IAEA-TECDOC-1823

IAEA TECDOC SERIES

IAEA-TECDOC-1823

Use of Carbon Isotopic Tracers in Investigating Soil Carbon Sequestration and Stabilization in Agroecosystems

IAEA

Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

IAEA
International Atomic Energy Agency

International Atomic Energy Agency
Vienna

IAEA-TECDOC-1823

USE OF CARBON ISOTOPIC TRACERS IN INVESTIGATING SOIL CARBON SEQUESTRATION AND STABILIZATION IN AGROECOSYSTEMS

PREPARED BY THE
JOINT FAO/IAEA DIVISION OF NUCLEAR TECHNIQUES IN FOOD AND AGRICULTURE

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2017

COPYRIGHT NOTICE

All IAEA scientific and technical publications are protected by the terms of the Universal Copyright Convention as adopted in 1952 (Berne) and as revised in 1972 (Paris). The copyright has since been extended by the World Intellectual Property Organization (Geneva) to include electronic and virtual intellectual property. Permission to use whole or parts of texts contained in IAEA publications in printed or electronic form must be obtained and is usually subject to royalty agreements. Proposals for non-commercial reproductions and translations are welcomed and considered on a case-by-case basis. Enquiries should be addressed to the IAEA Publishing Section at:

Marketing and Sales Unit, Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
fax: +43 1 2600 29302
tel.: +43 1 2600 22417
email: sales.publications@iaea.org
http://www.iaea.org/books

For further information on this publication, please contact:

Soil and Water Management and Crop Nutrition Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
Email: Official.Mail@iaea.org

© IAEA, 2017

Printed by the IAEA in Austria
September 2017

IAEA Library Cataloguing in Publication Data

Names: International Atomic Energy Agency.
Title: Use of carbon isotopic tracers in investigating soil carbon sequestration and stabilization in agroecosystems / International Atomic Energy Agency.
Description: Vienna : International Atomic Energy Agency, 2017. | Series: IAEA TECDOC series, ISSN 1011–4289 ; no. 1823 | Includes bibliographical references.
Identifiers: IAEAL 17-01110 | ISBN 978–92–0–106417–2 (paperback : alk. paper)
Subjects: LCSH: Stable isotope tracers. | Soils — Carbon content — Analysis. | Carbon sequestration.

此为试读，需要完整PDF请访问：www.ertongbook.com

USE OF CARBON ISOTOPIC TRACERS IN INVESTIGATING SOIL CARBON SEQUESTRATION AND STABILIZATION IN AGROECOSYSTEMS

The following States are Members of the International Atomic Energy Agency:

AFGHANISTAN
ALBANIA
ALGERIA
ANGOLA
ANTIGUA AND BARBUDA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
AZERBAIJAN
BAHAMAS
BAHRAIN
BANGLADESH
BARBADOS
BELARUS
BELGIUM
BELIZE
BENIN
BOLIVIA, PLURINATIONAL STATE OF
BOSNIA AND HERZEGOVINA
BOTSWANA
BRAZIL
BRUNEI DARUSSALAM
BULGARIA
BURKINA FASO
BURUNDI
CAMBODIA
CAMEROON
CANADA
CENTRAL AFRICAN REPUBLIC
CHAD
CHILE
CHINA
COLOMBIA
CONGO
COSTA RICA
CÔTE D'IVOIRE
CROATIA
CUBA
CYPRUS
CZECH REPUBLIC
DEMOCRATIC REPUBLIC OF THE CONGO
DENMARK
DJIBOUTI
DOMINICA
DOMINICAN REPUBLIC
ECUADOR
EGYPT
EL SALVADOR
ERITREA
ESTONIA
ETHIOPIA
FIJI
FINLAND
FRANCE
GABON
GEORGIA
GERMANY
GHANA
GREECE
GUATEMALA
GUYANA
HAITI
HOLY SEE
HONDURAS
HUNGARY
ICELAND
INDIA
INDONESIA
IRAN, ISLAMIC REPUBLIC OF
IRAQ
IRELAND
ISRAEL
ITALY
JAMAICA
JAPAN
JORDAN
KAZAKHSTAN
KENYA
KOREA, REPUBLIC OF
KUWAIT
KYRGYZSTAN
LAO PEOPLE'S DEMOCRATIC REPUBLIC
LATVIA
LEBANON
LESOTHO
LIBERIA
LIBYA
LIECHTENSTEIN
LITHUANIA
LUXEMBOURG
MADAGASCAR
MALAWI
MALAYSIA
MALI
MALTA
MARSHALL ISLANDS
MAURITANIA
MAURITIUS
MEXICO
MONACO
MONGOLIA
MONTENEGRO
MOROCCO
MOZAMBIQUE
MYANMAR
NAMIBIA
NEPAL
NETHERLANDS
NEW ZEALAND
NICARAGUA
NIGER
NIGERIA
NORWAY
OMAN
PAKISTAN
PALAU
PANAMA
PAPUA NEW GUINEA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
QATAR
REPUBLIC OF MOLDOVA
ROMANIA
RUSSIAN FEDERATION
RWANDA
SAN MARINO
SAUDI ARABIA
SENEGAL
SERBIA
SEYCHELLES
SIERRA LEONE
SINGAPORE
SLOVAKIA
SLOVENIA
SOUTH AFRICA
SPAIN
SRI LANKA
SUDAN
SWAZILAND
SWEDEN
SWITZERLAND
SYRIAN ARAB REPUBLIC
TAJIKISTAN
THAILAND
THE FORMER YUGOSLAV REPUBLIC OF MACEDONIA
TOGO
TRINIDAD AND TOBAGO
TUNISIA
TURKEY
TURKMENISTAN
UGANDA
UKRAINE
UNITED ARAB EMIRATES
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
UNITED REPUBLIC OF TANZANIA
UNITED STATES OF AMERICA
URUGUAY
UZBEKISTAN
VANUATU
VENEZUELA, BOLIVARIAN REPUBLIC OF
VIET NAM
YEMEN
ZAMBIA
ZIMBABWE

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

FOREWORD

Soil carbon is an important component of soil that affects its physical, chemical and biological properties. Physically, soil organic carbon (SOC) improves aggregation, resulting in a better soil structure that facilitates the movement of air and water through the soil and improves root growth. Chemically, SOC facilitates nutrient availability. Biologically, SOC is the source of carbon energy for many of the soil microorganisms that drive microbial transformations in soils and is essential to enhancing soil biodiversity. Soil organic matter (SOM) acts as a major sink and source of soil carbon. Accordingly, soils and SOM currently receive considerable attention in terms of the role they can play in mitigating the effects of elevated atmospheric carbon dioxide and associated climate change impacts.

Protecting soil carbon stocks and understanding the process of soil carbon sequestration and carbon fluxes in soil are integral to efforts to manage the global carbon balance. This is because many of the factors affecting the flow of carbon into and out of soils are directly affected by land management practices. Thus, appropriate management of SOC and SOM using a combination of soil conservation and best soil management practices provides a means of enhancing the capture and long term storage of atmospheric carbon dioxide, known as carbon sequestration, and thus sustaining or increasing SOM and crop production levels, and improving environmental quality.

This publication provides an overview of conventional and isotopic methods available for measuring and modelling soil carbon dynamics. It includes information on the use of carbon isotopes in soil and plant research, including both theoretical and practical aspects of nuclear and radioisotope tracer techniques for in situ glasshouse and field labelling techniques to assess SOM turnover and sequestration, and provides up-to-date information on topics related to soil carbon sequestration and stabilization in agroecosystems. With its focus on practical application of radiotracer and stable isotope tracer techniques, it will be particularly useful for university and national research scientists working to improve soil organic matter management and conservation in agricultural systems.

The IAEA and the Food and Agriculture Organization of the United Nations (FAO) wish to thank all the contributors involved in the preparation of this publication. The IAEA officers responsible for this publication were J.J. Adu-Gyamfi and L.K. Heng of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture.

EDITORIAL NOTE

This publication has been prepared from the original material as submitted by the contributors and has not been edited by the editorial staff of the IAEA. The views expressed remain the responsibility of the contributors and do not necessarily represent the views of the IAEA or its Member States.

Neither the IAEA nor its Member States assume any responsibility for consequences which may arise from the use of this publication. This publication does not address questions of responsibility, legal or otherwise, for acts or omissions on the part of any person.

The use of particular designations of countries or territories does not imply any judgement by the publisher, the IAEA, as to the legal status of such countries or territories, of their authorities and institutions or of the delimitation of their boundaries.

The mention of names of specific companies or products (whether or not indicated as registered) does not imply any intention to infringe proprietary rights, nor should it be construed as an endorsement or recommendation on the part of the IAEA.

The IAEA has no responsibility for the persistence or accuracy of URLs for external or third party Internet web sites referred to in this publication and does not guarantee that any content on such web sites is, or will remain, accurate or appropriate.

CONTENTS

SUMMARY 1

Overview of soil carbon sequestration and its importance 2

J.J. Adu-Gyamfi, G.M. Goh, M-L. Nguyen

Processes, factors and strategies for controlling soil carbon sequestration 8

G.M. Goh, J.J. Adu-Gyamfi, M-L. Nguyen

Assessment of soil carbon sequestration and decomposition of organic residues using different carbon isotopes 45

J.J. Adu-Gyamfi, G.M. Goh

Carbon isotope-labelling procedures: Techniques and safety issues 66

J.J. Adu-Gyamfi, F. Zapata

APPENDIX 73

IAEA PUBLICATIONS ON SOIL AND WATER MANAGEMENT AND CROP NUTRITION 106

ABBREVIATIONS AND ACRONYMS 108

CONTRIBUTORS TO DRAFTING AND REVIEW 109

此为试读,需要完整PDF请访问: www.ertongbook.com

SUMMARY

The global surface temperatures have been reported to increase at an average rate of 0.06oC (0.11oF) per decade. This observed climate change known as the greenhouse effect is attributed to the emission of greenhouse gases (GHGs), including carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O) to the atmosphere, resulting in helping to trap the heat near the earth's surface causing global warming. World soils are the largest reservoir of terrestrial carbon including soil organic carbon (SOC) and inorganic carbon and that soils are a source or sink of GHGs depending on land use management.

Recognizing the urgent need to address the soil organic matter constraints for a sustainable intensification of agricultural production in developing regions of the world to ensure food security of the ever growing population, the Soil and Water Management and Crop Nutrition Section of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture decided to produce this publication "Use of carbon isotopic tracers in investigating soil carbon sequestration and stabilization in agroecosystems" as a training and reference document for environmentalists, agronomists, crop and soil scientists, and other end-users in developing Member States.

This publication comprises four papers. The first paper is a short review of soil carbon sequestration and its importance in agricultural systems and the environment, and as a potential for mitigation of climate change. This paper discusses the management of organic carbon, the capturing and storing of C in plant biomass and soils (carbon farming) in the agricultural and forestry sectors as potential strategy in enhancing soil productivity. Lastly, the initiative under the French Government, to help increase soil organic carbon pool by 0.4% per year, commonly referred to as '4 per mille' is discussed.

The second paper discusses the process and mechanisms controlling and enhancing soil carbon sequestration in fields and wetlands. Some important mitigation options for carbon sequestration are also discussed.

The third paper describes the different measurement methods for assessment of soil carbon sequestration and organic residues using different carbon isotopes. Detailed experimental procedures, measurements, calculations and data interpretation related to the use of ^{13}C natural abundance techniques, ^{14}C dating, and 'Artificial' radiocarbon (the release of artificial radiocarbon to the atmosphere as a result of nuclear weapons testing) techniques are discussed.

In the fourth paper, the use of C isotope tracer techniques and procedures for the production of labelled plant materials, continuous pulse labelling (^{13}C, ^{14}C) and equipment used has been described. The paper also provides an insight into radiation protection and safety issues in handling carbon radioisotopes. The measurement of the activities of C radioisotopes using liquid scintillation counters/analysers is briefly covered.

Six case studies are presented in the Appendix. Two illustrates the use of ^{14}C to measure carbon turnover, two are on the use of ^{13}C to determine soil carbon sequestration; one is on field measurement of plant ^{13}C uptake and distribution, and the last two demonstrate the use of ^{14}C dating and thermonuclear techniques.

OVERVIEW OF SOIL CARBON SEQUESTRATION AND ITS IMPORTANCE

J.J. ADU-GYAMFI
Soil and Water Management and Crop Nutrition Section
Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture
International Atomic Energy Agency, Vienna, Austria

K.M. GOH
Soil and Physical Sciences Group, Agriculture and Life Sciences Division
Lincoln University
Canterbury, New Zealand

M-L. NGUYEN
Group One Consultancy Limited, Optimizing Nutrient Efficiency
St Heliers
Auckland 1740, New Zealand

Abstract

Soil carbon is probably the most import component in soils as it affects their physical, chemical and biological properties. Protecting soil carbon stocks and the process of soil carbon sequestration, or flux of carbon into the soil, have become integral parts in managing the global carbon balance. Thus, recognition of the vital role played by the soil carbon could mark an important, if subtle shift in the discussions about global warming, which has been the focus on curbing emission of fossil fuel. This is because many of the factors affecting the flow of carbon into and out of soils are affected directly by land management practices. Recently soil carbon sequestration, as a potential for mitigation of climate change, has received a considerable amount of research interest. Appropriate management of soil organic matter (SOM) using a combination of soil conservation and best soil management practices provides a means of enhancing the capture and long-term storage of atmospheric carbon dioxide (carbon sequestration), and thus sustaining and increasing SOM levels and crop production and improving environmental quality. This paper presents a short overview on carbon sequestration as a potential for mitigation of climate change. The initiative under the French Government, to help increase soil organic carbon pool by 0.4% per year, commonly referred to as '4 per mille' is discussed. Details on the processes and management practices are presented in the next paper.

1. INTRODUCTION

The global surface temperatures have been reported to increase at an average rate of 0.06°C (0.11°F) per decade [1]. This observed climate change known as the greenhouse effect is attributed to the emission of greenhouse gases (GHGs), including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) to the atmosphere, causing global warming.

World soils are the largest reservoir of terrestrial carbon including soil organic carbon (SOC) and inorganic carbon and that soils are a source or sink of GHGs depending on land use management [2]. It is reported that the largest active carbon pool is in soils, containing an estimated 1700 to 2500 Pg (1 Pg = 1 Gt =10^{15}g) of carbon, compared to 620 Pg of carbon in vegetation and 780 Pg of carbon in the atmosphere [3–4]. A review concluded that (i) long term experiments to understand feedbacks and processes of soil carbon stabilization, assess

soil carbon dynamics under different climates and land use/management scenarios, and identify policy interventions to promote the adoption of proven technologies are needed and (ii) attention should be paid to the protection and restoration of peatlands, and preservation of soils [2]. One of the strategies to manage soil organic carbon efficiently is to adopt those land use and management and practices which create positive soil ecosystem C budget [5].

Global CO_2 concentrations between October 2014 and October 2015 stand between 396.2 and 398.7 ppm (see Fig. 1 and also [6]). Concentrations of GHGs have increased by about 30% since the last two centuries [7]. Land use changes such as biomass burning, tropical deforestation and conversion of natural to agricultural ecosystems contributed about 10 to 30% of the total GHG emission since 1980 [2, 8].

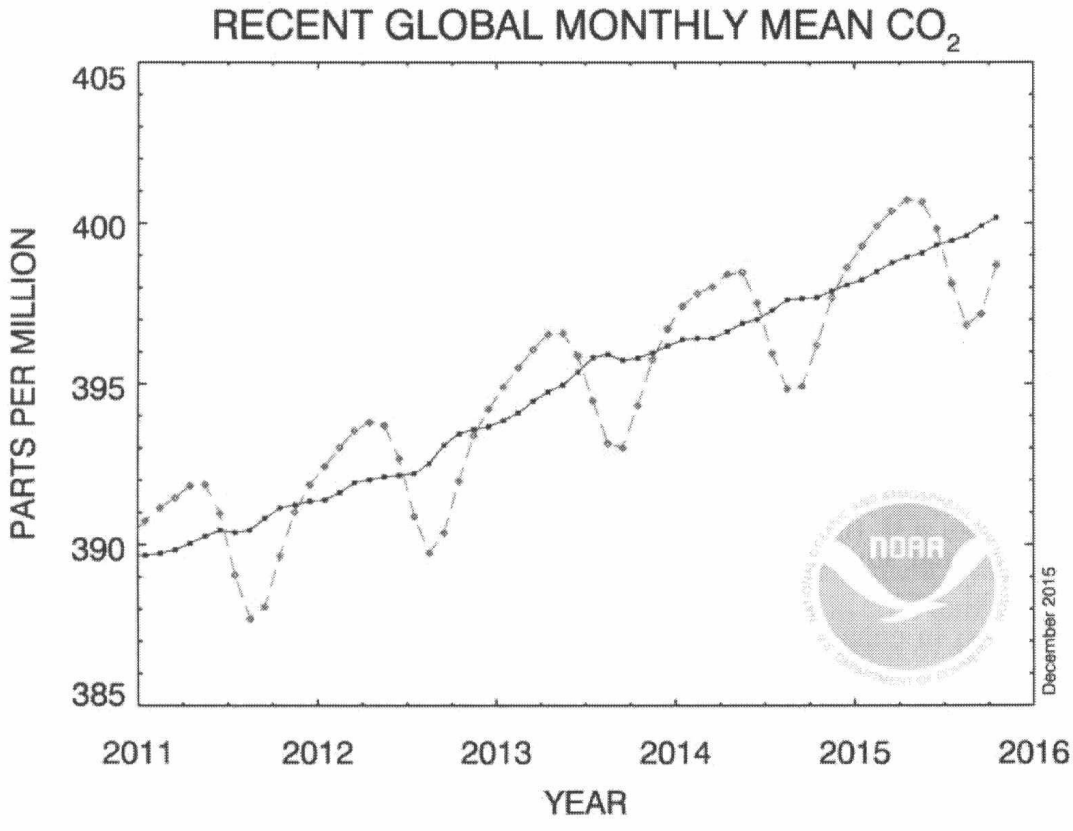

FIG. 1. Monthly mean carbon dioxide globally averaged over marine surface sites *[6]*.

2. SOIL CARBON SEQUESTRATION

The term "carbon sequestration" is used to describe both natural and deliberate processes by which CO_2 is either removed from the atmosphere or diverted from emission sources and stored in the ocean, terrestrial environments (vegetation, soils, and sediments), and geologic formations, It has been proposed as a way to slow the atmospheric and marine accumulation of greenhouse gases, which are released by burning fossil fuels [2, 9]. Data on the soil inorganic C pool (SIC) are highly variable and are estimated to be about 750–950 Pg [10]. Latest estimate from updates the global SOC mass within the top 1 m to 1325 Pg, including 421 Pg in tropical soils whereof 40 Pg occurs in tropical wetlands [11]. Global SOC

amount is just under 3000 Pg when estimates for deeper soil layers are included. Thus, a small change per unit area in the soil C pool can have important implications on the global C balance causing climate change. An increase in the soil C pool by 1 Pg will reduce the rate of CO_2 enrichment by 0.47 ppm [10].

2.1 The 4 per 1000 (quatre/mille)

This is a recent initiative under the leadership of the French Government to help increase soil organic carbon pool by 0.4% per year in the top 30 cm of soil. This proposal has been adopted globally under the auspices of UNFCC (COP–21) meeting in Paris in November– December 2015. This increase in SOC pool by 0.4% per year amounts to global SOC sequestration of (704 Pg x 0.4/100) 2.8 Pg C per year. Thus with a conversion rate of 0.47 ppm of CO_2 for 1 Pg C sequestered, the adoption of this initiative would cause atmospheric drawdown of CO_2 by 1.3 ppm per year [2, 5]. However, during a meeting of the International Year of Soils at the IAEA in Vienna on 7 December 2015, participants expressed the view that since each soil has its own properties and function, there is a need to hold regional and country meetings to explain the concept of 4 per 1000, by (i) raising awareness, (ii) doing more targeted research, (iii) promoting investments and (iv) building capacity.

2.2 Management of organic carbon

Direct sequestration of C in plants occurs when plants photosynthesize atmospheric CO_2 into plant biomass. Some of this plant biomass C is indirectly sequestered subsequently as SOM during the decomposition process. The net amount of C sequestered of a site depends on the balance between C uptake and C release. Through C sequestration, atmospheric CO_2 is reduced and SOM levels are increased.

Capturing and storing C in plant biomass and soils known as 'carbon farming' in the agricultural and forestry sectors is widely recognised not only as a potential mitigation strategy but also in enhancing soil productivity. The multiple benefits of SOM in food and fibre production are well documented [12–13]. Main benefits of SOM include acting as a source of major plant nutrients, a promoter of soil physical and chemical conditions, nutrient cycling processes and soil biota population. As shown in the long-term field experiments in Rothamsted, best yields of wheat and barley were obtained from plots receiving farmyard manure and nitrogen (N) fertilizer applications (Table 1 [14]).

TABLE 1. HIGHEST ANNUAL YIELDS (T HA^{-1}) OF WINTER WHEAT AND SPRING BARLEY IN PLOTS RECEIVING FERTILIZERS AND FARMYARD MANURE AT ROTHAMSTED, UNITED KINGDOM†.

Experiment and period	Crop	Treatment		
		NPK	FYM	FYM + N
Broadbalk	Winter wheat grown continuously in rotation			
		6.69	6.17	7.92
		8.61	7.89	9.36
Hoosefield 1988–91	Spring barley grown continuously			
		5.21	5.50	6.06

†From [14]

Soil organic matter plays a special role in the humid tropics because soils are highly weathered and strongly leached with low cation exchange capacity and low nutrient reserves [15]. Organic matter accounts for more than 80% of the cation exchange capacity and crop productivity relies mainly on the recycling of nutrients from SOM [16–17].

Thus the increase in soil C sequestration in agricultural and forest soils results in both the mitigation of climate change and enhanced soil productivity. This has been known as providing 'co-benefits' or a 'win-win' strategy [18], reversing the damage caused by agricultural land use changes and deforestation. Soils have the capacity to sequester substantial amounts of C from the atmosphere by photosynthesis [19–20], especially in degraded soils in the United States of America [20] and in the tropics [21].

Estimates of the potential for additional soil C sequestration in soils vary widely. Enhancing SOC pool in the tropics is especially difficult in soils of the tropics with perpetual high temperatures and low input of biomass carbon because of numerous competing uses of crop residue (e.g. fodder, fuel, fencing material, construction material). It is estimated that the rate of SOC sequestration with adoptions of recommended management practices (RMP) ranges from 100 kg C/ha/year in the arid tropics to 1000 kg C/ha/yr in cool temperate climates [9]. Appropriate and strategic management of SOM using a combination of soil conservation and best soil management practices provides a means of enhancing soil C sequestration and thus sustaining and increasing SOM levels and crop production and improving environmental quality [18, 22–23]. According to FAO better farming practices could help agriculture to bury about 10% of the atmospheric C from emissions caused by human activity over the next 25 years [18].

In order to apply the Kyoto Protocol, it is essential to determine the extent and the magnitude of soil C sequestration in different regions of the world and also to be able to verify the precision of these measurements. The use of different isotopic tracer techniques to assess the decomposition rates of organic residues in soils and soil C sequestration are also presented in the other papers.

REFERENCES

[1] National Climatic Data Center (NOAA), National Center For Environment Information (NCEI), State Of The Climate Global Analysis for October 2015, published online November 2015 retrieved on December 18, 2015 from http://www.ncdc.goc/sotc/global/201510 (2015).

[2] LAL, R., Soil carbon management and climate change, Carbon management **4** (2014) 439–462.

[3] LAL, R., Managing soils and ecosystems for mitigating anthropogenic carbon emission and advancing global food security, Biosciences **60** (2014) 708–721.

[4] RICE, C. W., Soils and Climate Change. In: Task Force: Soil Matters-Solutions under foot Ed. S Nortcliff, IUSS, Catena Verlag, GeoEcology Essays (2015) 61–64.

[5] LAL, R., Soil Carbon and diversity. In Task Force: Soil Matters-Solutions under foot Ed. S Nortcliff, IUSS, Catena Verlag, GeoEcology Essays (2015) 64–69.

[6] NATIONAL CLIMATIC DATA CENTER (NOAA)., EARTH SYSTEM RESEARCH LABORATORY (ESRL) Trends in Atmospheric Carbon Dioxide. In Ed E. Dlugokencky and Pieter Tans, NOAA/ESRL (www.esrl.noaa.gov/gmd/ccgg/trends/) (2015).

[7] INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC) The Third Governmental Panel on Climate Change Assessment Report, 2001. Climate Change 2001: Impacts, Adaptations and Vulnerability. Report of Working Group II (available at www.usgcrp.gov/ipcc/default.html (2001).

[8] JANZEN, H.H., Review: Carbon cycling in earth systems – a soil science perspective, Agric. Ecosyst. Environ. **104** (2004) 399–417.

[9] LAL, R., Review. Soil carbon sequestration to mitigate climate change, Geoderma **123** (2004) 1–22.

[10] LAL, R., Why carbon sequestration in agricultural soils. In: "Agricultural Practices and Policies for Carbon Sequestration in Soil", Ed. J.M. Kimble, R. Lal, and R.E. Follett. CRC Press, Boca Raton, Florida (2002a) 21–29.

[11] KOCHI, M., HIEDERER, R., FREIBAUER, A., Global distribution of soil organic carbon-Part 1: Masses and frequency distributions of SOC stocks for the tropics, permafrost regions, wetlands and the world, Soil 1 (2015) 351–365.

[12] WALLACE, A., Soil organic matter is essential to solving soil and environmental problems. Communications Soil Science Plant Analysis **25** (1994) 15–28.

[13] GREENLAND, D.J., Soil Science and sustainable land management. In: "Soil Science and Sustainable Management in the Tropics", Ed. J.K. Syers and D.L. Rimmer. CAB International, Wallingford (1994) 1–5.

[14] JOHNSTON, A.E., Significance of organic matter in agricultural soils. In: "Organic Substances in Soil and Water: Natural Constituents and their Influences on Contaminant Behaviour", Ed. A.J. Beck, K.C. Jones, M.H.B. Hayes and U. Mingelgrin. The Royal Society of Chemistry, Cambridge (1993) 3–18.

[15] GOH, K.M., Managing soil organic matter in sustainable land management. In: "Sustainable Land Management: Paradigms for the New Millennium", Ed. J. Shamshuddin, J. Hamdan and A.W. Samsur. The Malaysian Society of Soil Science, UPM Serdang, Malaysia (2002) 301–322.

[16] ADETUNJI, M.T., Organic residue management, soil nutrient changes and maize yield in a humid Ultisol, Nutri. Cycl. Agroecosyst. **47** (1997). 189–195.

此为试读，需要完整PDF请访问：www.ertongbook.com