austrian site, but amounts of manure applied were similar in the two rotations and so this does not in itself explain the differentiation between systems. The organic rotation was always monitored after the conventional rotation, indicating a potential for systematic soil temperature difference (Matthias et al., 1980; Smith et al., 1998), but this is unlikely to explain emission differences in the order observed (Griffith and Galle, 1998; Smith and Dobbie, 2001). Precipitation was 45% above normal at the Austrian site, so any difference in water holding capacity could have contributed to the difference in N_2O emissions.

Table 4.1. Annual emissions of N_2O from each crop and site in the monitoring program. The crop code is given in Table 2.1.

Code	Austria		Denmark		Finland		Italy		UK	
	Ave	SE	Ave	SE	Ave	SE	Ave	SE	Ave	SE
OR1	5,1	1,4	3,6	1,2	2,0	1,0	2,6	0,3	3,2	0,5
OR2	6,5	0,6	1,8	0,4	1,5	0,3	11,8	3,2	-	
OR3	7,3	2,5	4,1	0,9	5,4	1,2	0,3	1,0	-	
OR4	8,0	1,5	3,2	0,5	0,4	0,0	6,8	0,6	-	
OR5	5,9	0,7	-		-		-		-	
CO1	3,8	0,5	4,3	0,5	2,4	0,7	3,3	0,6	7,4	1,3
CO2	3,6	0,3	1,6	0,7	1,5	0,3	4,9	1,9	-	
CO3	2,0	0,9	5,6	1,7	1,6	0,4	5,8	0,9	-	
CO4	3,4	1,3	5,3	0,5	0,7	0,1	8,9	3,5	-	
CO5	3,4	0,6	-		-		-		-	

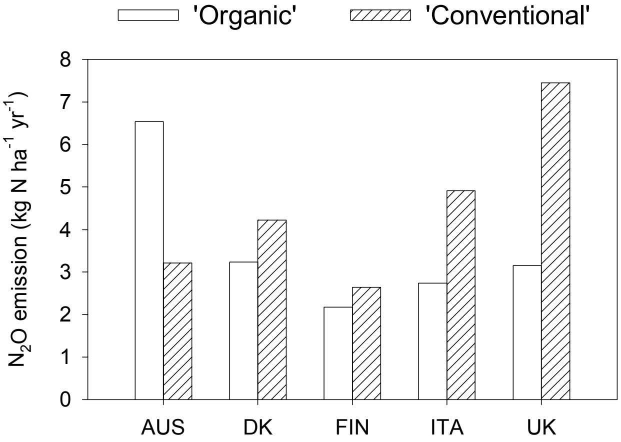

Fig. 4.6. Accumulated N_2O emission estimates for the one-year monitoring periods. The emissions for Italy were weighted according to area per crop (see Appendix 1).

4.2.3 Emission factors

Bouwman (1996) found that, for a selected database of long-term measurements from temperate climates, that N_2O emissions were related to N inputs via the equation:

$$N_2O\text{-N (kg ha}^{-1}\text{ yr}^{-1}) = (0.01 + 0.0125 \times N_{\text{fertilizer}}) \text{ (kg N ha}^{-1}\text{ yr}^{-1}), \quad \text{[Eq.2]}$$

indicating that on average 1.25% of N in fertilizers (mineral fertilizer or manure) were emitted as N_2O, and with a background emission in the order of 1 kg N ha^{-1} yr^{-1}. The emission factor of 1.25% has been adopted in the IPCC methodology, which also contains separate emission factors for crop residues and N fixed via symbiotic N fixation (also 1.25%).

This distinction between recent and older sources of N_2O is extremely difficult to handle in practice, especially in crop rotations with different recent crop prehistories, and therefore this study attempted to define emision factors at the level of crop rotations (EF_{CR}), and not at the level of individual crops. Total N inputs included organic and mineral fertilizer N, atmospheric N deposition and symbiotic N fixation, as well as N excreted by animals on grazed pastures.

EF_{CR} for each system and site are shown in Fig. 4.7. These total emission factors for the five crop rotations ranged from 1.5 to 4.6% of total N inputs. In numbers, the EF_{CR} (kg N_2O-N kg^{-1} N_{input}) for each site and system were: Austria, 0.038 (OR) and 0.015 (CO); Denmark, 0.038 (OR) and 0.026 (CO); Finland, 0.019 (OR) and 0.026 (CO); Italy, 0.024 (OR) and 0.018 (CO); and UK, 0.040 (OR) and 0.024 (CO). Emission factors for the organic crop rotation were higher than for the conventional crop rotation except in Finland, where fertilizer N inputs (as FYM and peat) exceeded the mineral N inputs in the conventional system (Tab. 2.2). Hence, N inputs were higher in the conventional crop rotations with the exception of Finland (cf. Fig. 2.1), whereas the proportion of N lost as N_2O was higher from the organic rotations.

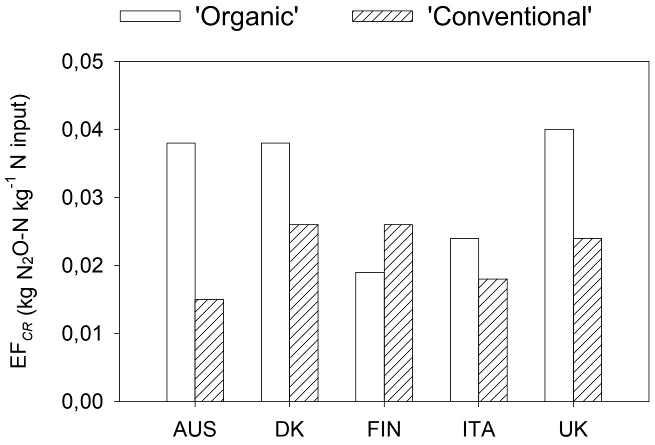

Fig. 4.7. Emission factors for the five crop rotations. N inputs include not only N in fertilizers, but also atmospheric N deposition, N fixation and N excreted by cattle.

The EF$_{CR}$ emission factors presented in Fig. 4.7 relate N_2O emissions to known N inputs to the crop rotations in the monitoring period. However, an unknown part of the emissions may be associated with turnover of N in organic matter derived from previous cropping seasons, or be related to long-term changes in soil organic matter as a result of cultivation. The importance of such 'background' N_2O emissions may be estimated by plotting measured N_2O emissions against total N inputs as shown in Fig. 4.8. There was

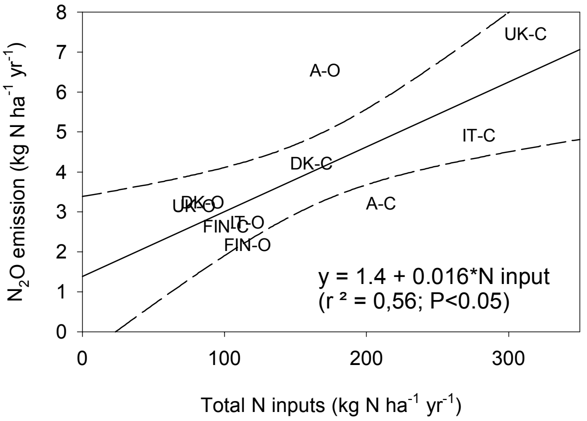

Fig. 4.8. Nitrous oxide emissions as a function of total N inputs via fertilizers, N fixation and atmospheric deposition. In the plot, the country-code is followed by 'O' for organic rotations, and by 'C' for conventional rotations.

a significant relationship between N inputs and N_2O emissions. The slope of the regression line corresponded to an EF of 1.6%, whereas the intercept, indicating the magnitude of 'background' emissions, were 1.4 kg N ha^{-1} yr^{-1}.

The overall emission level suggested in response to N inputs in Fig. 4.8 was thus higher than the EF for fertilizer N inputs of 1.25% adopted in the IPCC methodology. It should be stressed that N inputs in the present study included atmospheric deposition, and it included N excreted on grazed pastures for which the IPCC proposes a higher emission factor. Also, it is likely that a future revision of the IPCC methodology will attribute a higher emission factor to organic manures and perhaps lower the value for mineral fertilizer N. The background emission suggested by the intercept of the regression line was higher than indicated by Eq. 2, but with the uncertainties of both estimates in mind it is not possible to conclude that the two estimates are different.

4.3 Statistical analyses

4.3.1 Systems effects on N_2O emissions

The measurement data were used for a statistical analysis evaluating the dependency of N_2O emissions on crop and site. Nitrous oxide emissions are characterized by a very high spatial and temporal variability, and often experimental data are log-normal rather than normally distributed (Parkin, 1992; Kaiser et al., 1998). The analyses described below have been conducted assuming both distributions. To a very large extent the two approaches resulted in the same significant effects, and only the results for log-transformed data are reported.

Table 4.2 lists the class variables and treatments in each category. A general linear model was used which could accomodate the different experimental designs:

$$Y_{LICSBM} = \mu + \alpha_I + \beta_C + (\alpha\beta)_{IC} + \gamma_L + (\alpha\gamma)_{IL} + (\beta\gamma)_{CL} + (\alpha\beta\gamma)_{ICL} + D_{LS} + D'_{ICLS} + E_{CLSB} + E'_{ICLSB} + F_{ICLSBM}, \qquad \text{[Eq. 1]}$$

where greek letters describe treatment effects and capital letters are error terms; indices refer to the class variables of Table 4.1, i.e., *L* is location, *I* is input, *C* is crop category, *S* represents super-blocks and *B* blocks. *D*, *D'*, *E*, *E'* and *F* are random error terms. The program code is shown in Appendix 7.

Table 4.2. An overview of the inputs for class variables in the statistical model of systems effects. Crop categories were used in the model rather than specific crops; these are defined in the footnote.

	Austria	Denmark	Finland	Italy	UK
Location	A	D	F	I	U
Input (high/low)	1,2	1,2	1,2	1,2	2
Super-blocks	1,2,3	1	1	1	1
Blocks	1	1,2,3,4	1	1	1
(Crops[§])	d, a, e, f	m, d, k, l	b, c, d, g	g, h, i, j	g
Crop categories[#]	2, 1, 2, 3	1, 2, 3, 2	2, 1, 2, 4	4, 2, 1, 3	4
Measurements per block	1	1	1,2,3	1,2,3	1,2,3,4,5,6
No. measurements per sampling	2×3×1×4×1= 24	2×1×4×4×1= 32	2×1×1×4×3= 24	2×1×1×4×3= 24	2×1×1×1×6= 12

[§] a - clover/grass; b - rye; c - pea/oat; d – barley; e – winter wheat; f – potatoes; g – grassland; h – wheat; i – alfalfa; j – maize; k – beet root; l – oat/ryegrass; m – pea/barley.

[#] 1 (crops w. N-fixation) = a, c, i, m.
2 (cereals, undersown cereals) = b, d, e, h, l.
3 (forage crops) = f, j, k.
4 (grassland) = g.

Table 4.3 presents the probabilities determined for fixed effects described by Eq. 1. There was a highly significant effect of the interaction Location × Input, and also an effect of crop category. However, estimates of several effects could not be calculated since not all crop categories were represented in each location. Since Location × Cropcat and Location × Input ×Cropcat were not significant (cf. Table 4.3), a reduced model was adopted in which these interactions were excluded:

$$Y_{LICSBM} = \mu + \alpha_I + \beta_C + (\alpha\beta)_{IC} + \gamma_L + (\alpha\gamma)_{IL} + D_{LS} + D'_{ICLS} + E_{CLSB} + E'_{ICLSB} + F_{ICLSBM} \qquad \text{[Eq. 2]}$$

The program code is shown in Appendix 7.

Table 4.3. Probabilities of main effects and interactions observed with the full model and the reduced model (see text), respectively.

Effect	Full model	Reduced model
	P values	
Location	0.5520	0.4105
Input	0.5058	0.2536
Location × Input	<0.0001	0.0043
Cropcat	0.0122	0.0464
Location × Cropcat	0.0980	-
Input × Cropcat	0.1436	0.4077
Location × Input × Cropcat	0.1626	-

The results of the reduced model are shown in Table 4.3, last column. According to the reduced model, the interaction Location × Input was highly significant, indicating that organic and conventional crop rotations differed with respect to N_2O emissions, but that the pattern was not identical at all sites (cf. Fig. 4.6). The estimates for effects of Location × Input are shown in Table 4.4. In accordance with Fig. 4.6 they show that there were similar or higher emissions of N_2O in the 'conventional' crop rotations except in Austria.

Table 4.4. Estimates for effects of location × input on log-transformed N_2O emissions.

Effect	'Organic'	'Conventional'
Location × Input	($\times 10^{-2}$)	
Austria	3.70	1.53
Denmark	1.49	2.23
Finland	1.34	1.30
Italy	1.85	2.85
UK	2.36	4.70

Finally, there were significant differences between crop categories. The estimates for Crop category are shown in Table 4.5. They indicate that emissions from forage crops were higher than from cereal crops, N fixing crops or grassland.

Tab. 4.5. Estimates for effects of crop category on log-transformed N_2O emissions.

Crop category	Estimate
	($\times 10^{-2}$)
1. Crops with N fixation	2.00
2. Cereal crops	2.26
3. Forage crops	3.21
4. Grassland	1.88

4.3.2 Effects of soil conditions on N_2O emissions

In order to invetigate possible relationships between N_2O emissions and soil variables, a model with selected continuous variables was tested. The systematic effects of input, crop category and location, which were identified in the previous section, were included in the model together with inorganic N, soil moisture and temperature, soil C and clay content. The following interactions were also allowed for: Crop catergory × Moisture, Input × Ammonium, Input × Nitrate, and Moisture × Clay content.

$$Y_{LICSBM} = \mu + \alpha_I + \beta_C + (\alpha\beta)_{IC} + \gamma_L + \delta M + \delta_C M + \varepsilon A + \varepsilon_I A + \phi N + \phi_I N + \gamma Y + \gamma Y{*}M + \eta B + \kappa T + D_{LS} + D'_{ICLS} + E_{CLSB} + E'_{ICLSB} + F_{ICLSBM}, \quad \text{[Eq. 3]}$$

where *M* is gravimetric soil moisture (% of dry wt.), *A* is soil ammonium (mg kg^{-1}), *N* is soil nitrate (mg kg^{-1}), *Y* is clay content (%), *B* is soil carbon (% of dry wt.) and *T* is soil temperature at 10 cm depth. The program code is shown in Appendix 7.

Table 4.6 shows significance values for all effects in the model. Significant effects were identified by a so-called type 3 test of fixed effects in which significance of the individual variable is evaluated after first accounting for the variation explained by all other factors in the model. According to the model, both systems related factors (crop category, location), the soil environment (moisture, temperature) and soil N availability showed significant effects on N_2O emissions. It is notable that ammonium, but not nitrate, was related to N_2O emissions, indicating that nitrification may have been the main source of N_2O. It must be stressed, however, that the factors listed in Table 4.6 explained only around 10% of the total variation.

Table 4.6. Effects of systems and soil related variables on log-transformed N_2O emissions. Despite several highly significant relationships, the variables defined in the model accounted for only ca. 10% of the total variation.

Effect	P value	Variance explained
Input	0.1352	0.39
Crop category	0.0071	0.37
Input × Crop category	0.3109	0.22
Location	0.0004	2.60
Moisture	0.2583	0.09
Moisture × Crop category	0.1698	0.20
Ammonium	<0.0001	1.17
Ammonium × Input	0.0044	0.44
Nitrate	0.9699	0.002
Nitrate × Input	0.9610	0.01
% Clay	0.8613	0.31
Moisture × % clay	0.8709	0.001
% C	0.9706	0.09
Soil temperature	0.0038	0.58
Soil temperature × Location	<0.0001	3.16

4.4 Discussion

The objective of this study was to estimate system- and region-specific emission factors for N_2O emissions for organic and conventional crop rotations. The widely adopted methodology of the IPCC is a simplified approach intended for up-scaling of agricultural sources at the country level, and it was hoped that experimentally derived emission factors for the specific systems to be modelled in the MIDAIR project would improve the precision of farm models for each region, and for predicting effects of different mitigation options.

The IPCC methodology considers a pulse of N_2O emissions that is directly related to fertilizer inputs of N, and then a background emission from other sources. Presumably this background will be correlated with soil N turnover and thus influenced by the previous crop(s). For example, Eriksen (2001) studied N leaching during a three-year period after cultivation of pastures under different management. He found that N leaching of 12-36 kg N ha^{-1} in the first year after plowing decreased to 25-58% of these amounts in the third year after plowing. If N leaching is taken as a conservative estimate of soil N turnover, then this decrease over a three-year period is an indication that background emissions of N_2O would also differ between years. By considering entire crop rotations we hoped to obtain a balanced account of background emissions.

The locations chosen for the monitoring covered the main cattle producing regions in Europe, as well as the main differences in climatic conditions. The regional differences in climatic conditions were well reflected in the monthly mean temperature and precipitation recorded. Some deviations from long-term means were discussed in section 1.2.1 and 1.2.2; particularly precipitation was extreme in several countries, i.e., 45% above normal in Austria and 25-30% below normal in Finland and Italy. It was not attempted to correct measurement data for these deviations.

The soil conditions varied widely between sites in terms of soil texture and organic matter composition (Tables 1.3 and 1.4). The high C:N ratio in Finland was suggested to be a result of the high clay content giving protection against turnover of soil organic matter. Also, accelerated turnover of soil organic matter due to the warmer climate was suggested for the Italian soil.

Since the sampling strategy gave priority to cover entire crop rotations, the number of samplings for collection of N_2O flux data was relatively small. This was considered to be acceptable, since the main focus was on the comparison of systems. Gas samples were taken at the beginning and end of chamber deployment, i.e., linearity of N_2O accumulation was assumed. While this may often be an acceptable approximation (Anthony et al., 1995; Petersen, 1999), Pedersen et al. (2001) provided evidence for a systematic underestimation of fluxes by assuming linear regression. Therefore, the fluxes calculated probably represent minimum estimates.

An instrumental problem made it necessary to correct most of the Danish N_2O data and part of the N_2O data from Italy for interference from CO_2. Supplementary samplings are conducted in the spring and summer 2003 to validate the corrected values. The level of N_2O emissions estimated for these two countries were similar to the estimates obtained for Austria, Finland and the UK, indicating that the correction was acceptable. Any errors due to the corrections were expected to be un-biased and so should not weaken conclusions reached about systems effects or relationships between soil properties and N_2O emissions. All statistical analyses were conducted also without the Danish data-set and, except for a minor shift in the relationship with soil moisture and temperature, no conclusions were altered (see Appendix 8).

The emission factors recorded ranged from 1.5 to 4% of total N inputs via fertilizers, atmospheric deposition, N fixation and N excreted by grazing animals (Fig. 4.7). Other experimental studies have similarly found a wide range of emission factors. Kaiser et al. (1998) reported from a field experiment with different levels of N fertilization to several crops that EF ranged from 0.7 to 4.1% of the N in fertilizers added. Emission factors for the 87 studies compiled by Bouwman (1996) varied between 0 and 7% of fertilizer N inputs.

The EF was higher from the organic crop rotation (Fig. 4.7) except in Finland where a mixture of farmyard manure and peat was used as fertilizer in the organic crop rotation and total fertilizer N was similar to the conventional rotation. Lægreid and Aastveit (2002) examined several datasets of N_2O emissions, including the one used by Bouwman (1996) to derive the EF of 1.25%. They concluded from statistical evaluation of the total database that emissions from animal manure were probably higher than from mineral fertilizers. The same conclusion was reached by Klemedtsson and Klemedtsson (2002) in a study of data mainly from the Nordic countries. The reason may be that organic inputs induce oxygen consumption in the soil, thereby creating oxygen-depleted soil volumes where N_2O formation is stimulated. In the present study, total N_2O emissions tended to be lower from organic crop rotations, but the specific emissions (the proportion of N inputs emitted as N_2O) were higher from organic crop rotations. A distinction between organic and mineral fertilizers could not be made in this study where only one system [Finland, conventional system] received no organic fertilizers) Except for the organic rotation in Austria, the emissions could be described by a regression corresponding to an EF of 1.6% with a background emission of 1.4 kg N ha^{-1} yr^{-1}. It is stressed again that this relationship is based on total N inputs, i.e., fertilizer N + atmospheric deposition + N fixation + N excretion during grazing, and thus not directly comparable to the IPCC emission factor.

The statistical analysis of emission data indicated that N_2O emissions from organic and conventional crop rotations were different, but that effects of input differed between locations. Also, crop categories differed in their N_2O emissions with highest emissions from forage crops (beet roots, potatoes, maize), which is in accordance with the fact that these crops typically receive high inputs of fertilizer N; in the present study this was true for Denmark and Italy, but not for Austria.

Among a range of soil factors examined, only ammonium and soil temperature indicated effects on N_2O emissions that could not be explained by a combination of other variables. On the other hand, the test used was conservative which means that the effects actually identified are relatively important. The temperature effect is in accordance with many experimental results that have found a strong correlation between soil temperature and N_2O emissions on a diurnal basis (e.g., Smith et al., 1998; Williams et al., 1999). At the regional scale the relationship signifies that within Europe there are climatic gradients with a significant impact on soil N turnover and N_2O emissions.

The microbiological basis of N_2O emissions from agricultural systems are not well known. de Vries et al. (2003) identified this uncertainty as the main source of uncertainty in quantifying N_2O emissions. A significant role of nitrification as a source of N_2O has been reported in several studies (e.g., Merino et al., 2001; Wrage et al., 2001; Estavillo et al., 2002). The present study observed a significant relationship between ammonium and N_2O emissions across the five sites ($P<0.0001$), while no relationship with nitrate was even indicated ($P>0.95$). This observation is an indication that a significant part of N_2O emissions from agricultural soil is associated with ammonium oxidation.

4.5 Conclusions

Nitrous oxide emissions were monitored in high and low intensity crop rotations at five different locations across Europe. Total N inputs, including manure and mineral fertilizers, atmospheric deposition, symbiotic N fixation and excretal returns, were higher with the conventional rotations except in Finland, where inputs were similar but based on solid manure and mineral fertilizer, respectively. Annual mean values of both ammonium and nitrate showed consistently higher concentrations in the conventional compared to the organic rotation, but variability was high. For each site and crop rotation, average accumulated N_2O emissions were estimated which ranged from 1.9 to 7.5 kg N_2O-N ha^{-1} yr^{-1}. Nitrous oxide emissions were always higher from the conventional system except in Austria, where emissions from the organic rotation was twice as high. When emission factors for organic (OR) and conventional (CO) crop rotations were calculated as proportions of total N inputs (fertilizer N, N fixation, N deposition and N in excretal returns), the results were: Austria, 0.038 (OR) and 0.015 (CO); Denmark, 0.038 (OR) and 0.026 (CO); Finland, 0.019 (OR) and 0.026 (CO); Italy, 0.024 (OR) and 0.018 (CO); and UK, 0.040 (OR) and 0.024 (CO). Generally, emission factors were thus higher for the organic rotations except in Finland, where the values for the two systems were similar. A linear regression of N_2O against total N inputs indicated a significant relationship with a slope of 0.016 and an intercept of 1.4 kg N_2O-N ha^{-1} yr^{-1}. This average emission factor was similar to the one recommended by the IPCC for fertilizer N inputs, although it should be stressed that the emission factor presented here was based on total N inputs, not just fertilizer N. A multiple linear regression model indicated that log-transformed N_2O emissions depended significantly on the interaction Location × Input. There was also a significant effect of crop category on N_2O indicating higher emissions from forage crops than from N fixing crops, cereals or grassland. A second model examined effects of soil conditions on N_2O emissions. Significant effects of moisture, temperature and crop category were observed. There was a highly significant effect of ammonium, but no effect of nitrate, which could reflect that an important part of N_2O emissions from arable soil are associated with ammonium oxidation.

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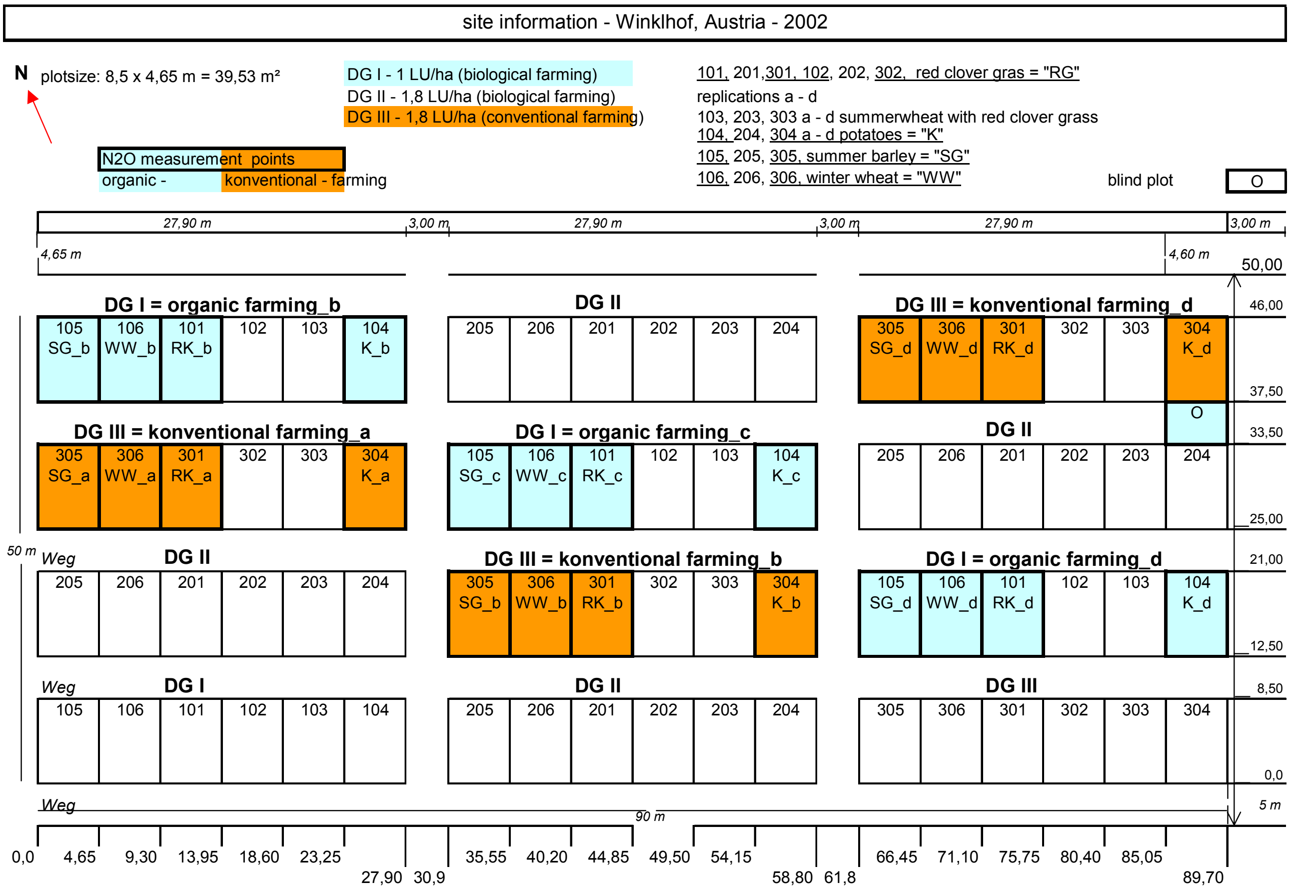
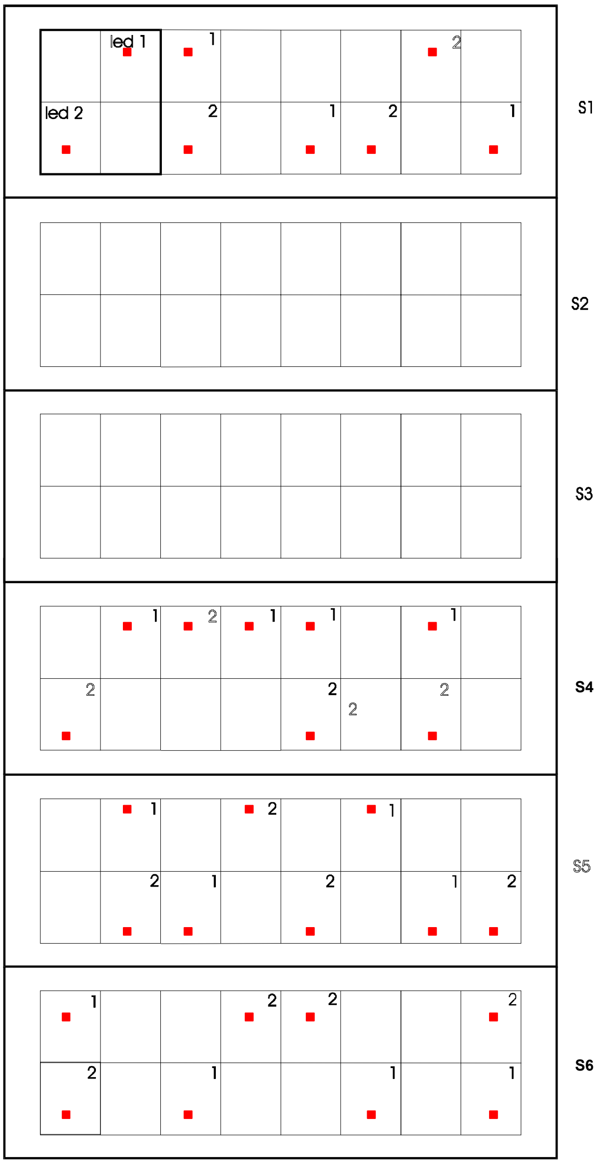
Appendix 1

Austria:



Denmark: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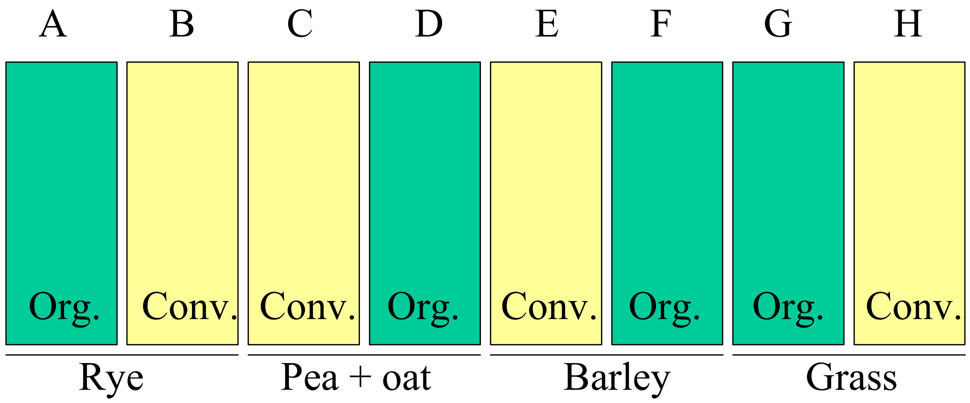
Finland:

MIDAIR SITE IN FINLAND



- size of the plot 50 x 100 m, 3 measuring points on each
- organic farming since 1990
- clay 75.7 %, silt 9.4 %, sand 14.9 %

Italy:

	OF **Organic Farm**	**CF** **Conventional Farm**
Herd size (n°)	42	60
Livestock density (ha^{-1})	1.5	2.3
UUA (Utilized Agricoltural Area) (ha)	40	36
Dairy cows diet	Grass and hay (*alfalfa, gramineous*) bio-concentrate (*5-11 kg head*$^{-1}$ *d*$^{-1}$)	Grass and hay (*alfalfa, gramineous*) concentrate (*6-11 kg head*$^{-}$*1 d*$^{-1}$)
Milk production (kg head^{-1} y^{-1})	6500	7000
Crop rotations (2002)	Permanent grassland (25%), winter wheat (16%), lolium+maize (2%), alfalfa (57%)	Permanent grassland (20%), winter wheat (15%), grassland+maize (5%), alfalfa (60%)
Soil type	Silty clay loam	Silty clay loam
Plot area for N_2O measurements (ha)	Permanent grassland = 1.1 winter wheat = 1.1 lolium+maize = 0.4 alfalfa = 0.6	Permanent grassland = 0.5 winter wheat = 3.2 grassland+maize = 1.2 alfalfa = 2.3
Chamber replication	3	3

Land use at the organic (OF) and conventional farm (CF).

	OF (ha)	CF (ha)
Grassland	10	7.2
Wheat	6.4	5.4
Alfalfa	22.8	21.6
Grass/lolium+maize	0.8	1.8

UK:

Permanent grassland		
Soil type	Sandy silt loam	
Climate	Atlantic	
	Organic	**Conv.**
Name	Well farm	Way “Higher Murchington farm”
Area (ha)	100 ha (4.05 chamber field)	60 ha (7.7 chamber field)
Herd size	100 dairy cows	150
Livestock Density (ha^{-1})	1	2.5
Mean dairy cows weight (kg)	500 (450-550)	475 (450-500)
Livestock Unit (LU ha^{-1})	1	2.375
Dairy cow breed	Friesian	Guernsey
Grazing period	mid Apr–end Oct (3 weekly intervals)	mid Apr–end Oct (4 block grazing)
Milk yield (l)	5200	6400
Concentrates (kg per cow)	850	1700
Composition (protein)	18% summer	20% +13.5 % energy
Inorganic fertilizer (NH4NO3-N)		109.25 kg (4 application in 2002)
Organic fertilizer (l per ha)	Thick slurry 20,563	
Grazing	Night	Day & night
Chamber replication	6	6
Manure type	Cattle, liquid + solid	Cattle, liquid + solid

Appendix 2

Model parameters for calculation of N_2 fixation in leguminous crops.

Crop	**N%**	**P_{fix}**	**$P_{root+stuble}$**	**$P_{trans-soil}$**	**$P_{trans-animal}$**	**$P_{immobile}$**	**P'**
Pea in pure stand for maturity	0.039	0.70	0.40				0.0382
Faba beans and lupine in pure stand	0.050	0.70	0.40				0.0490
Lucerne and red clover in stand	0.033	0.74	0.25			0.45	0.0415
Pea in mixture with cereals as whole crop	0.026	0.82	0.25				0.0267
Green fallow of grass-clover	0.038	0.90	0.25	0.25		0.57	0.0706
Cut younger (1-2 years) grass-red clover	0.033	0.90	0.25	0.05		0.38	0.0497
Cut younger (1-2 years) grass-white clover	0.043	0.90	0.25	0.10		0.57	0.0741
Cut older (>2 years) grass-white clover	0.043	0.90	0.25	0.20		0.38	0.0708
Grazed younger (1-2 years) grass-white clover	0.043	0.75	0.25	0.25	0.20	0.57	0.0730
Grazed older (>2 years) grass-white clover	0.043	0.75	0.25	0.20	0.20	0.38	0.0655

P' is the factor to multiply with legume dry matter (kg ha^{-1}) to obtain N_2 fixation (kg N ha^{-1}).

Calculations of N_2 fixation in leguminous crops for each country

Austria: At the Austrian site a 1st year grass-red clover was included in both the conventional and the organic cropping systems (Table 2.1). The crop was harvested three times during the growing season and total yield and proportion of clover measured.

Cropping system	Total dry matter yield Kg ha^{-1}	Proportion of legume %	P' from Table 1	N_2 fixation, kg N ha^{-1}		
				Total	Removed with harvest	Left in field
Conventional	9960	44.3	0.0497	219	131	88
Organic	8346	40.7	0.0497	169	101	68

In the permanent meadow three cuts were made in 2002 giving the flowing results.

Cropping system	Total dry matter yield Kg ha^{-1}	Proportion of legume %	P' from Table 1	N_2 fixation, kg N ha^{-1}		
				Total	Removed with harvest	Left in field
Conventional	12975	8.8	0.0497	57	34	23
Organic	10945	12.4	0.0497	67	40	27

Denmark: At the Danish site a pea-barley whole crop was included in both the conventional and the organic cropping systems (Table 2). The crop was harvested on July 23rd and total yield and proportion of pea measured.

Cropping system	Total dry matter yield kg ha^{-1}	Proportion of legume %	P' from Table 1	N_2 fixation, kg N ha^{-1}		
				Total	Removed with harvest	Left in field
Conventional	8986	17.2	0.0267	42	33	9
Organic	8935	20.0	0.0267	48	38	10

Finland: At the Finish site a pea-oat whole crop was included in both the conventional and the organic cropping systems (Table 2). The crop was harvested on August 22nd and total yield and proportion of pea measured.

Cropping system	Total dry matter yield Kg ha^{-1}	Proportion of legume %	P' from Table 1	N_2 fixation, kg N ha^{-1}		
				Total	Removed with harvest	Left in field
Conventional	2107	21.5	0.0267	12	10	2
Organic	840	12.5	0.0267	3	2	1

Italy: At the Italian site a 3rd and a 1st year alfalfa crop was included in the conventional and the organic cropping system, respectively (Table 2). The conventional crop was harvested five times (May 15th, June 15th, July 16th, August 2nd and October 31st) and the organic four times (June 13th, July 22nd, August 26th and October 3rd). Yields were measured at each harvest and accumulated for the entire season.

Cropping system	Total dry matter yield Kg ha^{-1}	Proportion of legume %	P' from Table 1	N_2 fixation, kg N ha^{-1}		
				Total	Removed with harvest	Left in field
Conventional	11400	100	0.0415	473	278	195
Organic	6740	100	0.0415	280	165	115

Appendix 3

MIDAIR, WP2.2 'Nitrous oxide monitoring'

Nitrogen replication test, 22-10-2001

Experimental. From one of the four replicate field plots (0.7 LU) in each of the four crops of the DK monitoring program, eight individual soil cores (i.d., 2 cm, depth, 20 cm) were sampled at random. The soil was sieved (<6 mm) and each subsample extracted in 1 M KCl, and then analyzed for ammonium and for nitrite+nitrate. Other subsamples were used to determine soil moisture.

The data were used for evaluating the variability by i) a normality test according to Shapiro and Wilk (1965), and then ii) for calculating the numbers of (sub)samples that it would require to obtain a pooled sample with a certain precision. Calculations are shown in the page 'Raw data and calculations', while the results are summarized in this page.

Results. The data indicate that it would require 2-7 samples to get within 35% of the true mean with 95% confidence, while the corresponding numbers for nitrite+nitrate are 1-4. Try changing the framed cells yourself to see how sampling requirements vary.

Conclusion. Soil concentrations in late October are rather low, which will increase the relative variability. However, it appears that at least four individual subsamples should be pooled to cover the within-plot variability in our monitoring program.

	Ammonium		Nitrate	
Field				
S1 (2nd year clover-rygrass)	Average (mg//kg)	1,594	Average (mg//kg)	0,853
	SD	0,319	SD	0,145
	Coefficient of variation	20	Coefficient of variation	17
	Within this fraction of true mean	**0,350**	Within this fraction of true mean	**0,350**
	t-value	2,365	t-value	2,365
	No. of samples=	2	No. of samples=	1
S4 (beet roots)	Average (mg//kg)	0,607	Average (mg//kg)	0,853
	SD	0,193	SD	0,131
	Coefficient of variation	32	Coefficient of variation	15
	Within this fraction of true mean	0,350	Within this fraction of true mean	0,350
	t-value	2,365	t-value	2,365
	No. of samples=	5	No. of samples=	1
S5 (oats undersown w/ryegrass)	Average (mg//kg)	0,648	Average (mg//kg)	1,076
	SD	0,257	SD	0,321
	Coefficient of variation	40	Coefficient of variation	30
	Within this fraction of true mean	0,350	Within this fraction of true mean	0,350
	t-value	2,365	t-value	2,365
	No. of samples=	7	No. of samples=	4
S6 (barley undersown w/pea)	Average (mg//kg)	0,614	Average (mg//kg)	0,788
	SD	0,132	SD	0,159
	Coefficient of variation	21	Coefficient of variation	20
	Within this fraction of true mean	0,350	Within this fraction of true mean	0,350
	t-value	2,365	t-value	2,365
	No. of samples=	2	No. of samples=	2

Appendix 4

Specific information about chamber design and samplings in each location.

	Austria	Denmark	Finland	Italy	UK
Base area (cm2)	60x60	75x75	60x60	60x60	40 diam.
Vent	-	+	+	+	-
Mixing	-	+	-	+	-
Replication	3	4	3	3	6
Gas sampling (min)	0, 60	0, 60,120	0, 60	0, 60	0, 30, 60

Appendix 5

Results of an N_2O intercomparison excersice involving six different laboratories within the MIDAIR consortium.

	Nitrous oxide concentration (ppmv)				
Participant	*Mean*	*S.D.*	*C.V. (%)*	*Recovery (%)*	*Instrument*
A	0,839	0,049	5,8	79	Hewlett Packard 5890
D	1,112	0,029	2,6	105	GC SIR 8610C
C	1,120	0,039	3,5	106	HP 6890 GC
F	1,024	0,105	10,3	97	ATI Unicam series 610
E	1,109	0,087	7,8	105	Varian 3300
B	1,113	0,064	5,8	105	Shimadzu GC 14APT

Nominal value: 1.06 ppmv N2O

				Temperatures (C)		
Participant	*Pre-column*	*Column*	*Carrier*	*Oven temp*	*Injector*	*Detector*
A	NA	Q (3.5 m x	Ar/CH4 95%/5%	80	100	300
D	apak Q (1 m x 2	ak Q (4 m x	N2 5.0 (35 ml/min)	35	Autosampler	320
C	NA	yesepQ (3	N2 (25 ml/min)		Autosampler	350
F	Porapak N (1 m	ayesep (2 r	N2 (40 ml/min)	50	Autosampler	300
E	NA	rapak T (1	Ar/CH4 95%/5%	50	Autosampler	300
B	NA	rapak Q (3	He (33.5 ml/min)	100	Autosampler	300

Nominal value: 1.06 ppmv N2O

Appendix 6

Approach to correct for interference from CO_2

Nitrous oxide measurements were corrected according to the principles out-lined below. Fluxes of CO_2 were either monitored, or they were modelled by the model FASSET (http://www.fasset.dk/) in combination with validation measurements. It was assumed that the CO_2 flux of a given crop, at comparable soil temperature, moisture and time of year, would be the same in two different years.

Time	*Gas*	*Area*
(Measured in monitoring program)		
t_0	$N_2O + CO_2$	A
t_0	N_2O	a
t_0	CO_2	A – a
t_1	$N_2O + CO_2$	B
(Model output or independent measurement)		
t_0	CO_2	C
t_1	CO_2	D
(Calculated)		
t_1	CO_2	D/C × (A – a) = E
t_1	N_2O	B – E

In these calculations, A-a = C = atmospheric CO_2, and a = atmospheric N_2O
The area corresponding to a was determined independently using standards.

Appendix 7

Systems analysis, full model

```
libname WP22 'C:\Fra D-drevet\data\Akt 5784 MIDAIR\WP 2.2\N2O summary
results';

/* Systems effects, full model */

data WP22.AUS;
Infile 'C:\Fra D-drevet\data\Akt 5784 MIDAIR\WP 2.2\N2O summary
results\AUS_log.csv';
Input Sampl_ID$ Location$ Input$ Supblock Block Cropcat Plot Sampling N2O
Moisture Ammonium Nitrate Percclay Perc_C Perc_N Soiltemp;
run;

data WP22.DK;
Infile 'C:\Fra D-drevet\data\Akt 5784 MIDAIR\WP 2.2\N2O summary
results\DK_log.csv';
Input Sampl_ID$ Location$ Input$ Supblock Block Cropcat Plot Sampling N2O
Moisture Ammonium Nitrate Percclay Perc_C Perc_N Soiltemp;
run;

data WP22.FIN;
Infile 'C:\Fra D-drevet\data\Akt 5784 MIDAIR\WP 2.2\N2O summary
results\FIN_log.csv';
Input Sampl_ID$ Location$ Input$ Supblock Block Cropcat Plot Sampling N2O
Moisture Ammonium Nitrate Percclay Perc_C Perc_N Soiltemp;
run;

data WP22.ITA;
Infile 'C:\Fra D-drevet\data\Akt 5784 MIDAIR\WP 2.2\N2O summary
results\ITA_log.csv';
Input Sampl_ID$ Location$ Input$ Supblock Block Cropcat Plot Sampling N2O
Moisture Ammonium Nitrate Percclay Perc_C Perc_N Soiltemp;
run;

data WP22.UK;
Infile 'C:\Fra D-drevet\data\Akt 5784 MIDAIR\WP 2.2\N2O summary
results\UK_log.csv';
Input Sampl_ID$ Location$ Input$ Supblock Block Cropcat Plot Sampling N2O
Moisture Ammonium Nitrate Percclay Perc_C Perc_N Soiltemp;
run;

data WP22.all;
set WP22.AUS WP22.DK WP22.FIN WP22.ITA WP22.UK;
run;

Proc mixed
data=WP22.all;
Class location input supblock block cropcat plot sampling;
Model N2O = location|input|cropcat /outp=outp DDFM=Satterth;
random supblock(location) supblock(location*input*cropcat)
       block(location*supblock*cropcat)block(location*input*cropcat*supblock);
ods output solutionr=sr; ods listing exclude solutionr;
lsmeans location|input|cropcat @2/tdiff adjust=Tukey;
run;
```

Systems analysis, reduced model

```
libname WP22 'C:\Fra D-drevet\data\Akt 5784 MIDAIR\WP 2.2\N2O summary
results';

/* Systems effects, reduced model without location*cropcat interactions */

data WP22.AUS;
Infile 'C:\Fra D-drevet\data\Akt 5784 MIDAIR\WP 2.2\N2O summary
results\AUS_log.csv';
Input Sampl_ID$ Location$ Input$ Supblock Block Cropcat Plot Sampling N2O
Moisture Ammonium Nitrate Percclay Perc_C Perc_N Soiltemp;
run;

data WP22.DK;
Infile 'C:\Fra D-drevet\data\Akt 5784 MIDAIR\WP 2.2\N2O summary
results\DK_log.csv';
Input Sampl_ID$ Location$ Input$ Supblock Block Cropcat Plot Sampling N2O
Moisture Ammonium Nitrate Percclay Perc_C Perc_N Soiltemp;
run;

data WP22.FIN;
Infile 'C:\Fra D-drevet\data\Akt 5784 MIDAIR\WP 2.2\N2O summary
results\FIN_log.csv';
Input Sampl_ID$ Location$ Input$ Supblock Block Cropcat Plot Sampling N2O
Moisture Ammonium Nitrate Percclay Perc_C Perc_N Soiltemp;
run;

data WP22.ITA;
Infile 'C:\Fra D-drevet\data\Akt 5784 MIDAIR\WP 2.2\N2O summary
results\ITA_log.csv';
Input Sampl_ID$ Location$ Input$ Supblock Block Cropcat Plot Sampling N2O
Moisture Ammonium Nitrate Percclay Perc_C Perc_N Soiltemp;
run;

data WP22.UK;
Infile 'C:\Fra D-drevet\data\Akt 5784 MIDAIR\WP 2.2\N2O summary
results\UK_log.csv';
Input Sampl_ID$ Location$ Input$ Supblock Block Cropcat Plot Sampling N2O
Moisture Ammonium Nitrate Percclay Perc_C Perc_N Soiltemp;
run;

data WP22.all;
set WP22.AUS WP22.DK WP22.FIN WP22.ITA WP22.UK;
run;

Proc mixed
data=WP22.all;
Class location input supblock block cropcat plot sampling;
Model N2O = location|input cropcat input*cropcat /outp=outp DDFM=Satterth;
random supblock(location) supblock(location*input*cropcat)
block(location*supblock*cropcat)
        block(location*input*cropcat*supblock);
ods output solutionr=sr; ods listing exclude solutionr;
lsmeans location|input cropcat input*cropcat @2/tdiff adjust=Tukey;
run;
```

Soils analysis

```
libname WP22 'C:\Fra D-drevet\data\Akt 5784 MIDAIR\WP 2.2\N2O summary
results';

data WP22.AUS;
Infile 'C:\Fra D-drevet\data\Akt 5784 MIDAIR\WP 2.2\N2O summary
results\AUS_log.csv';
Input Sampl_ID$ Location$ Input$ Supblock Block Cropcat Plot Sampling N2O
Moisture Ammonium Nitrate Percclay Perc_C Perc_N Soiltemp;
run;

data WP22.DK;
Infile 'C:\Fra D-drevet\data\Akt 5784 MIDAIR\WP 2.2\N2O summary
results\DK_log.csv';
Input Sampl_ID$ Location$ Input$ Supblock Block Cropcat Plot Sampling N2O
Moisture Ammonium Nitrate Percclay Perc_C Perc_N Soiltemp;
run;

data WP22.FIN;
Infile 'C:\Fra D-drevet\data\Akt 5784 MIDAIR\WP 2.2\N2O summary
results\FIN_log.csv';
Input Sampl_ID$ Location$ Input$ Supblock Block Cropcat Plot Sampling N2O
Moisture Ammonium Nitrate Percclay Perc_C Perc_N Soiltemp;
run;

data WP22.ITA;
Infile 'C:\Fra D-drevet\data\Akt 5784 MIDAIR\WP 2.2\N2O summary
results\ITA_log.csv';
Input Sampl_ID$ Location$ Input$ Supblock Block Cropcat Plot Sampling N2O
Moisture Ammonium Nitrate Percclay Perc_C Perc_N Soiltemp;
run;

data WP22.UK;
Infile 'C:\Fra D-drevet\data\Akt 5784 MIDAIR\WP 2.2\N2O summary
results\UK_log.csv';
Input Sampl_ID$ Location$ Input$ Supblock Block Cropcat Plot Sampling N2O
Moisture Ammonium Nitrate Percclay Perc_C Perc_N Soiltemp;
run;

data WP22.all;
set WP22.AUS WP22.DK WP22.FIN WP22.ITA WP22.UK;
run;

Proc mixed
data=WP22.all;
Class location input supblock block cropcat plot sampling;
Model N2O = Input|Cropcat Location Moisture Moisture*Cropcat
             Ammonium Ammonium*Input Nitrate Nitrate*Input
            Percclay Percclay*Moisture Perc_C Soiltemp Soiltemp*Location
            /outp=outp DDFM=Satterth solution;
random supblock(location) supblock(location*input*cropcat)
block(location*supblock*cropcat) block(location*input*cropcat*supblock);
ods output solutionr=sr; ods listing exclude solutionr;
lsmeans Input|Cropcat Location  @2/tdiff adjust=Tukey;
run;
```

Appendix 8

Table 4.3. Probabilities of main effects and interactions observed with the full model and the reduced model (see text), respectively.

Effect	Full model	Reduced model
	P values	
Location	0.5520	0.4105
Input	0.5058	0.2536
Location × Input	<0.0001	0.0043
Cropcat	0.0122	0.0464
Location × Cropcat	0.0980	-
Input × Cropcat	0.1436	0.4077
Location × Input × Cropcat	0.1626	-

Without DK:

Table 4.3. Probabilities of main effects and interactions observed with the full model and the reduced model (see text), respectively.

Effect	Full model	Reduced model
	P values	
Location	0.5002	0.4059
Input	0.9547	0.4476
Location × Input	<0.0001	0.0094
Cropcat	0.0223	0.0548
Location × Cropcat	0.1282	-
Input × Cropcat	0.1011	0.2884
Location × Input × Cropcat	0.1473	-

Table 4.4. Estimates for effects of location × input on log-transformed N_2O emissions.

Effect	'Organic'	'Conventional'
Location × Input	($\times 10^{-2}$)	
Austria	3.70	1.53
Denmark	1.49	2.23
Finland	1.34	1.30
Italy	1.85	2.85
UK	2.36	4.70

Without DK:

Table 4.4. Estimates for effects of location × input on log-transformed N_2O emissions.

Effect	'Organic'	'Conventional'
Location × Input	($\times 10^{-2}$)	
Austria	3.67	1.53
Denmark	-	-
Finland	1.35	1.34
Italy	1.85	2.85
UK	2.35	4.71

Tab. 4.5. Estimates for effects of crop category on log-transformed N_2O emissions.

Crop category	Estimate ($\times 10^{-2}$)
1. Crops with N fixation	2.00
2. Cereal crops	2.26
3. Forage crops	3.21
4. Grassland	1.88

Without DK:

Tab. 4.5. Estimates for effects of crop category on log-transformed N_2O emissions.

Crop category	Estimate ($\times 10^{-2}$)
1. Crops with N fixation	1.92
2. Cereal crops	2.46
3. Forage crops	3.46
4. Grassland	1.99

Table 4.6. Effects of systems and soil related variables on log-transformed N_2O emissions. Despite several highly significant relationships, the variables defined in the model accounted for only ca. 10% of the total variation.

Effect	P value	P value without DK	Variance explained*
Input	0.1352	0.0269	0.39
Crop category	0.0071	0.0190	0.37
Input × Crop category	0.3109	0.0855	0.22
Location	0.0004	0.0008	2.60
Moisture	0.2583	0.0265	0.09
Moisture × Crop category	0.1698	0.3747	0.20
Ammonium	<0.0001	0.0002	1.17
Ammonium × Input	0.0044	0.0004	0.44
Nitrate	0.9699	0.9070	0.002
Nitrate × Input	0.9610	0.4250	0.01
% Clay	0.8613	0.1916	0.31
Moisture × % clay	0.8709	0.5376	0.001
% C	0.9706	0.8802	0.09
Soil temperature	0.0038	0.1235	0.58
Soil temperature × Location	<0.0001	<0.0001	3.16

* Variances for the model without DK could not be calculated due to singularity in covariance matrix (see output file).