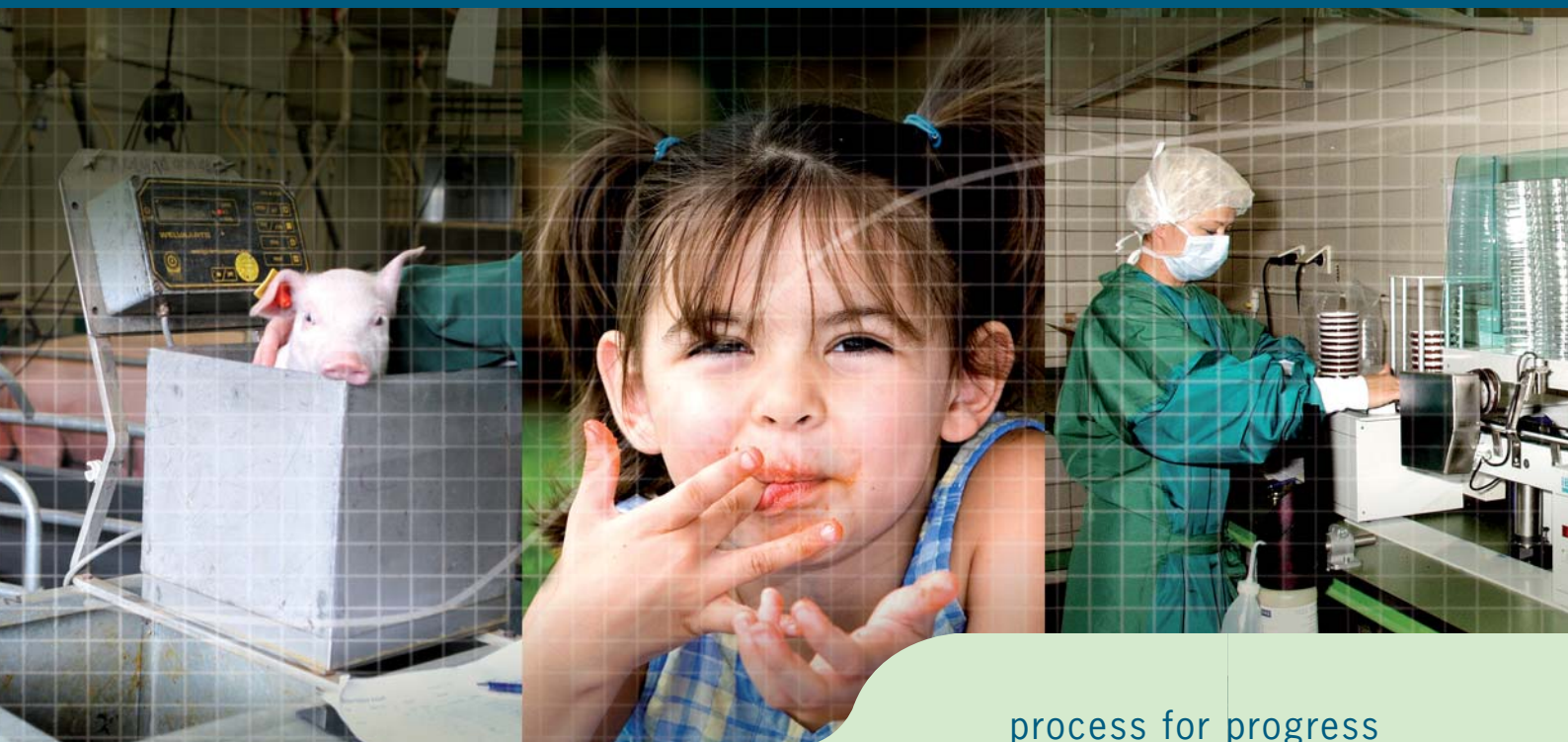


# Animal Sciences Group

Divisie Veehouderij, kennispartner voor de toekomst



process for progress

Report 77

Greenhouse gas fluxes from arable land  
in the Netherlands

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## Abstract

This report shows the results of a monitoring study performed to quantify the emissions of  $N_2O$  and  $CH_4$  from two different agricultural (arable) soils in the Netherlands. Both sites were net sources for  $N_2O$ , with values ranging from  $-3.8$  to  $179.5$  g  $N_2O-N$   $ha^{-1}$   $d^{-1}$ .  $CH_4$  fluxes ranged from  $-6.3$  to  $5.9$  g  $CH_4-C$   $ha^{-1}$   $d^{-1}$  at the field location Langeweg, and from  $-103$  to  $1590$  g  $CH_4-C$   $ha^{-1}$   $d^{-1}$  at the field location Vredepeel. Soil water content did not significantly influence the fluxes of  $N_2O$  and  $CH_4$ . However, an increase in soil water content after the application of manure into the field resulted in higher  $N_2O$  emissions at both sites. Fertilisation (both with organic manure and mineral fertiliser) resulted in higher  $N_2O$  emissions, whereas its effect on  $CH_4$  ranged from no significant effect (Langeweg) to higher emissions (Vredepeel).

**Keywords:** greenhouse gases, methane, nitrous oxide, arable land, fluxes, BSIK

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Report 77

# Greenhouse gas fluxes from arable land in the Netherlands

J. Mosquera

J.M.G. Hol

J.W.H. Huis in 't Veld

November 2007

## **Preface**

This project was executed within the framework of the BSIK-KvR (Climate changes Spatial Planning) programme, and was partially financed by the Dutch Ministry of Agriculture, Nature and Food Quality (LNV).

## Samenvatting

Koolstofdioxide (CO<sub>2</sub>), methaan (CH<sub>4</sub>) en lachgas (N<sub>2</sub>O) zijn de belangrijkste broeikasgassen, die verantwoordelijk zijn voor de opwarming van de aarde (klimaatverandering). Het is van belang om broeikasgasemissies uit verschillende bronnen te kunnen kwantificeren. In dit rapport worden de resultaten gepresenteerd van N<sub>2</sub>O en CH<sub>4</sub> emissiemetingen bij twee akkerbouw locaties in Nederland. Deze emissiemetingen werden uitgevoerd in het kader van het BSIK Klimaat voor Ruimte programma als onderdeel van het project ME-1 (Integrated observations and modelling of greenhouse gas budgets at the ecosystem level in the Netherlands). Beide locaties waren N<sub>2</sub>O bronnen, met emissiewaarden die varieerden tussen -3,8 en 179,5 g N<sub>2</sub>O-N ha<sup>-1</sup> dag<sup>-1</sup>. CH<sub>4</sub> fluxen varieerden tussen -6,3 en 5,9 g CH<sub>4</sub>-C ha<sup>-1</sup> dag<sup>-1</sup> bij de locatie Langeweg (zware zavel / lichte klei), en tussen -103 en 1590 g CH<sub>4</sub>-C ha<sup>-1</sup> dag<sup>-1</sup> bij de locatie Vredepeel (zand). Bodemvochtgehalte had geen significant effect op de fluxen van N<sub>2</sub>O en CH<sub>4</sub>. Na bemesting werden op beide locaties hogere N<sub>2</sub>O emissies gemeten. Bemesting van organische mest resulteerde in hogere CH<sub>4</sub> emissies (locatie Vredepeel). Bemesting met kunstmest had op beide locaties geen effect op de emissies van CH<sub>4</sub>.

## Summary

Carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) are the most important greenhouse gases in the atmosphere. Greenhouse gases are considered to be responsible for the increased global warming, associated with climate change. It is therefore important to quantify greenhouse gas emissions from different sources. This report shows the results of a monitoring study performed to quantify the emissions of N<sub>2</sub>O and CH<sub>4</sub> from two different agricultural (arable) soils in the Netherlands. These measurements were performed within the framework of the BSIK "Climate changes Spatial Planning" programme, as part of the project ME-1 (Integrated observations and modelling of greenhouse gas budgets at the ecosystem level in the Netherlands). Both sites were net sources for N<sub>2</sub>O, with values ranging from -3.8 to 179.5 g N<sub>2</sub>O-N ha<sup>-1</sup> d<sup>-1</sup>. CH<sub>4</sub> fluxes ranged from -6.3 to 5.9 g CH<sub>4</sub>-C ha<sup>-1</sup> d<sup>-1</sup> at the field location Langeweg (loam to sandy loam), and from -103 to 1590 g CH<sub>4</sub>-C ha<sup>-1</sup> d<sup>-1</sup> at the field location Vredepeel (fine sand). Soil water content did not significantly influence the fluxes of N<sub>2</sub>O and CH<sub>4</sub>. Fertilisation (both with organic manure and mineral fertiliser) resulted in higher N<sub>2</sub>O emissions, whereas its effect on CH<sub>4</sub> ranged from no significant effect for mineral fertiliser (both locations) to higher emissions for organic manure (Vredepeel).

# Contents

Preface

Samenvatting

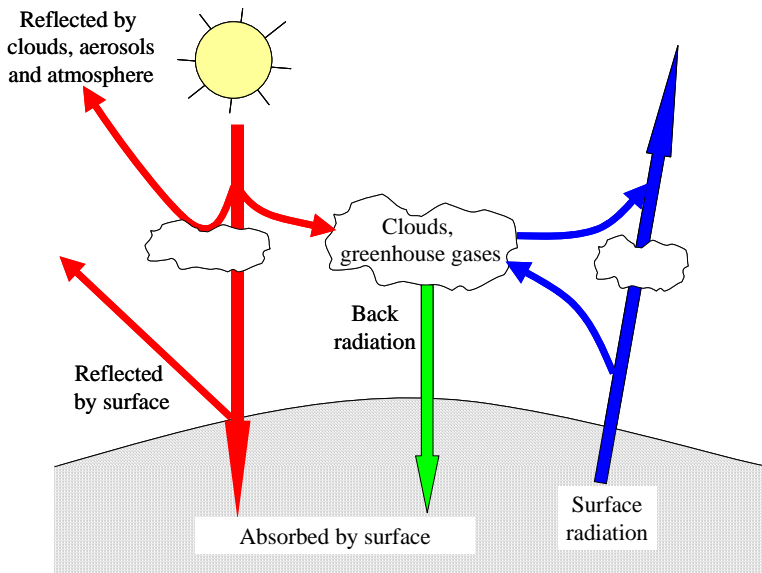
Summary

<b>1</b>	<b>Introduction</b> .....	<b>1</b>
<b>2</b>	<b>Materials and methods</b> .....	<b>5</b>
2.1	Field locations: site characteristics and field management .....	5
2.2	Measurement methods .....	7
2.2.1	Topsoil structure: volumetric soil water content .....	7
2.2.2	Soil gas flux rate determinations.....	8
<b>3</b>	<b>Results and discussion</b> .....	<b>10</b>
3.1	Nitrous oxide (N <sub>2</sub> O) emissions.....	10
3.2	Methane (CH <sub>4</sub> ) emissions.....	11
<b>4</b>	<b>Conclusions</b> .....	<b>13</b>
	<b>Literature</b> .....	<b>14</b>

## 1 Introduction

Greenhouse gases are present in the atmosphere as trace gases. They are transparent for incoming short-wave radiation from the sun, but do absorb and re-emit the outgoing infrared radiation from the Earth's surface, thereby warming the atmosphere (figure 1). This warming is referred to as "natural greenhouse effect", and is highly beneficial: without it, the average temperature on Earth would be about 33°C colder, making life in its present form impossible.

**Figure 1** The greenhouse effect



Greenhouse gases differ in their ability to absorb heat in the atmosphere. In order to be able to compare the emissions of all different greenhouse gases, the concept of Global Warming Potential (GWP) was introduced. The GWP expresses the emission of a gas in terms of carbon dioxide (CO<sub>2</sub>) emissions (CO<sub>2</sub> equivalents). Since greenhouse gases have different lifetimes (IPCC, 2001; table 1), the GWP is always coupled to a particular time interval (time horizon). For example, on a molecular basis and over a 100-year time horizon, the GWP of methane (CH<sub>4</sub>) is 23 times that of CO<sub>2</sub>, and nitrous oxide (N<sub>2</sub>O) has a GWP 296 times greater than carbon dioxide (IPCC, 2001; table 1). The emissions of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O account for respectively 50, 18 and 6% of the total overall global warming effect arising from human activities.

**Table 1** Some characteristics of the main greenhouse gases (IPCC, 2001)

Greenhouse gases	Pre-industrial concentration	Concentration in 1998	Atmospheric Lifetime [years]	Global warming potential (100 year time horizon)
Carbon dioxide (CO <sub>2</sub> )	280 ppm	365 ppm	5-200	1
Methane (CH <sub>4</sub> )	700 ppb	1745 ppb	12	23
Nitrous oxide (N <sub>2</sub> O)	270 ppb	314 ppb	114	296

The concentration of greenhouse gases remained relatively constant for about a thousand years before the industrial revolution. Since then, the concentration of various greenhouse gases has drastically increased. As an example, atmospheric concentrations of carbon dioxide have increased nearly 30%, CH<sub>4</sub> concentrations have more than doubled, and N<sub>2</sub>O concentrations have risen by about 15% (IPCC, 2001; table 1). This has resulted in a positive radiative forcing, which tends to warm the surface ("enhanced greenhouse effect"). In the last decades, early signs of enhanced global warming have already been observed (IPCC, 2001): the Earth's surface temperature has risen by about 0.6 °C over the 20<sup>th</sup> century, with accelerated warming during the past two decades; the sea level has risen during the 20<sup>th</sup> century by 10 to 20 cm; snow cover in the Northern Hemisphere and floating ice in the Arctic Ocean has decreased; annual land precipitation over land has increased in mid- and high latitudes of the Northern Hemisphere and over most Southern Hemisphere land areas, but over the tropical and the Northern Hemisphere subtropical land areas conditions have become dryer. In his Third Assessment



Report, IPCC (2001) predicted a further temperature rise of 1.4 to 5.8 °C over the next 100 years, with higher maximum and minimum temperatures, more intense precipitation events, and intensified droughts and floods. Concern about the enhanced greenhouse effect has prompted international action to reduce emissions. A first agreement, intended to stabilise emissions at 1990 levels by 2000, was signed in 1992 at the Earth Summit in Rio de Janeiro. A more binding agreement was reached at Kyoto, Japan, in 1997. Under the Kyoto Protocol (entry into force 16 February 2005), thirty industrialised countries are legally bound to reduce their combined emission of six major greenhouse gases during the five-year period 2008-2012 to below 1990 levels. The European Union, for example, should reduce by 8% its combined emissions. For the Netherlands, a reduction target of 6% has been assigned. In order to achieve this emission reduction, it is important to quantify greenhouse gas emissions from different sources.

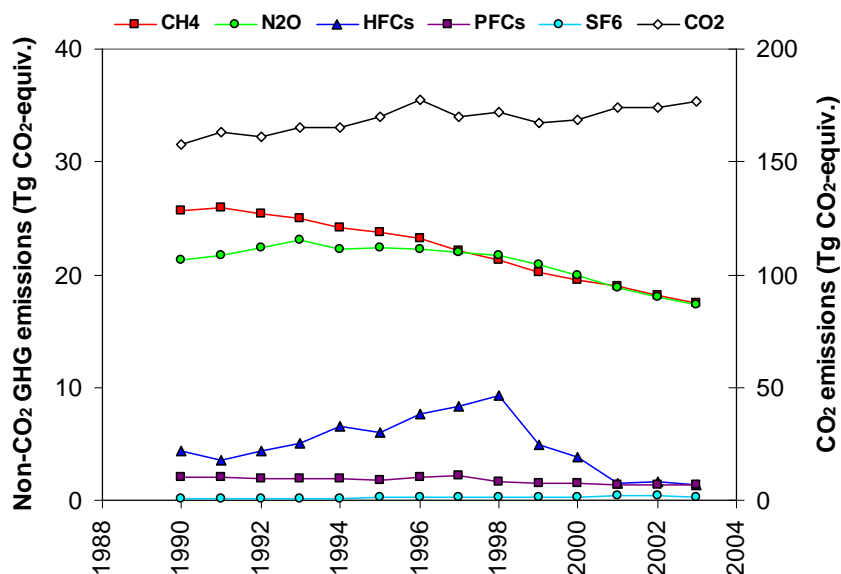
The UNFCCC and the Kyoto protocol specify six main greenhouse gases whose emissions should be reported:

- Carbon dioxide (CO<sub>2</sub>)
- Methane (CH<sub>4</sub>)
- Nitrous oxide (N<sub>2</sub>O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulphur hexafluoride (SF<sub>6</sub>)

Emissions of CO<sub>2</sub> increased in 2003 by about 12% relative to 1990 (figure 2), which is considered to be the reference year for the emissions of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O. In contrast, the emissions of CH<sub>4</sub> and N<sub>2</sub>O decreased (in the same period) by about 32% and 19%, respectively. The total emission of the fluorinated gases (HFCs, PFCs, SF<sub>6</sub>) decreased by 60% in 2003 relative to 1995, the reference year for these gases. In particular, emissions of HFCs and PFCs decreased by about 75% and 25%, respectively, while SF<sub>6</sub> emissions increased by 11%.

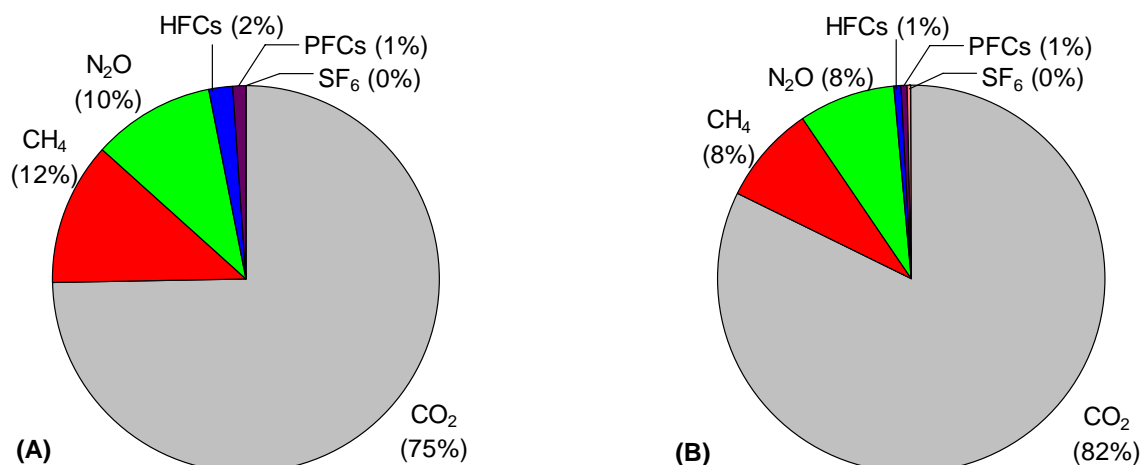
**Figure 2** Trend in greenhouse gas emissions in the Netherlands during the period 1990-2003.

Source: Klein Goldewijk *et al.* (2005).



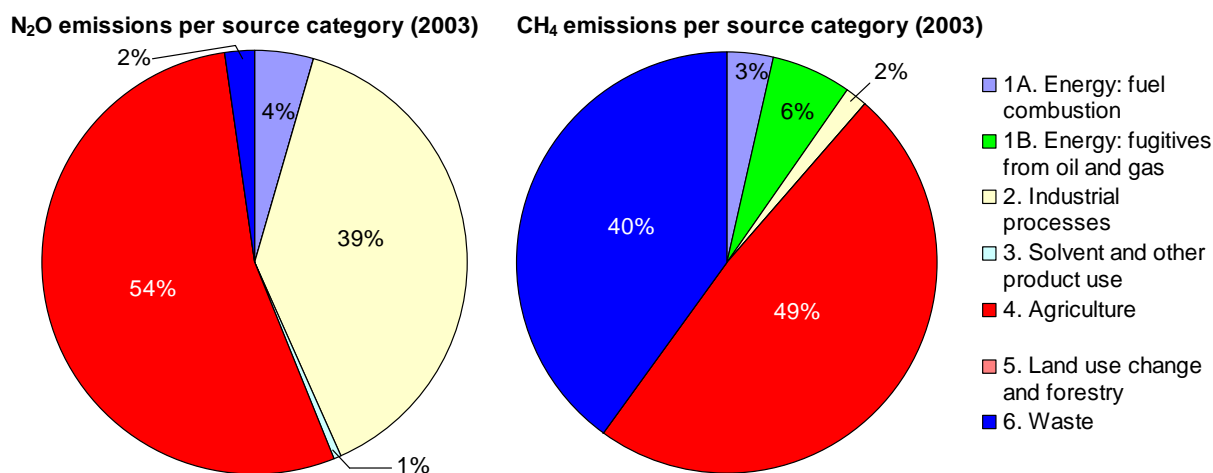
The contribution of CO<sub>2</sub> emissions to the total greenhouse gas emission in the Netherlands increased from approximately 75% in 1990, to 82% in 2003 (figure 3). CH<sub>4</sub> and N<sub>2</sub>O are the most important non-CO<sub>2</sub> greenhouse gases in the Netherlands. Together they were responsible for about 16% of total greenhouse gas emissions in the Netherlands in 2003. Compared to CO<sub>2</sub>, their contribution to the total emissions has been reduced by 6% since 1990.

**Figure 3** Shares of greenhouse gases in total emissions in the Netherlands in (A) the reference year (1990 for CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O; 1995 for F-gases), and in (B) the year 2003. Source: Klein Goldewijk *et al.* (2005).



Agriculture is the most important source of N<sub>2</sub>O and CH<sub>4</sub> in the Netherlands (figure 4), and contributes about 8% to the total national greenhouse gas emissions in 2003 (10% in 1990). N<sub>2</sub>O emissions are responsible for about 53% of total greenhouse gas emissions from agriculture, whereas CH<sub>4</sub> is responsible for the rest (47%). Emissions of N<sub>2</sub>O from agriculture, mainly from agricultural soils (1: direct emissions through application of animal wastes/fertilizer to soils; 2: indirect emissions from nitrogen leaching and run-off), accounted for 54% of national total N<sub>2</sub>O emissions. CH<sub>4</sub> emissions from agriculture accounted for 49% of the national total CH<sub>4</sub> emissions in 2003, and were related to enteric fermentation (75% of total agricultural CH<sub>4</sub> emissions) and animal waste management systems (25% of total CH<sub>4</sub> emissions from agriculture).

**Figure 4** Emissions of N<sub>2</sub>O and CH<sub>4</sub> in the Netherlands (2003) per source category. Source: Klein Goldewijk *et al.* (2005).



Within the framework of the BSIK "Climate changes Spatial Planning" programme, a project (ME-1: Integrated observations and modelling of greenhouse gas budgets at the ecosystem level in the Netherlands) was started in 2004 with the following objectives:

- To measure the fluxes of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O at different arable and grassland sites in the Netherlands, and relate these emissions to land use
- To validate existing emission models and to develop new parameterisations to better understand the emission processes
- To study the effect of land use change of changes in land management on the emissions of these greenhouse gases
- To assign emission factors for different land use systems, and to monitor these emissions

This report summarizes the results of greenhouse gas flux measurements performed at two different cropland sites in the Netherlands. First of all, the measurement locations used in this study are described according to soil type, management and cultivation. In addition, the experimental set-up and the measurement methods used to determine soil gas flux rates of CH<sub>4</sub> and N<sub>2</sub>O are explained. Section 3 describes the main results of this research. Finally, some conclusions are presented.

## 2 Materials and methods

From the total land surface in the Netherlands (~3.7 million ha), approximately 52% (~1.9 million ha) is used for grassland-based and arable farming (table 2). Of this surface, approximately 42% is under arable crops. Cereals and silage maize were the most important arable crops in the Netherlands in 2003 according to the total area used for cultivation, followed by potatoes and sugar beet (table 3). When looking at the crop yield, potatoes and sugar beet have the largest share (table 3).

**Table 2** Area under grassland-based and arable farming (2003).  
Source: CBS (Centraal Bureau voor de Statistiek, <http://statline.cbs.nl>).

Farmland	Area [x 1000 ha]
Arable	814
Horticulture	116
Grassland (permanent)	791
Grassland (temporal)	195
Fallow Fields	4
Other	4
<b>TOTAL</b>	<b>1923</b>

**Table 3** Area under arable crops and crop yield (2003).  
Source: CBS (Centraal Bureau voor de Statistiek, <http://statline.cbs.nl>).

Farmland	Area [x 1000 ha]	Crop yield [x10 <sup>6</sup> kg]
Cereals	195.3	1533
Potatoes		
- seed potatoes	39.3	4647
- eating potatoes	70.6	3240
- starch potatoes	48.8	1822
Sugar beet	102.8	6210
Onions	23.2	1572
Silage maize	217.0	10
Legumes	11.8	23
Other	105.2	305

Due to their high cultivation area and economic value, potatoes (2005) and sugar beet (2006) were selected for this study.

### 2.1 Field locations: site characteristics and field management

The experimental sites were situated in the south of the Netherlands (figure 5). In 2005, measurements were performed at a potato field, whereas in 2006 a field cultivated with sugar beets was selected. Tables 4 and 5 summarize some available general information describing the management treatments at both locations.

**Figure 5** Experimental sites**Table 4** Langeweg: site description

Soil classification	International classification (Driessen <i>et al.</i> , 2001): Calcaric epigleyic Fluvisol		
	Dutch classification (Bakker en Schelling, 1989): Poldervaaggrond		
Crop	Potatoes for consumption		
Year	2005		
Surface area (ha)	8.65		
Measurement period	9 May – 12 July		
Planting	24 April		
Harvesting	6-7 October		
Fertilisation			
Day of application	7 February	11 May	24 June
Fertiliser type	Mineral (Kali-60)	Mineral (26-14-0)	Mineral (kalkamonsalpeter)
Fertiliser rate	360 kg K <sub>2</sub> O ha <sup>-1</sup>	112 kg N ha <sup>-1</sup> 60 kg P <sub>2</sub> O <sub>5</sub> ha <sup>-1</sup>	108 kg N ha <sup>-1</sup>

**Table 5** Vredepeel: site description

Soil classification	International classification (Driessen <i>et al.</i> , 2001): Anthric entric Podzol			
	Dutch classification (Bakker en Schelling, 1989): Veldpodzolgrond			
Crop	Sugar beets			
Year	2006			
Surface area (ha)	10			
Measurement period	22 March- 22 November			
Planting	11 April			
Harvesting	7 November			
Fertilisation				
Day of application	2 March	6 March	22 March	15 May
Fertiliser type	Mineral (rock salt)	Mineral (borium)	Organic (cattle slurry)	Mineral (kalkamonsalpeter)
Fertiliser rate	200 kg ha <sup>-1</sup> (50% Na)	10 kg ha <sup>-1</sup> (borium)	177 kg N ha <sup>-1</sup> 76 kg P ha <sup>-1</sup> 236 kg K ha <sup>-1</sup>	41 kg N ha <sup>-1</sup>

Field 1: Langeweg

The soil is classified as "Calcaric epigleyic Fluvisol" (international classification; Driessen *et al.*, 2001) or as "Poldervaaggrond" (Dutch classification; Bakker en Schelling, 1989), and has a loam to sandy loam texture. This location was cultivated in 2005 with potatoes for consumption, and had previously been used in the last five years to grow grass seed (2003 and 2004), parsley (2002), winter wheat (2001) and potatoes for consumption (2000). The potatoes were planted the 24<sup>th</sup> of April, and were harvested between 6-7 October. Measurements of N<sub>2</sub>O and CH<sub>4</sub> fluxes were performed during the period 9 May-12 July.

Field 2: Vredepeel

The soil is classified as "Anthric entric Podzol" (international classification; Driessen *et al.*, 2001) or as "Veldpodzolgrond" (Dutch classification; Bakker en Schelling, 1989), and has a fine sand texture. This location was cultivated in 2006 with sugar beets, which were planted on April 11, and harvested on November 7. Measurements of N<sub>2</sub>O, CH<sub>4</sub> and CO<sub>2</sub> fluxes were performed during the period 22 March - 22 November.

## 2.2 Measurement methods

### 2.2.1 Topsoil structure: volumetric soil water content

Soil structure during crop growth was characterised by volumetric soil water content. Soil water content was measured in the field with the ECH<sub>2</sub>O Dielectric Aquameter Sensor (Decagon Devices, Inc.; figure 6). This sensor determines soil (volumetric) water content by measuring the dielectric constant of the soil. Since the dielectric constant of water is much higher than that of air or soil minerals, the dielectric constant of the soil is a sensitive measure of soil water content. The sensor is introduced into the soil to a depth of approximately 10 cm, in order to measure soil water content at the upper 10-cm soil layer. Topsoil structure was characterised at the beginning and at the end of every gas flux rate measurement (at every measurement day and for every flux chamber).

**Figure 6** ECH<sub>2</sub>O Dielectric Aquameter sensor



The ECH<sub>2</sub>O probes come pre-calibrated for most soil types, although specific calibrations for a particular soil are also possible. The standard calibration for the probe, which is suitable for soils with low to moderate sand content, is:

$$\theta_v = 0.0905 \cdot X - 34$$

Where  $\theta_v$  (m<sup>3</sup>/m<sup>3</sup>; %) represents the volumetric water content and X (mV) is the response (output) of the ECH<sub>2</sub>O probe.

### 2.2.2 Soil gas flux rate determinations

Gas exchange between the soil surface and the atmosphere was measured using closed flux chambers. Chamber methods can be used to measure small fluxes, they are easy to use and their construction is relatively simple and inexpensive. They have however some disadvantages:

1. Disturbances by inserting the chamber into the soil may release N<sub>2</sub>O or CH<sub>4</sub> trapped by the soil. In order to minimize this effect, flux chambers were not inserted into the soil, but placed on permanently installed wooden frames (inserted 5-10 cm into the soil; figure 7).
2. If the chamber is not completely sealed, leakage will be dependent on weather conditions (particularly wind speed) outside the chamber. In order to measure the leakage (ventilation rate) through the chamber, the rate of decay method (see description below) was applied.
3. Build-up of high CH<sub>4</sub> concentrations may affect N<sub>2</sub>O or CH<sub>4</sub> fluxes from the soil. Scott *et al.* (1999) showed that the increase in concentration in the chambers was linear for a period of about 3 h, suggesting no strong effect of the chamber on the production/consumption rates. In this study, a measurement time of 40 minutes was used.
4. In order to get a representative sampler of the whole measured area under the chamber, good mixing inside the chamber should be provided. In order to minimize this problem, every chamber was equipped with a small axial flow fan and an external 12-V battery.
5. High spatial and temporal variability of N<sub>2</sub>O and CH<sub>4</sub> emissions at local scales makes extrapolation to large-scale landscape units very problematic. This problem was minimised by increasing the number and size of the flux chambers used. In the experiments presented here, four chambers per treatment, each covering an experimental area of 3.5 m<sup>2</sup>, were used. The volume of the chambers with (without) the frame was 1.84 (1.5) m<sup>3</sup>.
6. Chambers are labour intensive.

**Figure 7** Flux chamber placed on permanently installed frames. (A): Potato field (Langeweg); (B): Field with sugar beets (Vredepeel)



Flux chambers use de law of conservation of mass to determine the gas exchange between the soil surface and the atmosphere:

$$V \cdot \frac{dC_i}{dt} = -\phi \cdot (C_i - C_e) + Q - f$$

Where: V = volume of the flux chamber  
 C<sub>i</sub> = concentration of the measured gas inside the chamber  
 C<sub>e</sub> = concentration of the measured gas outside the chamber (background)  
 φ = leakage / ventilation rate  
 Q = gas emission from the measured area  
 f = adsorption and absorption losses

When the ventilation rate, the emission, and the adsorption/absorption losses remain constant during the whole measurement period, the concentration of the gas inside the flux chamber can be determined according to:

$$C_i = \left( \frac{\phi \cdot C_e + Q}{\phi + Q} \right) \cdot \left( 1 - e^{-\frac{\phi+Q}{V} \cdot t} \right) + C_0 \cdot e^{-\frac{\phi+Q}{V} \cdot t}$$

Where  $C_0$  represents the gas concentration inside the chamber at time  $t=0$ . By injecting a known amount of a tracer gas (in our case  $SF_6$ ) into the chamber and following the decay in concentration of the tracer gas with time, an estimate of the leakage over the whole measurement period can be obtained by using the tracer gas rate of decay (Mosquera *et al.*, 2002). This method also relies on the law of conservation of mass, and can be expressed as:

$$V \cdot \frac{dC_i}{dt} = -\phi \cdot (C_i - C_e)$$

When the ventilation rate remains constant during the whole measurement period, the concentration of the tracer gas inside the chamber at a particular time  $t$  can be calculated according to:

$$C_i = C_0 \cdot e^{-\frac{\phi}{V} \cdot t}$$

For short measurement periods, when the leakage (ventilation rate) is considered to be negligible, the emission can be determined from the linear increase of concentration with time according to:

$$C_i = C_0 + \frac{Q}{V} \cdot t$$

After placing the flux chamber on top of the soil or on the installed frames and switching on the ventilator, a known amount of tracer gas ( $SF_6$ ) was injected into the chamber. Three gas samples were collected in 30 ml syringes 0, 20 and 40 min after the start of the measurements. The gas samples were analysed the same day *in situ* by using a gas chromatograph equipped with an electron capture detector (ECD) for  $N_2O$  and  $SF_6$ , and a flame ionisation detector (FID) for  $CH_4$ .

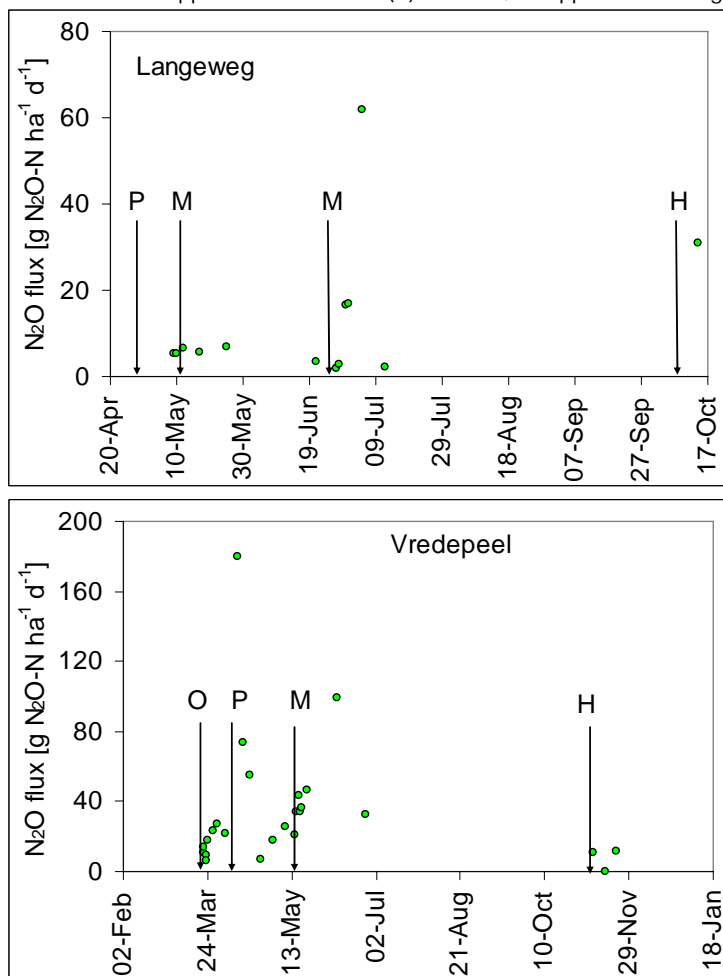


### 3 Results and discussion

#### 3.1 Nitrous oxide (N<sub>2</sub>O) emissions

Variation of the N<sub>2</sub>O flux rates with time was large for both sites: from  $1.9 \pm 1.0$  to  $61.7 \pm 11.9$  g N<sub>2</sub>O-N ha<sup>-1</sup> d<sup>-1</sup> for Langeweg; from  $-3.8 \pm 4.8$  to  $179.5 \pm 100.1$  g N<sub>2</sub>O-N ha<sup>-1</sup> d<sup>-1</sup> for Vredepeel (figure 8). The average coefficient of variation varied between 35 and 40%, with maximum values of up to 120% for individual measurements. The spatial variation could not be explained by differences in volumetric soil water content. However, an increase in soil water content after the application of manure into the field resulted in higher N<sub>2</sub>O emissions at both sites. Application of manure into the field resulted in higher N<sub>2</sub>O emissions at both sites (figure 8). This effect was observed in the first 2 weeks after fertilisation. Emissions decayed rapidly and lasted for no more than 1-2 weeks.

**Figure 8** Individual N<sub>2</sub>O flux and volumetric soil water content measurements at both measurement locations. M: application of mineral (N) fertilizer; O: application of organic manure/slurry; P: planting; H: harvesting.



The N<sub>2</sub>O fluxes measured at Langeweg were in the same order of magnitude as those found in the literature. Smith *et al.* (1998) measured during 1 year the N<sub>2</sub>O fluxes from the ridges and furrows of a potato field in Scotland. They found N<sub>2</sub>O fluxes < 20 g N<sub>2</sub>O-N ha<sup>-1</sup> d<sup>-1</sup> from the ridges, but up to 80 g N<sub>2</sub>O-N ha<sup>-1</sup> d<sup>-1</sup> from the furrows (after fertilizer application). Ruser *et al.* (2001) measured during 1 year the N<sub>2</sub>O fluxes from the ridges of two potato fields in Germany. They found N<sub>2</sub>O fluxes up to 120 g N<sub>2</sub>O-N ha<sup>-1</sup> d<sup>-1</sup> at one of the sites. At the other sites, fluxes up to 190 g N<sub>2</sub>O-N ha<sup>-1</sup> d<sup>-1</sup> were measured. Flessa *et al.* (2002) measured during two growing seasons the N<sub>2</sub>O fluxes from two adjacent fields planted with potatoes in Germany. N<sub>2</sub>O flux rates from the compacted furrows ranged from 0 to 264 g N<sub>2</sub>O-N ha<sup>-1</sup> d<sup>-1</sup>. From the ridges and uncompacted furrows, N<sub>2</sub>O fluxes up to 60 g N<sub>2</sub>O-N ha<sup>-1</sup> d<sup>-1</sup> were found. Dobbie and Smith (2003) measured during 1 year average N<sub>2</sub>O fluxes (from ridges and furrows in a potato field in Scotland) ranging from 0 to 30 g N<sub>2</sub>O-N ha<sup>-1</sup> d<sup>-1</sup>. Using reduced tillage in a

soil in northern Japan cultivated with potatoes, Koga *et al.* (2004) found during a period of 15 months low  $N_2O$  flux rates (always  $<5 \text{ g } N_2O\text{-N } ha^{-1} d^{-1}$ ). Thomas *et al.* (2004) measured during the growing season the  $N_2O$  fluxes from a field in New Zealand cultivated with potatoes. They found fluxes up to  $10 \text{ g } N_2O\text{-N } ha^{-1} d^{-1}$  for uncompacted furrows, up to  $50 \text{ g } N_2O\text{-N } ha^{-1} d^{-1}$  for the ridges, and up to  $100 \text{ g } N_2O\text{-N } ha^{-1} d^{-1}$  for compacted furrows.

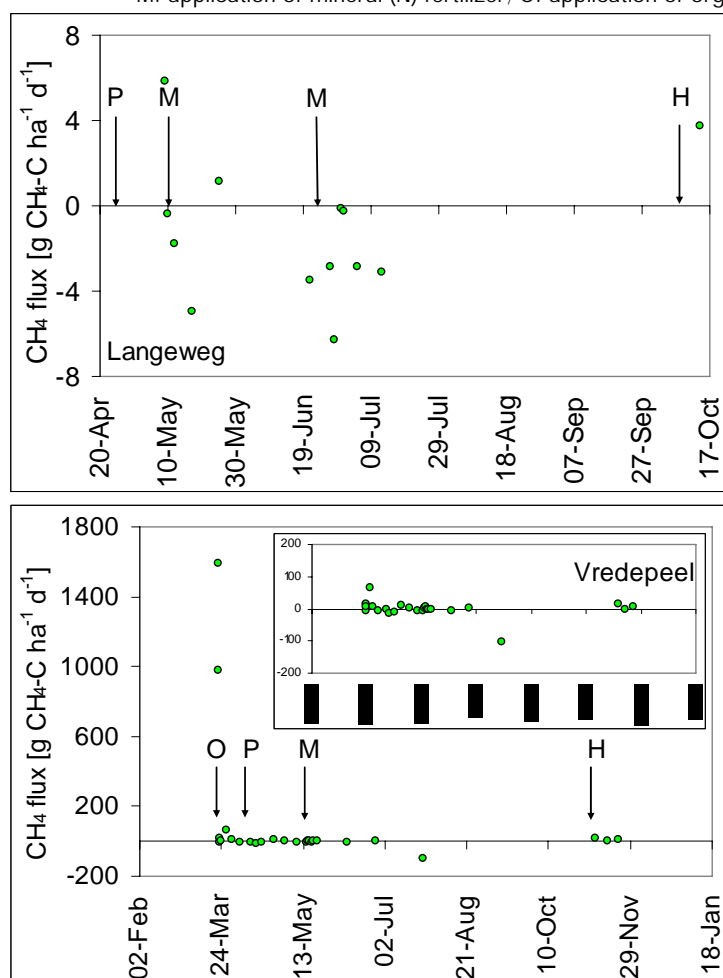
The  $N_2O$  fluxes measured at Vredepeel were large when compared with similar studies as found in the literature. Goosens *et al.* (2001) found values ranging from  $-1.6 \pm 2.9$  to  $8.8 \pm 7.3 \text{ g } N_2O\text{-N } ha^{-1} d^{-1}$  during a 1-year study on a Belgian soil cultivated with sugar beet. Kaiser *et al.* (1998) found  $N_2O$  flux rates up to  $100 \text{ g } N_2O\text{-N } ha^{-1} d^{-1}$  when measuring during 33 months the  $N_2O$  release from a German soil. Koga *et al.* (2004), on the other hand, found values up to  $280 \text{ g } N_2O\text{-N } ha^{-1} d^{-1}$  when using conventional tillage in northern Japan.

### 3.2 Methane (CH<sub>4</sub>) emissions

Variation of the  $CH_4$  flux rates with time was low for the location Langeweg. Fluxes ranged from  $-6.3 \pm 1.3$  to  $5.9 \pm 1.4 \text{ g } CH_4\text{-C } ha^{-1} d^{-1}$  (figure 9). For the location Vredepeel, on the other hand, a large variation of the  $CH_4$  flux rates with time was observed: from  $-103 \pm 103$  to  $1590 \pm 474 \text{ g } CH_4\text{-C } ha^{-1} d^{-1}$  (figure 9). These large  $CH_4$  emission values were originated from the organic manure being applied into the field, and lasted for no more than 1-2 days. The variation in  $CH_4$  flux rates when these values are not considered is then low: from  $-103 \pm 103$  to  $66 \pm 9 \text{ g } CH_4\text{-C } ha^{-1} d^{-1}$ . At both locations,  $CH_4$  fluxes showed a large within-site variation. The average coefficient of variation for the spatial variation usually ranged between 10 and 150%, although values as high as 500% were found for individual measurements. The spatial variation could not be explained by differences in volumetric soil water content. The effect of manure application on  $CH_4$  fluxes was not consistent between different sites. Fertilisation did not significantly affect  $CH_4$  emissions at the field site Langeweg.

**Figure 9** Individual  $CH_4$  flux measurements at both measurement locations.

M: application of mineral (N) fertilizer; O: application of organic manure/slurry; P: planting; H: harvesting.



The CH<sub>4</sub> fluxes measured during this study were in the same order of magnitude as those found in the literature. Flessa *et al.* (2002) measured during two growing seasons the CH<sub>4</sub> fluxes from two adjacent fields planted with potatoes in Germany. Both sites were net sinks for atmospheric CH<sub>4</sub> (uptake rates up to 14 g CH<sub>4</sub>-C ha<sup>-1</sup> d<sup>-1</sup>). Koga *et al.* (2004) found during a period of 15 months CH<sub>4</sub> flux rates ranging from -50 to 70 g CH<sub>4</sub>-C ha<sup>-1</sup> d<sup>-1</sup> in soils in northern Japan cultivated with either potatoes or sugar beet.

## 4 Conclusions

This report shows the results of a monitoring study performed to quantify the emissions of  $\text{N}_2\text{O}$  and  $\text{CH}_4$  from two different agricultural (arable) soils in the Netherlands. The selected crops were potatoes and sugar beets, due to their high cultivation area and economic value. Both sites were net sources for  $\text{N}_2\text{O}$ , with emissions ranging from  $1.9 \pm 1.0$  to  $61.7 \pm 11.9$   $\text{g N}_2\text{O-N ha}^{-1} \text{ d}^{-1}$  at the potato field (Langeweg), and from  $-3.8 \pm 4.8$  to  $179.5 \pm 100.1$   $\text{g N}_2\text{O-N ha}^{-1} \text{ d}^{-1}$  at the field planted with sugar beet (Vredepeel). High  $\text{N}_2\text{O}$  emissions were measured approximately two weeks after the application of both manure and mineral fertilizer.  $\text{N}_2\text{O}$  fluxes from the potato field were in the same order of magnitude as those found in the literature. The fluxes from the field with sugar beet were high compared to other studies found in the literature. The variation in  $\text{CH}_4$  fluxes was low at Langeweg (fluxes ranged from  $-6.3 \pm 1.3$  to  $5.9 \pm 1.4$   $\text{g CH}_4\text{-C ha}^{-1} \text{ d}^{-1}$ ) and high for the location Vredepeel (fluxes ranged from  $-103 \pm 103$  to  $1590 \pm 474$   $\text{g CH}_4\text{-C ha}^{-1} \text{ d}^{-1}$ ). These high  $\text{CH}_4$  emission values at the location Vredepeel were originated from the organic manure being applied into the field, and lasted for no more than 1-2 days. The variation in  $\text{CH}_4$  flux rates when these values are not considered is low: from  $-103 \pm 103$  to  $66 \pm 9$   $\text{g CH}_4\text{-C ha}^{-1} \text{ d}^{-1}$ . These values are in the same order of magnitude as those found in the literature. At both locations,  $\text{N}_2\text{O}$  and  $\text{CH}_4$  fluxes showed a large within-site variation. No emission factor was calculated, since the limited number of measurements performed during this study and the importance of soil and weather conditions on the fluxes of  $\text{N}_2\text{O}$  and  $\text{CH}_4$  from soils make the calculation of such an emission factor inaccurate.

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