Chapter 1
Greenhouse Gases from Agriculture

M. Zaman, K. Kleineidam, L. Bakken, J. Berendt, C. Bracken, K. Butterbach-Bahl, Z. Cai, S. X. Chang, T. Clough, K. Dawar, W. X. Ding, P. Dörsch, M. dos Reis Martins, C. Eckhardt, S. Fiedler, T. Frosch, J. Goopy, C.-M. Görres, A. Gupta, S. Henjes, M. E. G. Hofmann, M. A. Horn, M. M. R. Jahangir, A. Jansen-Willems, K. Lenhart, L. Heng, D. Lewicka-Szczebak, G. Lucic, L. Merbold, J. Mohn, L. Molstad, G. Moser, P. Murphy, A. Sanz-Cobena, M. Šimek, S. Urquiaga, R. Well, N. Wrage-Mönnig, S. Zaman, J. Zhang, and C. Müller

Abstract The rapidly changing global climate due to increased emission of anthropogenic greenhouse gases (GHGs) is leading to an increased occurrence of extreme weather events such as droughts, floods, and heatwaves. The three major GHGs are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The major natural sources of CO_2 include ocean–atmosphere exchange, respiration of animals, soils

M. Zaman (✉) · L. Heng
Soil and Water Management & Crop Nutrition (SWMCN) Section, Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, International Atomic Energy Agency (IAEA), Vienna, Austria
e-mail: m.zaman@iaea.org; zamanm_99@yahoo.com

K. Kleineidam · C. Eckhardt · A. Jansen-Willems · G. Moser · C. Müller
Institute of Plant Ecology, Justus Liebig University Giessen, Giessen, Germany

L. Bakken
Norwegian University of Life Sciences (NMBU), Aas, Norway

J. Berendt · S. Fiedler · N. Wrage-Mönnig
University of Rostock, Rostock, Germany

C. Bracken
School of Agriculture and Food Science and Earth Institute, University College Dublin, Dublin, Ireland

K. Butterbach-Bahl
Institute of Meteorology and Climate Research, Atmospheric Environmental Research (IMK-IFU), Karlsruhe Institute of Technology, Karlsruhe, Germany

Z. Cai
School of Geography Sciences, Nanjing Normal University, Jiangsu, China

S. X. Chang
Department of Renewable Resources, University of Alberta, Edmonton, AB T6G 2E3, Canada

T. Clough
Department of Soil & Physical Sciences, Faculty of Agriculture & Life Sciences, Lincoln University, Lincoln, New Zealand

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(microbial respiration) and plants, and volcanic eruption; while the anthropogenic sources include burning of fossil fuel (coal, natural gas, and oil), deforestation, and the cultivation of land that increases the decomposition of soil organic matter and crop and animal residues. Natural sources of CH_4 emission include wetlands, termite activities, and oceans. Paddy fields used for rice production, livestock production systems (enteric emission from ruminants), landfills, and the production and use of fossil fuels are the main anthropogenic sources of CH_4. Nitrous oxide, in addition to being a major GHG, is also an ozone-depleting gas. N_2O is emitted by natural processes from oceans and terrestrial ecosystems. Anthropogenic N_2O emissions occur mostly through agricultural and other land-use activities and are associated with the intensification of agricultural and other human activities such as increased use of synthetic fertiliser (119.4 million tonnes of N worldwide in 2019), inefficient use of irrigation water, deposition of animal excreta (urine and dung) from grazing animals, excessive and inefficient application of farm effluents and animal manure to croplands and pastures, and management practices that enhance soil organic N mineralisation and C decomposition. Agriculture could act as a source and a sink of GHGs. Besides direct sources, GHGs also come from various indirect sources, including upstream and downstream emissions in agricultural systems and ammonia (NH_3) deposition from fertiliser and animal manure.

K. Dawar
Department of Soil and environmental Sciences, University of Agriculture, Peshawar, Pakistan

W. X. Ding
Institute of Soil Science, Chinese Academy of Sciences, Nanjing, China

P. Dörsch · L. Molstad
Faculty of Environmental Sciences and Natural Resource Management,
Norwegian University of Life Sciences (NMBU), Aas, Norway

T. Frosch
Leibniz Institute of Photonic Technology, Technical University
Darmstadt, Darmstadt, Germany

J. Goopy
International Livestock Research Institute (ILRI), Nairobi, Kenya

C.-M. Görres
Department of Soil Science and Plant Nutrition/Department of Applied Ecology, Hochschule
Geisenheim University, Geisenheim, Germany

A. Gupta
Independent Consultant India, Mumbai, India

S. Henjes · M. A. Horn
Institute of Microbiology, Leibniz University Hannover, Hannover, Germany

M. E. G. Hofmann
Picarro B.V., ‘s-Hertogenbosch, The Netherlands

M. M. R. Jahangir
Department of Soil Science, Bangladesh Agricultural University, Mymensingh, Bangladesh

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1.1 Introduction

The global climate is changing rapidly. This leads to the increasing occurrence of extreme weather events such as droughts and floods. The major cause of these events is the rising temperature in the Earth's atmosphere, which is driven by increasing emissions of climate-relevant greenhouse gases (GHGs) that trap heat in the atmosphere. Major GHGs include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) (Fig. 1.1).

Carbon dioxide is the major GHG responsible for the increasing greenhouse effect of the atmosphere. Key natural sources of CO_2 include ocean–atmosphere exchange, respiration of animals, soils (microbial respiration) and plants, and volcanic eruption. Major anthropogenic sources of CO_2 include burning of fossil fuel (coal, natural gas, and oil), deforestation, and the cultivation of land that increases the decomposition of soil organic matter and crop and animal residues (Xu and Shang 2016).

Aside from CO_2, CH_4 is a major GHG, which is emitted by natural and anthropogenic processes. Natural sources of CH_4 emission include wetlands, termite activities, and occan. Paddy fields used for rice production, livestock production systems

J. Zhang
School of Geography, Nanjing Normal University, Nanjing, China

K. Lenhart
Bingen University of Applied Sciences, Berlinstr. 109, Bingen 55411, Germany

D. Lewicka-Szczebak
Laboratory of Isotope Geology and Geoecology, Institute of Geological Sciences, University of Wrocław, Wrocław, Poland

G. Lucic
Picarro Inc., Santa Clara, CA, USA

L. Merbold
Mazingira Centre, International Livestock Research Institute (ILRI), Nairobi, Kenya

J. Mohn
Laboratory for Air Pollution & Environmental Technology, Empa Dübendorf, Dübendorf, Switzerland

P. Murphy
Environment & Sustainable Resource Management Section, School of Agriculture & Food Science, and UCD Earth Institute, University College, Dublin, Ireland

A. Sanz-Cobena
Research Center for the Management of Environmental and Agricultural Risks (CEIGRAM), ETSIAAB, Universidad Politécnica de Madrid, Madrid, Spain

M. Šimek
Institute of Soil Biology, Biology Centre of the Czech Academy of Sciences, and Faculty of Science, University of South Bohemia, České Budějovice, Czech Republic

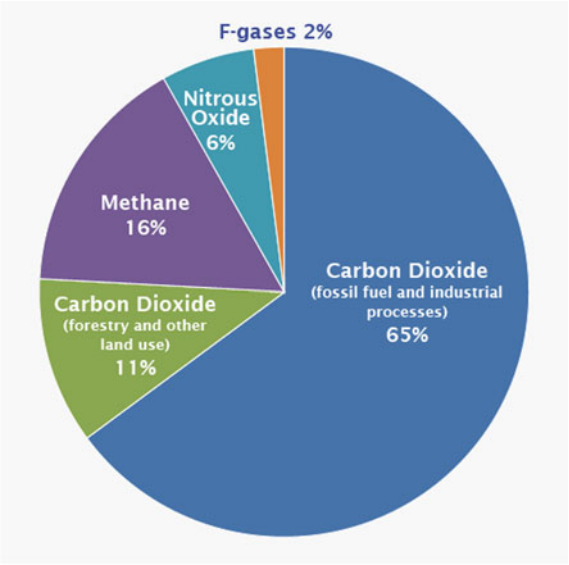

Fig. 1.1 Major greenhouse gas emissions and contributions by various sectors (IPCC 2014a, b)

(enteric emission from ruminants), landfills, and production and use of fossil fuels are the main anthropogenic sources of CH_4. Furthermore, CH_4 can be produced by anaerobic mineralization by methanogenic archaea in both natural and man-made systems. Also, plants have been shown to emit CH_4.

The third major GHG is N_2O (Zaman et al. 2012). Besides being a major GHG, N_2O is a major ozone-depleting gas (Ravishankara et al. 2009). Oceans and soils under natural vegetation are non-anthropogenic sources of N_2O. However, at a global scale, the emission of N_2O is mostly caused by, or related to, anthropogenic agricultural and other land-use activities. The atmospheric concentration of N_2O has increased by more than 20% from ~271 ppb to 331 ppb since the industrial era (ca. 1750) to 2018 (WMO 2019). Over the last decade, the rate of N_2O increase was equal to 0.95 ppb yr^{-1} (IPCC 2013b; WMO 2019) with an increasing trend (Makowski 2019; Thompson et al. 2019). In 2006, the total anthropogenic source of N_2O was 6.9 Tg N_2O-N. Out of these direct emissions, agricultural sources dominated (4.1 Tg N_2O-N), while indirect emissions accounted for 0.6 (with a range of 0.1–2.9) Tg N_2O-N (IPCC 2013a). Such a large N_2O emission is attributed to various factors including the intensification of agricultural and other human activities, increased use of synthetic fertiliser (119.4 million tonnes of N worldwide in 2019), inefficient

M. dos Reis Martins · S. Urquiaga
EMBRAPA Agrobiologia Seropédica, Brazilian Agricultural Research Corporation, Seropedica, RJ, Brazil

R. Well
Thünen Institute of Climate-Smart Agriculture, Braunschweig, Germany
S. Zaman
University of Canterbury, Christchurch, New Zealand

use of irrigation water, deposition of animal excreta (urine and dung) from grazing animals, excessive and inefficient application of farm effluents and animal manure to croplands and pastures, and management practices that enhance soil organic N mineralisation and C decomposition. These activities affect the N cycle. The N cycle is rather complex, and it has even been disrupted due to increased N inputs and intensification of agriculture. Sources of increased N inputs, in particular reactive N, into the N cycle stem, for instance, from the Haber–Bosch process (Erisman et al. 2011), thereby transforming the N cycle into the so-called N cascade, which is characterised by the release of reactive N forms into the environment with various consequences (Sutton et al. 2011). There are still many uncertainties concerning the N cycle. For example, the role of individual factors controlling the occurrence and rate of the key N transformation processes, such as denitrification and nitrification, is uncertain (Butterbach-Bahl et al. 2013; Müller and Clough 2014; Smith 2017). Nitrification results in ammonium (NH_4^+) being converted to nitrate (NO_3^-) under aerobic conditions, while denitrification is the reduction of NO_3^- to N_2 under anaerobic conditions. Nitrifier denitrification occupies the niche between nitrification and denitrification and occurs as oxygen concentrations approach an anaerobic status. Under these conditions, nitrifiers actually convert nitrite into N_2O and N_2 instead of nitrate (Wrage-Mönnig et al. 2018).

The three GHGs (CO_2, CH_4, and N_2O), derived from various sectors, play a major role in regulating Earth's temperature (Fig. 1.1). Without GHGs in the atmosphere, the average global soil surface temperature would be ~19 °C, compared to the present values of 14 °C (Hossain 2019).

Recent data from the UN Intergovernmental Panel on Climate Change (IPCC) clearly show that anthropogenic emissions of GHGs are at the highest in history (IPCC 2014a). Since 1990, Earth's average surface air temperature has increased by about 0.8 °C, with much of the emission increases taking place since the mid-1970s (Fig. 1.2).

The global warming potential (GWP) of a GHG relates to the amount of heat trapped by a certain mass of a gas to the amount of heat trapped by a similar mass of CO_2 calculated over a 100-year time horizon (IPCC 2016). For example, the GWP of N_2O is 265–298, which means if the same masses of N_2O and CO_2 were emitted into the atmosphere, N_2O would trap 265–298 times more heat than CO_2 over a 100-year time period (Table 1.1) (IPCC 2016).

The Kyoto Protocol was negotiated by parties to the United Nations Framework Convention on Climate Change (UNFCCC) in an effort to stabilise the continued increase in atmospheric GHG concentrations. The Kyoto protocol outlines GHG reduction targets for participating countries. The signatories to the protocol must develop and report on their annual national inventory of anthropogenic GHG emissions. Guidelines on how to construct inventories were prescribed by the IPCC (2014b). Country-specific emission data can be considered but that requires accurate inventory data based on precise GHG measurements.

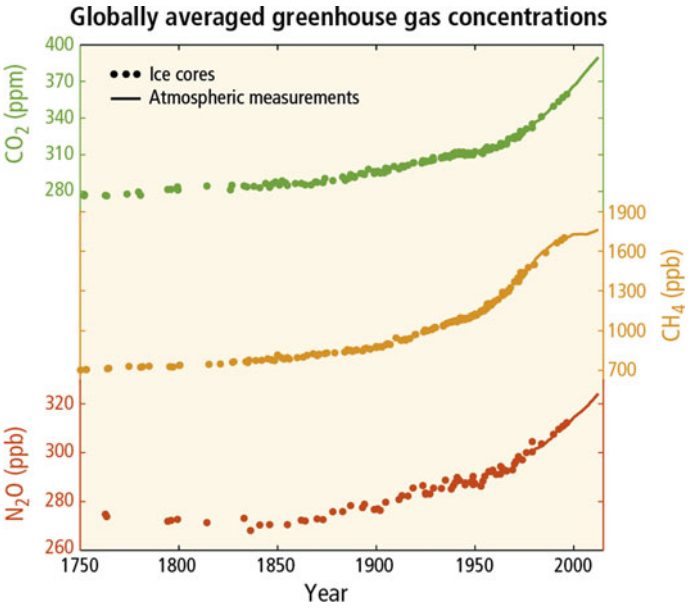

Fig. 1.2 Recent anthropogenic emissions of GHGs (IPCC 2014a; WMO 2019)

Table 1.1 Global warming potential (GWP) and atmospheric lifespan of various GHGs (IPCC 2016)

Greenhouse gas	Chemical formula	Global warming potential (GWP) for a 100-year time horizon	Lifespan (years)
Nitrous oxide	N_2O	265–310	114
Methane	CH_4	21–28	12
Carbon dioxide	CO_2	1	Variable
Water vapour	H_2O	n/a	Variable
Ozone	O_3	n/a	Hours to days

1.2 Impact of Ammonia on GHG Emissions

Besides direct sources, GHGs also come from different indirect sources such as upstream and downstream in agricultural systems (Plate 1.1).

Ammonia (NH_3) itself has no direct greenhouse effect. It is a gas with a relatively short residence time in the atmosphere (2–10 days) compared to some GHGs, such as CO_2 (3–4 years), CH_4 (12 years), and N_2O (114 years). However, after NH_3 is emitted to the atmosphere and reacts with acids, it forms salts. These salts then return to The Earth's surface and act as a N source source for N_2O emissions, similar to a fertiliser-N application. When the soil is submitted to conditions near the optimum for

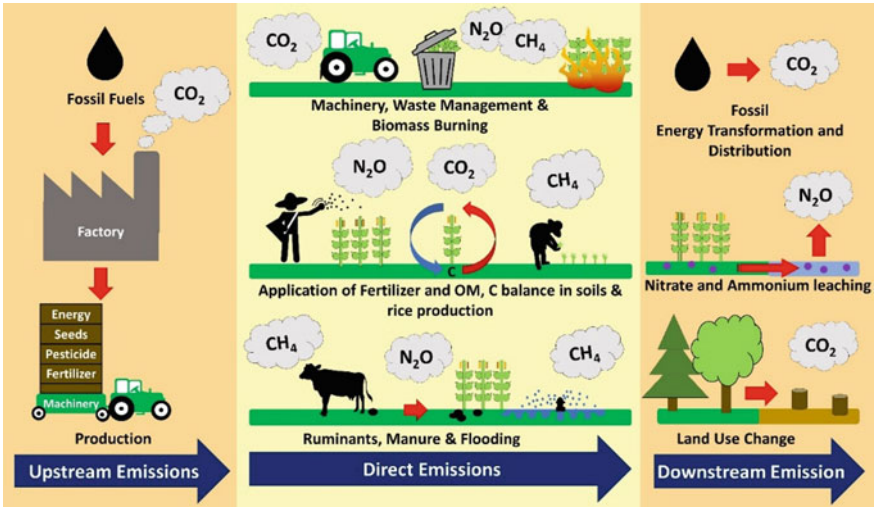

Plate 1.1 Schematic representation of direct (from the cropping system) and indirect (upstream and downstream) GHG emissions from crop production. As an example, ammonia emitted from a cropping system will be deposited and potentially oxidised to nitrate, which can further be denitrified, thus enhancing the risk for N_2O emission (Aguilera Fernández 2016)

urease activity (e.g. pH close to neutrality, soil moisture near field capacity, temperature >30 °C), the N losses through NH_3 volatilisation from urea-based fertilisers applied on soil surface can be as high as 50% (Martins et al. 2017; Rochette et al. 2013). Therefore, the measurement of NH_3 emission is important to estimate indirect N_2O emissions derived from soil amendments, such as urea-based fertilisers, green manures, animal excreta, or ammonium-based fertilisers in alkaline soils. A default emission factor defined by IPCC, known as EF_4, can be applied for the estimation of indirect N_2O emissions derived from volatilisation of NH_3 and other nitrogen oxides (NO_x) (IPCC 2006). The mean value of EF_4, considering the N volatilisation and consequent re-deposition, is 0.01 kg N_2O-N per kg N volatilised as NH_3 with an uncertainty ranging from 0.002 to 0.05 (IPCC 2006). Therefore, management options that reduce NH_3 volatilisation from soils are considered mitigation practices because they reduce indirect N_2O emissions (IPCC 2014a; Lam et al. 2017).

1.3 Aim of the Book

In 1992, the International Atomic Energy Agency (IAEA) published a "Manual on measurement of CH_4 and N_2O emissions from agriculture" (IAEA 1992). Since the publication of the manual, progress has been made in analytical techniques. The progress includes advances in automation technologies as well as the theoretical understanding of how soil microbial processes affect CH_4 and N_2O emissions and the factors influencing those microbial processes.

Hence, the aim of this book is to provide an updated account of the state-of-the-art techniques to measure direct GHG emissions (Plate 1.1), as a necessary step to propose and assess any mitigation strategy. The focus is on CH_4 and N_2O emissions. Additionally, information on techniques to measure indirect GHG sources is provided. Indirect GHG sources in this book include volatilised ammonia (NH_3). NH_3 is a reactive N gas highly affecting the environment through eutrophication and acidification of natural ecosystems as well as human health due to the promotion of particulate matter formation (Sanz Cobena et al. 2014). Moreover, in line with the 1992 IAEA Tecdoc document, the hands-on approach is also followed here so that researchers, who want to use the techniques described in this book, can easily apply them to their own work.

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