

ADVANCES IN SOIL SCIENCE



THE SOIL—HUMAN HEALTH NEXUS

Edited by

Rattan Lal



CRC Press
Taylor & Francis Group

The Soil–Human Health Nexus

Advances in Soil Science

Series Editor:

Rattan Lal

Assessment Methods for Soil Carbon

R. Lal, J. M. Kimble, and R. F. Follett

Soil Erosion and Carbon Dynamics

E.J. Roose, R. Lal, C. Feller, and B. Barthès

Soil Quality and Biofuel Production

Rattan Lal and B.A. Stewart

World Soil Resources and Food Security

Rattan Lal and B.A. Stewart

Soil Water and Agronomic Productivity

Rattan Lal and B.A. Stewart

Principles of Sustainable Soil Management in Agroecosystems

Rattan Lal and B.A. Stewart

Soil Management of Smallholder Agriculture

Rattan Lal and B.A. Stewart

Soil-Specific Farming: Precision Agriculture

Rattan Lal and B.A. Stewart

Soil Phosphorus

Rattan Lal and B.A. Stewart

Urban Soils

Rattan Lal and B.A. Stewart

Soil Nitrogen Uses and Environmental Impacts

Rattan Lal and B.A. Stewart

Soil and Climate

Rattan Lal

Food Security and Soil Quality

R. Lal

Soil Degradation and Restoration in Africa

Rattan Lal and B.A. Stewart

Soil and Fertilizers: Managing the Environmental Footprint

Rattan Lal

The Soil–Human Health Nexus

Rattan Lal

The Soil–Human Health Nexus

Edited by

Rattan Lal, Ph.D.

Distinguished University Professor of Soil Science, and
Director, Carbon Management and Sequestration Center,
The Ohio State University
Columbus, USA



CRC Press

Taylor & Francis Group

Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

First edition published 2021

by CRC Press

6000 Broken Sound Parkway NW, Suite 300, Boca Raton, FL 33487-2742

and by CRC Press

2 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN

© 2021 Taylor & Francis Group, LLC

CRC Press is an imprint of Taylor & Francis Group, LLC

Reasonable efforts have been made to publish reliable data and information, but the author and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The authors and publishers have attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint.

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, access www.copyright.com or contact the Copyright Clearance Center, Inc. (CCC), 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. For works that are not available on CCC please contact mpkbookspermissions@tandf.co.uk

Trademark notice: Product or corporate names may be trademarks or registered trademarks and are used only for identification and explanation without intent to infringe.

Library of Congress Cataloging-in-Publication Data

Names: Lal, R., editor.

Title: The soil-human health-nexus / Rattan Lal.

Other titles: Advances in soil science (Boca Raton, Fla.)

Description: First edition. | Boca Raton, FL : CRC Press, 2020. |

Series: Advances in soil science series | Includes bibliographical references

and index. | Summary: "This volume discusses the relation between soil

health and human health in relation to plant, animal, and human nutrition;

pest and pathogen infection from soil; deficiency of micronutrients;

toxicity of heavy metals; geophagy, and other factors"—Provided by publisher.

Identifiers: LCCN 2020047666 (print) | LCCN 2020047667 (ebook) |

ISBN 9780367422141 (hardback) | ISBN 9780367422134 (paperback) |

ISBN 9780367822736 (ebook)

Subjects: LCSH: Soils—Health aspects. | Environmental health. | Soil ecology.

Classification: LCC S591 .S6943 2020 (print) | LCC S591 (ebook) |

DDC 577.5/7—dc23

LC record available at <https://lccn.loc.gov/2020047666>

LC ebook record available at <https://lccn.loc.gov/2020047667>

ISBN: 978-0-367-42214-1 (hbk)

ISBN: 978-0-367-42213-4 (pbk)

ISBN: 978-0-367-82273-6 (ebk)

Typeset in Times

by codeMantra

Contents

Preface.....	vii
Editor	ix
Contributors	xi
Chapter 1 The Soil–Human Health–Environment Trinity	1
<i>Rattan Lal</i>	
Chapter 2 Health of Soil, Plants, Animals, and People	13
<i>Kathi J. Kemper, Ye Xia, Jeffrey Lakritz, and Rattan Lal</i>	
Chapter 3 Transport of Mineral Elements from Soil and Human Health.....	47
<i>Sheng Huang and Jian Feng Ma</i>	
Chapter 4 Soils and Human Health: Communication between Soil Scientists and Health Care Providers	59
<i>David Collier and Eric C. Brevik</i>	
Chapter 5 Soil and Cancer	81
<i>Marium Husain</i>	
Chapter 6 Addressing Urban Mal- and Undernourishment through Sustainable Home Gardens.....	111
<i>Neeraj H. Tayal</i>	
Chapter 7 Improving Human Health by Remediating Polluted Soils.....	129
<i>Darryl D. Siemer</i>	
Chapter 8 Managing Soil for Global Peace by Eliminating Famines and Pandemics	143
<i>Rattan Lal</i>	
Chapter 9 Illustrating a Disjoint in the Soil–Plant–Human Health Nexus with Potassium	159
<i>Kaushik Majumdar, T. Scott Murell, Sudarshan Dutta, Robert L. Mikkelsen, Ashwin Kotnis, Shamie Zingore, Gavin Sulewski, and Thomas Oberthür</i>	
Chapter 10 Soil Aquaphotomics for Understanding Soil–Health Relation through Water–Light Interaction.....	197
<i>Jelena Muncan, Balkis Aouadi, Flora Vitalis, Zoltan Kovacs, and Roumiana Tsenkova</i>	

Chapter 11	Healthy Soils—Healthy People: Soil and Human Health—The Reality of the Balkan Region	223
	<i>Ratko Ristić, Marijana Kapović Solomun, Ivan Malužević, Slavko Ždrale, Boris Radić, Siniša Polovina, and Vukašin Milćanović</i>	
Chapter 12	Heavy Metals Bioavailability in Soils and Impact on Human Health	249
	<i>Bal Ram Singh, Hamisi Tindwa, Abul M. Kashem, Dheeraj Panghaal, and Ernest Semu</i>	
Chapter 13	Managing Soil Biology for Multiple Human Benefits	275
	<i>André L.C. Franco, Steven J. Fonte, and Diana H. Wall</i>	
Chapter 14	Structural Attributes of Disease-Suppressive Soils and Their Impact on Human Health	303
	<i>Rattan Lal</i>	
Chapter 15	Soil Health and Human Nutrition	315
	<i>Rattan Lal</i>	
Index		327

Preface

The Soil–Human Health Nexus is based on the premise that the “health of soil, plants, animals, people, and the environment is one and indivisible.” This phrase, “health of soil, plants, animals and people is indivisible,” proposed by Sir Albert Howard (1920) when he was working in Indore, India, has been expanded to include the term “environment” or “ecosystems” in response to realities of the 21st century. The degradation of soil, an integral component of the environment, affects and is affected by the environment. Further, the importance of a strong “soil–human health nexus” can never be overemphasized. Soil health, dependent on activity and species diversity of soil biota, along with the quality and quantity of soil organic matter content in the root zone, affects human health directly and indirectly. Directly, soil health can affect the intake of heavy metals/contaminants and pathogens. Indirectly, soil health can be a source of medicines (e.g., antibiotics) and micronutrients through the food grown on healthy soil. There are 17 essential micronutrients for human health, and their availability in soil is essential to their uptake and concentration in food grains and other agricultural products. Thus, nutrition-sensitive agriculture is an important strategy to enhance human health. Food is also a potent medicine. As an ancient Vedic proverb states, “When food is right, medicine is of no need; when food is wrong, medicine is of no use”.

Environmental quality, an important control of human health, comprises a trinity of environmental parameters: soil, water, and air. The quality of water and air is strongly affected by that of soil. By denaturing and filtration of pollutants, soil purifies the water passing through it. Indeed, soil (as a misnomer called “dirt”) is the best media to purify dirty water. Therefore, the sustainable management of soil health is critical to quality and renewability of water and a solution to the problems of anoxia, algal bloom, and other eutrophication issues. Soil properties and processes also affect the quality of air as a source or sink of greenhouse gases (CO_2 , CH_4 , and N_2O). Soil can also be a major source of dust (wind erosion and dust storms), aerosols, and other pollutants. In contrast, conservation and sustainable management of soil is a major sink of atmospheric CO_2 through sequestration into humus as organic carbon, oxidation of methane (CH_4), and formation of pedogenic or secondary carbonates. There is a strong need to formulate and implement a “soil protection policy” to complement the existing Air Quality Act and Water Quality Act. It is the right time to formulate and enact “Soil Quality Act” and respect the “Rights-of-Soil.”

As Barry Commoner stated in his book, “The Closing Circle,” there is “no way to throw away,” and, certainly, everything released into nature must go somewhere. Indeed, the environmental cost (footprint) of the food produced through agricultural intensification is steep and rising due to the leakage of chemicals (i.e., fertilizers and pesticides) into the environment, and impacting all vital components—air, water, soil, vegetation, and biodiversity. Despite these adverse impacts, the use of agrochemicals is increasing because the demand for the production of victuals (i.e., food, feed, fiber, and fuel) is rising for the growing and increasingly affluent world population.

Therefore, the objective of this 15-chapter volume is to deliberate the technological options that reconcile the need for increasing the global supply of essential victuals with the urgency of restoring and sustaining the environment and decreasing risks to human health. Decline in soil health has a cascading impact on human health through pollution of the environment and degradation of the entire food production chain.

This 15-chapter book explains the linkages between soil health and those of plants, animals, people, and ecosystems. Thus, invited authors, including soil scientists, plant scientists, veterinarians, and practicing physicians, represent diverse disciplines. Therefore, I thank all the authors for their outstanding contributions and for sharing their knowledge and experience with the global soil science community.

Preparation of the manuscript, involving collation and synthesis of the literature and interpretation of the data from context-specific situation, is a time-consuming process that requires dedication

and commitment. All authors are dedicated professionals committed to excellence. Source of all material cited has been listed and credited in the text, tables, and or figures, and acknowledged.

Thanks are also due to the editorial staff of Taylor and Francis for their timely help and prompt response to numerous questions and queries from the editor and authors. Appreciations and thanks are also due to the staff of the Carbon Management and Sequestration Center (C-MASC) of The Ohio State University for providing support to the flow of the manuscripts between authors and editors and making valuable contributions in timely submission of the book. In this context, special thanks and appreciation are due to Ms. Maggie Weidner-Willis who formatted the text, checked references, followed the guidelines, compiled list of the contributors, and prepared it for final submission to the publisher. Help received from other staff of C-MASC (i.e., Mr. Kyle Sklenka, Ms. Janelle Watts, and Ms. Gabrielle Collier) is also acknowledged. While it is a major challenge to list all those who made direct and indirect contributions toward completion of this book, it is important to thank contributions of all those who supported the completion of this volume. It is also important to build upon the contributions of all those who study properties, processes, and management of soil in relation to human health over the last century and share the knowledge contained in this volume with others from around the world.

A handwritten signature in black ink, reading "Rattan Lal". The signature is written in a cursive style with a large, stylized initial 'R'.

Rattan Lal 20th July 2020
The Ohio State University
Columbus, OH, USA

Editor

Rattan Lal, Ph.D., is a Distinguished University Professor of Soil Science and Director of the Carbon Management and Sequestration Center, The Ohio State University, and an Adjunct Professor of University of Iceland. His current research focus is on climate-resilient agriculture, soil carbon sequestration, eco-intensification, enhancing use efficiency of agroecosystems, and sustainable management of soil resources of the tropics. He has received honorary degrees of Doctor of Science from Punjab Agricultural University (2001), the Norwegian University of Life Sciences, Aas (2005), Alecu Russo Balti State University, Moldova (2010), Technical University of Dresden, Germany (2015), University of Lleida, Spain (2017), Gustavus Adolphus College, Saint Peter, Minnesota, and PUCV, Valparaiso, Chile (2019). He was the President of the World Association of the Soil and Water Conservation (1987–1990), the International Soil Tillage Research Organization (1988–1991), the Soil Science Society of America (2005–2007), and the International Union of Soil Science (2017–2018). He was a member of the Federal Advisory Committee on U.S. National Assessment of Climate Change—NCADAC (2010–2013), member of the SERDP Scientific Advisory Board of the US-DOE (2011–2018), Senior Science Advisor to the Global Soil Forum of Institute for Advanced Sustainability Studies, Potsdam, Germany (2010–2015), member of the Advisory Board of Joint Program Initiative of Agriculture, Food Security and Climate Change (FACCE-JPI) of the European Union (2013–2016), and Chair of the Advisory Board of the Institute for Integrated Management of Material Fluxes and Resources of the United Nation University (UNU-FLORES), Dresden, Germany (2014–2019). Prof. Lal was a lead author of IPCC (1998–2000). He has mentored 115 graduate students, 54 postdoctoral researchers, and hosted 174 visiting scholars. He has authored/co-authored 950 refereed journal articles and has written 20 and edited/co-edited 75 books. For 6 years (2014–2019), Reuter Thomson listed him among the world’s most influential scientific minds and having citations of publications among top 1% of scientists in agricultural sciences. He is the recipient of the 2018 GCHERA World Agriculture Prize, 2018 Glinka World Soil Prize, 2019 Japan Prize, 2020 World Food Prize, and 2020 Arrell Global Food Innovation Prize in Research.



Taylor & Francis

Taylor & Francis Group

<http://taylorandfrancis.com>

Contributors

Balkis Aouadi

Department of Physics and Control
Faculty of Food Science
Szent István University
Budapest, Hungary

Eric C. Brevik

Department of Natural Sciences and
Department of Agriculture and Technical
Studies
Dickinson State University
Dickinson, North Dakota

David Collier

Brody School of Medicine
Department of Pediatrics
East Carolina University
Greenville, North Carolina

Sudarshan Dutta

African Plant Nutrition Institute
Benguérir, Morocco
and
Université Mohamed VI Polytechnique
Benguérir, Morocco

Steven J. Fonte

Department of Soil and Crop Sciences
Colorado State University
Fort Collins, Colorado

André L.C. Franco

Department of Biology
Colorado State University
Fort Collins, Colorado

Sheng Huang

Institute of Plant Science and Resources
Okayama University
Kurashiki, Japan

Marium Husain

James Comprehensive Cancer Center
The Ohio State University
Columbus, Ohio

Marijana Kapović Solomun

Faculty of Forestry
University of Banja Luka
Republic of Srpska, BIH
Banja Luka

Abul M. Kashem

Department of Soil Science
University of Chittagong
Chittagong, Bangladesh

Kathi J. Kemper

College of Medicine
The Ohio State University
Columbus, Ohio

Ashwin Kotnis

Department of Biochemistry
All India Institute of Medical Sciences
Bhopal, India

Zoltan Kovacs

Department of Physics and Control
Faculty of Food Science
Szent István University
Budapest, Hungary

Jeffrey Lakritz

College of Veterinary Medicine
The Ohio State University
Columbus, Ohio

Rattan Lal

Carbon Management and Sequestration Center
The Ohio State University
Columbus, Ohio

Jian Feng Ma

Institute of Plant Science and Resources
Okayama University
Kurashiki, Japan

Kaushik Majumdar

African Plant Nutrition Institute
Benguérir, Morocco
and
Université Mohamed VI Polytechnique
Benguérir, Morocco

Ivan Malušević

Faculty of Forestry
University of Belgrade
Belgrade, Serbia

Robert L. Mikkelsen

African Plant Nutrition Institute
Benguérir, Morocco
and
Université Mohamed VI Polytechnique
Benguérir, Morocco

Vukašin Milčanović

Faculty of Forestry
University of Belgrade
Belgrade, Serbia

Jelena Muncan

Biomeasurement Technology Laboratory
Graduate School of Agricultural Science
Kobe University
Kobe, Japan

T. Scott Murell

African Plant Nutrition Institute
Benguérir, Morocco
and
Université Mohamed VI Polytechnique
Benguérir, Morocco

Thomas Oberthür

African Plant Nutrition Institute
Benguérir, Morocco
and
Université Mohamed VI Polytechnique
Benguérir, Morocco

Dheeraj Panghaal

Department of Soils
CCS Haryana Agricultural University
Hisar, India

Siniša Polovina

Faculty of Forestry
University of Belgrade
Belgrade, Serbia

Boris Radić

Faculty of Forestry
University of Belgrade
Belgrade, Serbia

Ratko Ristić

Faculty of Forestry
University of Belgrade
Belgrade, Serbia

Ernest Semu

Department of Soil and Geological Sciences
Sokoine University of Agriculture
Morogoro, Tanzania

Darryl D. Siemer

Retired Idaho National Laboratory
Consulting Scientist

Bal Ram Singh

Faculty of Environmental Sciences and Natural
Resources
Norwegian University of Life Sciences
Ås, Norway

Gavin Sulewski

African Plant Nutrition Institute
Benguérir, Morocco

Neeraj H. Tayal

Division of General Internal Medicine and
Geriatrics
Department of Internal Medicine
The Ohio State University
Columbus, Ohio

Hamisi Tindwa

Department of Soil and Geological Sciences
Sokoine University of Agriculture
Morogoro, Tanzania

Roumiana Tsenkova

Biomeasurement Technology Laboratory
Graduate School of Agricultural Science
Kobe University
Kobe, Japan

Flora Vitalis

Department of Physics and Control
Faculty of Food Science
Szent István University
Budapest, Hungary

Diana H. Wall

Department of Biology and
School of Global Environmental Sustainability
Colorado State University
Fort Collins, Colorado

Ye Xia

College of Food, Agriculture,
and Environmental Sciences
The Ohio State University
Columbus, Ohio

Slavko Ždrale

Faculty of Medicine
University of East Sarajevo
Republic of Srpska, BIH

Shamie Zingore

African Plant Nutrition Institute
Benguérir, Morocco
and
Université Mohamed VI Polytechnique
Benguérir, Morocco



Taylor & Francis

Taylor & Francis Group

<http://taylorandfrancis.com>

1 The Soil–Human Health Environment Trinity

Rattan Lal

The Ohio State University

CONTENTS

1.1	Introduction	1
1.2	Soil Organic Matter in Relation to the Health of Soil and the Environment	2
1.3	Historic Depletion of the Terrestrial C Stock	4
1.4	Soil Organic Matter Depletion and Soil/Environment Degradation	5
1.5	The Soil–Human Health Nexus	5
1.6	Interconnected Vicious Cycles Prevalent in Degraded Soils of Agroecosystems.....	6
1.7	Choice of Entry Points for Breaking the Vicious Circles	7
1.8	Enhancing Human Nutrition by Soil Management	8
1.9	Research and Development Priorities.....	9
1.10	Conclusions.....	9
	References.....	9

1.1 INTRODUCTION

The prime soil resources are finite, unequally distributed globally, and fragile upon land misuse and soil mismanagement. Humanity, despite all of its scientific advances and modern discoveries in every aspect of the terrestrial and extra-terrestrial processes, is even more fragile than the soil on which it depends. This truism has been documented by the rapid spread of the COVID-19 pandemic which paralyzed 8 billion people over a short span of 10 months from December 2019 to September 2020, and there is no end in sight. As of September 20, 30 million people had tested positive and ~1 million had perished. The mighty COVID-19 does not differentiate between rich or poor nations, developed or developing countries, scientifically advanced or less progressive societies, and even among those with or without the so-called “weapons of mass destruction” (WMDs). As a matter of fact, COVID-19 is the WMD that humans have yet to get their grip on. Surprisingly, humanity also has a short-lived memory. Not only has it forgotten the demise of once thriving civilizations (i.e., Mesopotamia, Indus, Maya, Aztec), but the transient nature of humanity’s memory is vividly demonstrated by complacency not of the relatively distant plague, smallpox, and HIV but also more recent Ebola, Zika, and other pandemics of modern era.

The societal lockdown enforced by COVID-19 has not only documented the vulnerability of the economy of all rich and poor nations alike but also how rapidly the atmospheric chemistry responds to the industrial shutdown. By the end of March 2020, within 3 months of onslaught of COVID-19 on humanity, the atmospheric concentration of NO₂ declined over several cities in Europe (Abnett 2020; Holcombe and O’Key 2020). The concentration of NO₂ levels is a contributing factor to coronavirus fatalities (Ogen 2020). Furthermore, seasonal changes in the atmospheric concentration of CO₂, as shown by the Keeling curve, may also be affected by the long-term shut down. It is estimated that the global fossil fuel use would have to decline by 10% for a full year to show up in carbon dioxide concentrations of only about 0.5 parts per million (Monroe 2020). Across the whole year, Betts et al. (2020) estimated that CO₂ levels will rise by 2.48 parts per million (ppm),

which is 0.32 ppm smaller than if there had been no lockdown. This decrease is equivalent to 11% of the expected rise (Betts et al. 2020). Disappointingly, carbon dioxide recorded at the Mauna Loa Observatory in Hawaii reached 417 parts per million (ppm) in May 2020, higher than the record of 414.8 ppm set last year (Reuters 2020).

Pollution levels declined across cities in India because of the lockdown related to COVID-19. Mahato, Pal, and Ghosh (2020) reported that concentrations of PM₁₀ and PM_{2.5} were reduced by >50% as compared with the prelockdown phase. In comparison with 2019 for the same period, the reduction of PM₁₀ and PM_{2.5} is 60% and 39%, respectively. Among other pollutants, NO₂ has been decreased by –53% and CO by –30% during the lockdown phase (Mahato, Pal, and Ghosh 2020). Goswami (2020) outlined four environmental changes in India due to the COVID-19 lockdown: (i) the air quality index in Delhi dropped from 90 in the worst-case scenarios to below 20 in May because 11 million registered cars were taken off the roads, and factories and constructions were stopped, and the PM_{2.5} concentration declined from 71% to 26%; (ii) South Asian river dolphins, listed among endangered species, were spotted at different locations in Kolkata Ghats; (iii) thousands of flamingos were seen in Mumbai; and (iv) the water of the river Ganges was of a drinkable quality (Goswami 2020). Cities of Europe also reported cleaner air during the lockdown (Abnett 2020).

Therefore, prudential management along with a planned reduction in the use of fossil fuel and its substitution by noncarbon fuel sources may bring about the much-needed decline in the increase of the atmospheric concentration of greenhouse gases (GHGs). This is an important lesson that must be followed upon by the policymakers after the COVID-19 pandemic. Such a rapid response indicates a possibility that a strong commitment to recarbonization of the terrestrial biosphere (i.e., soil, vegetation, and wetlands) at a global scale (Lal et al. 2018) may also make a measurable impact on the atmospheric chemistry within a foreseeable future. Admittedly, the tragic pandemic of COVID-19 cannot be dubbed having a silver lining, but the fact that atmospheric chemistry can be altered rapidly provides strong motivation toward adoption of negative emission technologies (NET).

Improvement of soil health, through conversion of degraded and agriculturally marginal lands to restorative ecosystems (i.e., by afforestation and set-aside or land retirement programs) and adoption of recommended management practices (RMPs), is a pertinent example of NET. These strategies would restore soil organic matter (SOM) content because of the progressive development of the positive soil/ecosystem carbon (C) budget on a decadal scale. The positive soil C budget would restore soil health and strengthen the provisioning of essential ecosystem services (ESs) for an effective functioning of nature via nutrient cycling, increase in activity and species diversity of biota, water purification and renewability, and above all, sequestration of atmospheric CO₂ into SOM and in the above and below-ground biomass. Therefore, the objective of this chapter is to deliberate the soil–human health–environment trinity, and how restoration of the soil health can simultaneously improve the resilience of humanity through improvement of the environment and functioning of nature. The specific objective of this article is to deliberate the impact of soil degradation caused by SOC depletion on the nutritional quality of crops and on human health.

1.2 SOIL ORGANIC MATTER IN RELATION TO THE HEALTH OF SOIL AND THE ENVIRONMENT

Soil components have an important impact on human health (Nieder, Benbi, and Reichl 2018). An important among these components is soil organic carbon (SOC) content. In conjunction with afforestation of degraded and agriculturally marginal lands, enhancing and sustainable management of SOC stock on depleted agricultural soils is critical to mandatory reduction in the atmospheric concentration of carbon dioxide (CO₂) and other GHGs (i.e., nitrous oxide or N₂O and methane or CH₄). The SOC stock and its management is a critical climate variable (IPCC 2019). Whereas measuring SOC stock requires access to facilities and understanding of the processes, there is also a

large variation in SOC concentration and stock at soil scape or landscape levels because of the large variations in control factors both vertically and horizontally even at short distances.

Yet, credible assessments of SOC stocks are needed to understand the impact on a range of pedological processes whose degradation may lead to reversal of ESs (Figure 1.1) which are essential to human and nature. Assessment of SOC stocks and their temporal changes are also needed to evaluate impacts on atmospheric concentrations of GHGs in relation to anthropogenic climate change. A severe decline in SOC stock, below the critical threshold for the specific land use and soil type, can create numerous disservices (Figure 1.2) with adverse impacts on human well-being and nature

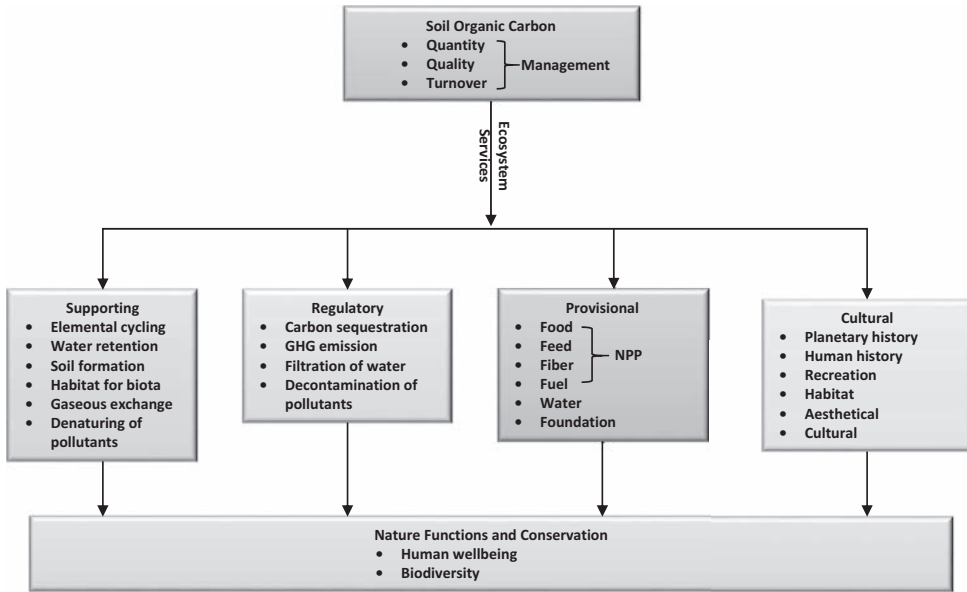


FIGURE 1.1 SOC and ESs (NPP, net primary production; GHG, greenhouse gases).

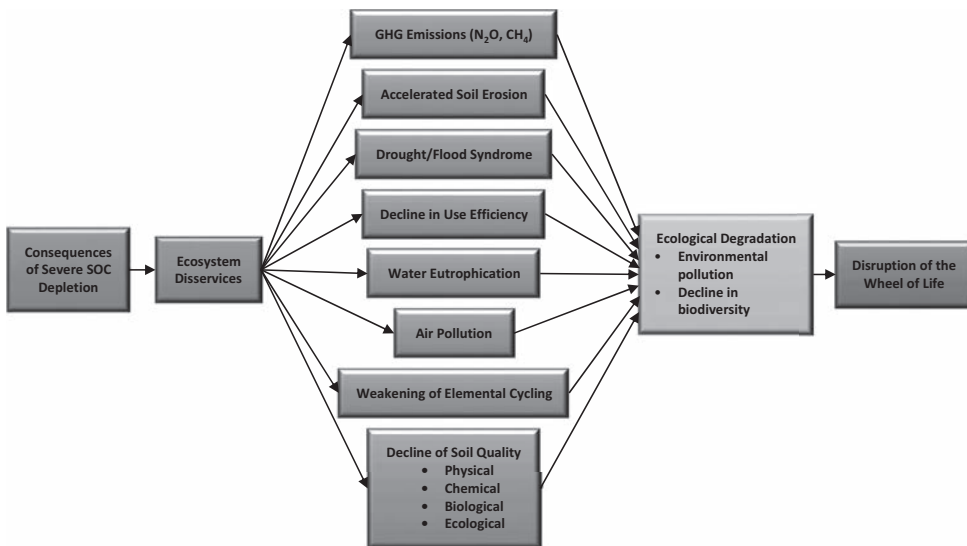


FIGURE 1.2 Ecosystem disservices created by severe depletion of SOC stock leading to the disruption of the Wheel of Life (Birth—Growth—Reproduction—Death—Birth).

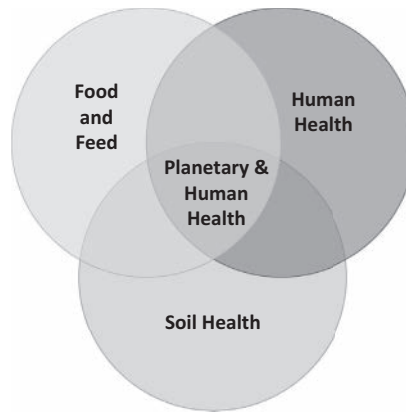


FIGURE 1.3 Soil–Food–Human–Planet Health Nexus, dependent on SOC and its management.

functions. The strong food–human health–soil nexus (Figure 1.3), affecting human and the planetary health, necessitates restoration and sustainable management of SOC stock at soil scale, landscape, farm, regional, national, and global scale. The nexus between soil health and food quality, and that of diet quality and human health, has been recognized in ancient cultures. An Ayurvedic proverb is a pertinent example of this interconnectivity: “When diet is wrong, medicine is of no use; when diet is correct, medicine is of no need.” Contextualizing the soil and farming system effects of SOC depletion indicates its strong significance to the productivity, sustainability, and environmental quality of the small land-holder farmers from around the world. Just as air and water quality can be changed through the management of transport and industrial effluents, soil health and functionality can also be changed through the sequestration of SOC and improvement of its quality. Improvements in the health of soil, water, and air would improve human health and well-being.

1.3 HISTORIC DEPLETION OF THE TERRESTRIAL C STOCK

Anthropogenic activities, conversion of natural to managed ecosystems, have depleted the terrestrial C stock. Erb et al. (2018) estimated that in the hypothetical absence of land use, the potential vegetation C stock may be as much as 916 Pg C compared with the actual stock of 450 Pg C (Table 1.1). Similarly, compared with the actual SOC stock of 1,477.2 Pg, the prehistoric SOC stock to 1-M depth was estimated by Buringh (1984) at 2,014.1 Pg (Table 1.2) with the SOC loss of 537 Pg C or 27% of the global SOC stock. The depletion of SOC stock is exacerbated by soil degradation, and ~33% of world soils are degraded (FAO and ITPS 2015). The human impact on soil and

TABLE 1.1

Land Use Type and the Actual vs. Potential Biomass Carbon Stocks

Land Use	Biomass Stock (Pg C)		Difference (%)
	Actual	Potential	
Cropland	10	139–141	93
Grassland and grazing land	119–121	374–379	69–70
Forests	297–368	443–460	22–33
Unused nonforest	16–17	16–17	0
Infrastructure	1	12	92–93
Total	407–476	875–906	48–54

Source: Adapted from Erb et al. (2018).

TABLE 1.2
Prehistoric and the Present Soil Organic Carbon Stock to 1-m Depth

Soil Order	SOC Stock (Pg C)		Percent Lost
	Prehistoric	Present	
Alfisols	388.9	254.8	34.5
Aridisols	33.8	33.0	2.4
Entisols	198.7	144.6	27.2
Histosols	41.5	41.5	0
Inceptisols	279.4	206.6	26.1
Mollisols	165.6	156.9	5.3
Oxisols	255.5	173.0	32.3
Spodosols	62.9	50.7	19.4
Ultisols	165.2	112.9	31.7
Vertisols	40.6	32.2	45.3
Mountain Soils	382.0	281.0	26.4
Total	2,014.1	1,477.2	26.7

Source: Adapted from Buringh (1984).

environment is not new (Balfour 1949) and has been known for millennia (Lal 2013). What is new is the magnitude of the impact of a large population with insatiable demands on soil and environment quality on one hand and on the pace at which the change is occurring is on the other. These are the characteristics of the Anthropocene (Crutzen 2002; Crutzen and Stoermer 2000). The magnitude of change (i.e., extent and severity of degradation, multiple GHG emission, water depletion and eutrophication, and biodiversity loss) is alarming, and the term “big” is of the past. Degradation of soil and the environment has a strong impact on human health and well-being.

1.4 SOIL ORGANIC MATTER DEPLETION AND SOIL/ ENVIRONMENT DEGRADATION

There exists a strong relationship between SOM content and soil quality (Johnston 1986; Mahajan et al. 2019; Page, Dang, and Dalal 2020). SOM originates from the transfer of atmospheric CO₂ into plant biomass and the latter’s decomposition by microbial processes into organo-mineral complexes. Because the input of chemical fertilizers alone cannot restore soil quality, adopting the strategy of integrated nutrient management (INM) is essential. The latter involves restoring and sustaining SOM content, maintaining nutrient supply, and improving soil physical properties and processes by following the Law of Return (Howard 1943). The ever-increasing inputs of fertilizers, irrigation, and tillage required to achieving the desired crop yield in soils depleted of their SOM stocks is indicative of the need for a paradigm shift in the management of agroecosystems (Ball, Hargreaves, and Watson 2018). But for the paradigm shift, the rate and magnitude of SOM depletion may increase with the current and projected increase in global temperature (Semenchuk et al. 2019).

1.5 THE SOIL–HUMAN HEALTH NEXUS

Soil health has both direct and indirect effects on human health (Figure 1.4, Oliver and Gregory 2015). Directly, soil can affect human health as a source of infectious pests and pathogens, medicines and antibodies, and by producing healthy and nutritious foods. Indirectly, degraded soil can affect human health by producing nutrient-deficient food of low yield and aggravate both under and malnutrition. Degraded soil, through low yield, can reduce the farm income and aggravate poverty

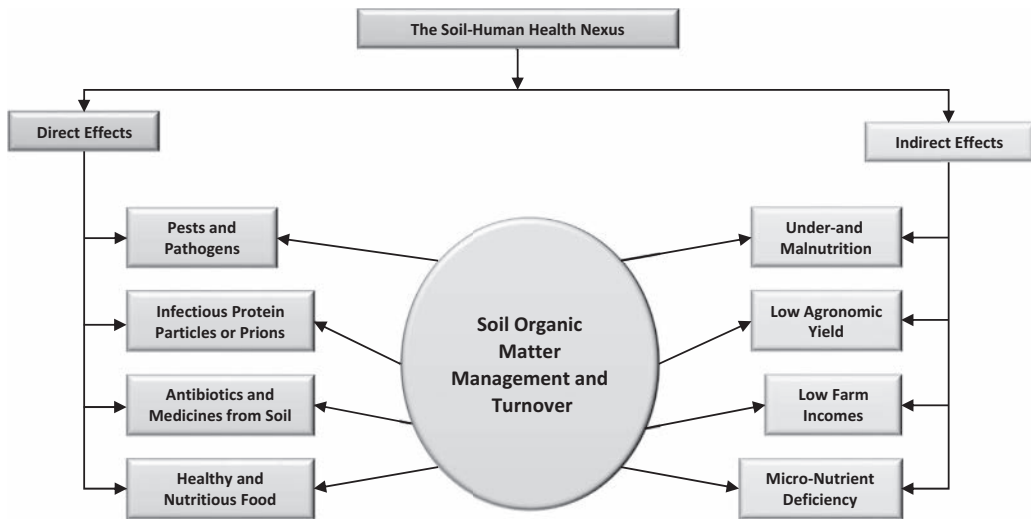


FIGURE 1.4 Direct and indirect effects of soil health on human health through SOM management and turnover.

(Figure 1.4). Because of the strong implications of soil quality to human health (Abrahams 2002), there is a growing concern that soil degradation may cause human malnutrition (Lal 2009; Long 1999; Mayer 1997; Ball, Hargreaves, and Watson 2018; Jack 1998; Jones et al. 2013). Long (1999) observed that the vitamin and mineral content of US and the British food may be decreasing. Contamination of soil with organic pollutants (Cachada et al. 2012) and with heavy metals such as lead can also adversely impact human health (Filippelli and Laidlaw 2010). Deficiency of micronutrients in the degraded soils is an important factor impacting human health (Lal 2009; Abrahams 2002; Oliver and Gregory 2015; Jones et al. 2013). Thus, adoption of sustainable management practices is critical to simultaneously advancing both food and nutritional security (Abrahams 2002; Bindraban et al. 2020; Ball, Hargreaves, and Watson 2018; Watson et al. 2002). There is a strong need to develop nutrition-sensitive agriculture and identify appropriate cropping systems in developing countries for improving human nutrition without degrading soil resources (Amede, Stroud, and Aune 2004).

1.6 INTERCONNECTED VICIOUS CYCLES PREVALENT IN DEGRADED SOILS OF AGROECOSYSTEMS

Despite a strong progress in the amount of total grain and animal-based products since the onset of Green Revolution circa 1960s, there are about 820 million people prone to undernourishment (FAO et al. 2018) and about 1.9 billion affected by malnourishment (WHO 2019). Incidences of both under and malnourishment are aggravated by increase in the extent and severity of soil degradation. There are a series of interconnected degradation processes, the so-called vicious circles that feed one another, which are set-in-motion by land misuse and soil mismanagement (Lal 2020). Oliver and Gregory (2015) and Benton (2019) described scenario analyses that affect human health and food security through soil degradation. Such mutually enhancing circles started by land misuse and soil mismanagement are the basic causes of food-insecurity, malnourishment and of the global warming. The latter is aggravated by the emission of GHGs from degraded soils of agroecosystems and increased by inappropriate use of inputs (i.e., fertilizers, pesticides, tillage, and irrigation) to mitigate the adverse effects of soil degradation. The food-insecurity and global warming circles in turn set-in-motion by others which adversely affect human health, exacerbate soil degradation, and aggravate the effects of pandemics (Lal 2020).

There is a strong link between soil degradation and human health by direct and indirect effects (Figure 1.4), especially those related to the deficiency of micronutrients and protein. A new infectious proteinaceous particle called “proline” has been defined by Prusiner (1982, 1998) and explained by Oliver and Gregory (2015). Deficiency of some and toxicity of other trace elements (heavy metals) can also have a strong adverse effect on human health. Important among heavy metals with adverse impacts on human health are lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg). Micronutrients whose deficiency affects human health include iron (Fe), iodine (I), cobalt (Co), chromium (Cr), copper (Cu), manganese (Mg), molybdenum (Mn), nickel (Ni), selenium (Se), and Zinc (Zn) (Lal 2009). The last among the series of interconnected circles is the hydrological cycle characterized by the increase in intensity and frequency of the drought/flood syndrome. The desperateness of the growing population leads to encroachment of the remaining forces and natural ecosystems but also to civil strife and unrest and flux of the so-called “soil-refugees” or “climate refugees” (Lal 2020). It is important to identify the entry point(s) to break these self-feeding and self-perpetuating vicious circles. Such interdependent and mutually reinforcing degradation processes have made food systems dependent on the intensive use of external inputs (e.g., fertilizer, pesticides, and irrigation) with adverse effects on the environment and eventually on human health (Benton 2019). Furthermore, these circles have introduced a degree of fragility into the food systems which is vulnerable to numerous factors. Increase in agricultural produce and the cheaper availability of food have aggravated malnourishment and obesity on one hand and soil and environmental degradation is on the other (Benton and Bailey 2019). Therefore, the proposed paradigm shift is to focus on the overall production and efficiency in terms of the number of people that can be fed healthily and sustainably while reducing the inputs (Benton and Bailey 2019).

1.7 CHOICE OF ENTRY POINTS FOR BREAKING THE VICIOUS CIRCLES

The interconnected problems of food insecurity, malnourishment, and soil degradation are widespread in Sub-Saharan Africa (Kim et al. 2019), South Asia (Singh 2015), in the Andean region (Vanek, Jones, and Drinkwater 2016), and elsewhere in the developing world. The problem of degrading soil fertility, poor crop nutrition, and climate change is akin to opening of Pandora’s box in developing countries where recurring drought, low soil fertility, and increasing population are posing a daunting challenge (St. Clair and Lynch 2010). Soil degradation being the principal reason of malnourishment (Lal 2009), zero tolerance on soil degradation (Nguyen, Zapata, and Dercon 2010; Lal, Safriel, and Boer 2012; Cowie et al. 2018) is the prudent strategy and the first choice of an entry point to break the vicious circle. Among other important entry points include the following: (i) diversification of the food production systems (Dwivedi et al. 2017) involving judicious integration of diverse crops with trees and livestock to produce healthy diets and reduce diet-related illnesses, (ii) restoration of soil health for improving plant nutrition (El-Ramady et al. 2014) with a view to consider soil and human health as a whole, (iii) integration of plant nutrition research with plant genetics and molecular biology (Cakmak 2002; Clark and Duncan 1991), (iv) use of soil amendments such as biochar (Martos et al. 2020) and phytoremediation techniques (Radwan, Al-Awadhi, and El-Nemr 2000) to enhance crop safety as food and mitigate pollution by agrochemicals, (v) adoption of soil-less culture (Villagra et al. 2012) and to promote urban farming based on the recycling of urban waste (Lal and Stewart 2017), (vi) reduction of air pollution (SO_2 , NO_2 , O_3) and its effects on shoot–root interactions (Rennenberg, Herschbach, and Polle 1996) and of the minimization of environmental pollution (i.e., acid deposition, excess N deposition, and soil solution) on soil and forest nutrition (Johnson and Ball 1990), and (vii) adoption of innovative techniques of balanced input of macro- and micronutrients in the developed and developing countries to ensure the production of healthy, nutritious, and safe food (Loneragan 1997). Above all, there is an urgent need of safeguarding human and planetary health through critical and an objective review of the global fertilizer sector (Bindraban et al. 2020). Innovative technologies, as entry points to break the vicious circles, are needed to address the interconnectivity of food, soil, and environmental trinity (Figure 1.3).

1.8 ENHANCING HUMAN NUTRITION BY SOIL MANAGEMENT

Soil degradation, low soil quality, inadequate nutrient management, and lack of recycling are among the major concerns of human malnutrition. Yang, Chen, and Feng (2007) observed that more than 374 million people in China suffer from goiter disease, caused by deficiency of iodine (I). These constraints must be alleviated through the adoption of RMPs based on the strategies of INM and restoration of SOM content and stocks. A total of 14 nutrients are essential for plant growth (Lal 2009; Grusak, Broadley, and White 2016), yet most cropland soils, especially those in developing countries, have severe growth-limiting constraints of the nutrient imbalance (deficiency or toxicity). Thus, there is a need for the adoption of innovative options including that of biotechnology to enhance human nutrition (Kishore and Shewmaker 1999). The strategy is to advance human nutrition and alleviate the deficiency of micronutrients along with protein and macronutrients in developing countries without degrading soil resources (Amede, Stroud, and Aune 2004). Micronutrient uptake in food crops can also be increased by the foliar application of Zn and Ca fertilizers and that of Fe and Zn in grains and roots/tuber by plant breeding and genetic engineering (Frossard et al. 2000). In China, Yang, Chen, and Feng (2007) observed that 40% of the total land area is deficient in Fe and Zn, and they proposed an ecologically sound strategy of sustainable flow of micronutrients in soil-plant systems to improve human micronutrient nutrition. Enhancing soil health by improving SOM content is the long-term strategy to ensure an adequate mineral composition in plant produce. Root-induced changes in the rhizosphere can also impact nutrient availability and uptake. Management-induced changes in rhizosphere pH may be 2 units higher or lower than the bulk pH with a strong impact on nutrient uptake. Marschner et al. (1986) observed that low-molecular weight root exudates may also enhance the mobilization of nutrients, such as mobilization of phosphorus in the rhizosphere in white lupin (*Lupinus albus*). Thus, mixed cropping of wheat and white lupin can enhance the uptake of P by wheat (Marschner et al. 1986).

The outline in Figure 1.5 depicts the strategy of “One Health” concept through a sustainable management of soil health. The 3-step process involves (i) integration of crops with trees and livestock to restore SOM content and stock; (ii) restoration of soil, plant health, and animal health over a decadal scale, and improvement in nutritional quality of food leading to improvement in health of plants, animals, and people, which eventually translates into restoration and sustainable management of the overall environment. The major driver of the process depicted in Figure 1.5 is the buildup of SOM content and stock that strengthens ESs while also reconciling the need for advancing food and nutritional quality with the necessity of improving the environment.

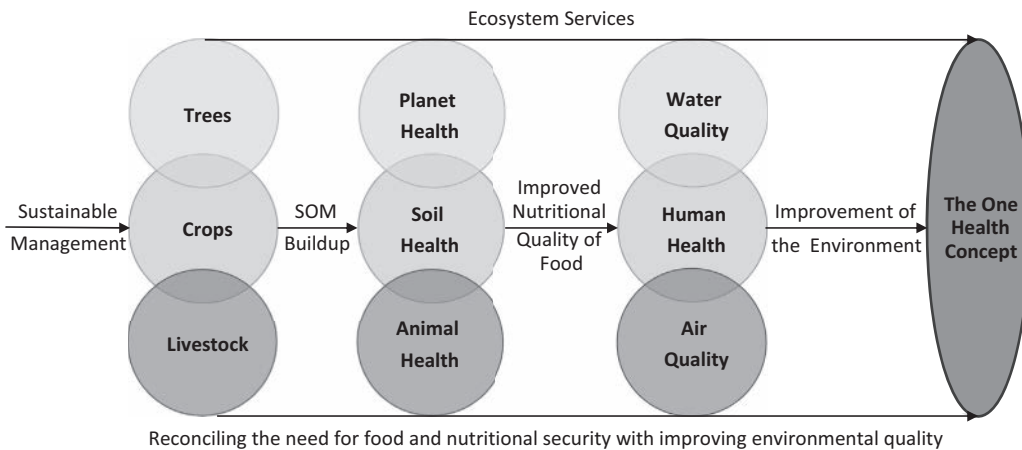


FIGURE 1.5 Integration of crops with trees and livestock and sustainable management of soil is the basis of the “One Health” concept: the health of soils, plants, animals, people, and the environment is one and indivisible.

1.9 RESEARCH AND DEVELOPMENT PRIORITIES

Soil health is being impacted by industrialization and disposal of effluents on soil including the use of wastewater in irrigation (Becerra-Castro et al. 2015). Because of the strong interconnectivity, the future research on the soil management and restoration must focus on the “One Health” initiative (Ohno and Hettiarachchi 2018). The strategy is to enhance environmental quality through multidisciplinary research that links, plant, animal, human, and environmental health through a sustainable management of soil health. Thus, there is a need for a systematic review of the way by which food is produced, processed, distributed, cooked, consumed, and the waste disposed. The entire food chain has been based on producing more and more with utter disregard to the quality of the food, health of the people, and status of the environment. It is important to produce more of a quality food while simultaneously restoring and sustaining the environment: health of soil, water, air, and biodiversity. The fragility of the current food system must be addressed. In addition, the research and education must be reoriented toward the “One Health” concept. Future agriculture must be nutrition-sensitive. Rather than the gross production, quality of the produce must be judged on the basis of nutrients, protein, and vitamins harvested. Furthermore, the produce harvested must have restorative and positive impacts on the environment.

1.10 CONCLUSIONS

The importance of a strong link between soil health and human healthy can never be overemphasized. Nature, properties, and processes of soil affect human health through their effects on plant growth and nutritional quality. Soil properties also affect human health through inhalation, ingestion, and dermal absorption of pollutants and pathogens. Indirect effects of soil on human health are through alterations in the properties and processes of atmosphere, hydrosphere, and the biosphere. Degradation of soil health by overexploitation, extractive farming practices, and soil mismanagement can adversely impact the environment and human health. Soil pollution, with industrial effluents and reuse of wastewater in irrigation, can adversely impact soil and human health. Thus, restoration and sustainable management of SOM content, a principal determinant of soil health, is important to improving quality and quantity of food and feed while improving the environment. Being the foundation of human and environmental health, a sustainable management of soil is also critical to well-being of the present and future generations and of the health of the planet. In pursuance of the “One Health” concept, multidisciplinary research must be pursued to understand interdependence between human, animal, and environmental health. In addition to research and education, it is also pertinent to translate science into action through direct dialogue with the policymakers.

REFERENCES

- Abnett, K. 2020. Coronavirus Lockdowns Give Europe’s Cities Cleaner Air. *Reuters*. <https://www.reuters.com/article/us-health-coronavirus-air-pollution/coronavirus-lockdowns-give-europes-cities-cleaner-air-idUSKBN21G0XA>.
- Abrahams, P.W. 2002. Soils: Their Implications to Human Health. *Science of the Total Environment* 291, no. 1–3 (May 27): 1–32.
- Amede, T., A. Stroud, and J. Aune. 2004. Advancing Human Nutrition without Degrading Land Resources through Modeling Cropping Systems in the Ethiopian Highlands. *Food and Nutrition Bulletin* 25, no. 4: 344–353.
- Balfour, E. 1949. *The Living Soil : Evidence of the Importance to Human Health of Soil Vitality, with Special Reference to National Planning*. Rev. ed. London, UK: Faber and Faber Ltd.
- Ball, B.C., P.R. Hargreaves, and C.A. Watson. 2018. A Framework of Connections between Soil and People Can Help Improve Sustainability of the Food System and Soil Functions. *Ambio* 47, no. 3 (April 1): 269–283. doi:10.1007/s13280-017-0965-z.
- Becerra-Castro, C., A.R. Lopes, I. Vaz-Moreira, E.F. Silva, C.M. Manaia, and O.C. Nunes. 2015. Wastewater Reuse in Irrigation: A Microbiological Perspective on Implications in Soil Fertility and Human and Environmental Health. *Environmental International* 75: 117–135. <http://www.sciencedirect.com/science/article/pii/S0160412014003237>.

- Benton, T.G. 2019. Using Scenario Analyses to Address the Future of Food. *EFSA Journal* 17, no. S1 (July 1): e170703.
- Benton, T.G., and R. Bailey. 2019. The Paradox of Productivity: Agricultural Productivity Promotes Food System Inefficiency. *Global Sustainability* 2: e6. <https://www.cambridge.org/core/article/paradox-of-productivity-agricultural-productivity-promotes-food-system-inefficiency/4D5924AF2AD829EC1719F52B73529CE4>.
- Betts, R., C. Jones, Y. Jin, R. Keeling, J. Kennedy, J. Knight, and A. Scaife. 2020. Analysis: What Impact Will the Coronavirus Pandemic Have On Atmospheric CO₂? *Carbon Brief*. <https://www.carbonbrief.org/analysis-what-impact-will-the-coronavirus-pandemic-have-on-atmospheric-co2>.
- Bindraban, P.S., C.O. Dimkpa, J.C. White, F.A. Franklin, A. Melse-Boonstra, N. Koele, R. Pandey, et al. 2020. Safeguarding Human and Planetary Health Demands a Fertilizer Sector Transformation. *Plants, People, Planet*: ppp3.10098. <https://onlinelibrary.wiley.com/doi/abs/10.1002/ppp3.10098>.
- Buringh, P. 1984. Organic Carbon in Soils of the World. In *The Role of Terrestrial Vegetation in the Global Carbon Cycle: Measurement by Remote Sensing*, 23, 91–109. New York: Wiley.
- Cachada, A., P. Pato, T. Rocha-Santos, E.F. da Silva, and A.C. Duarte. 2012. Levels, Sources and Potential Human Health Risks of Organic Pollutants in Urban Soils. *Science of The Total Environment* 430: 184–192. <http://www.sciencedirect.com/science/article/pii/S004896971200647X>.
- Cakmak, I. 2002. Plant Nutrition Research: Priorities to Meet Human Needs for Food in Sustainable Ways. *Plant and Soil* 247: 3–24. Springer.
- St. Clair, S.B., and J.P. Lynch. 2010. The Opening of Pandora's Box: Climate Change Impacts on Soil Fertility and Crop Nutrition in Developing Countries. *Plant and Soil* 335, no. 1: 101–115.
- Clark, R.B., and R.R. Duncan. 1991. Improvement of Plant Mineral Nutrition through Breeding. *Field Crops Research* 27, no. 3 (October 1): 219–240.
- Cowie, A.L., B.J. Orr, V.M. Castillo Sanchez, P. Chasek, N.D. Crossman, A. Erlewein, G. Louwagie, et al. 2018. Land in Balance: The Scientific Conceptual Framework for Land Degradation Neutrality. *Environmental Science & Policy* 79: 25–35. <http://www.sciencedirect.com/science/article/pii/S1462901117308146>.
- Crutzen, P.J. 2002. Geology of Mankind. *Nature* 415: 23. Nature Publishing Group.
- Crutzen, P.J., and E.F. Stoermer. 2000. The Anthropocene, Global Change. International Geosphere–Biosphere Programme (IGBP).
- Dwivedi, S.L., E.T. Lammerts van Bueren, S. Ceccarelli, S. Grando, H.D. Upadhyaya, and R. Ortiz. 2017. Diversifying Food Systems in the Pursuit of Sustainable Food Production and Healthy Diets. *Trends in Plant Science* 22: 842–856. Elsevier Ltd.
- El-Ramady, H.R., T.A. Alshaal, M. Amer, É. Domokos-Szabolcsy, N. Elhawat, J. Prokisch, and M. Fári. 2014. Soil Quality and Plant Nutrition. In *Sustainable Agriculture Reviews*, vol. 14, 345–447. Cham, Switzerland: Springer.
- Erb, K.H., T. Kastner, C. Plutzer, A.L.S. Bais, N. Carvalhais, T. Fetzel, S. Gingrich, et al. 2018. Unexpectedly Large Impact of Forest Management and Grazing on Global Vegetation Biomass. *Nature* 553, no. 7686 (January 4): 73–76.
- FAO, IFAD, UNICEF, WFP, and WHO. 2018. *The State of Food Security and Nutrition in the World 2018: Building Climate Resilience for Food Security and Nutrition*. Rome, Italy: FAO.
- FAO, and ITPS. 2015. *Status of the World's Soil Resources (SWSR) – Main Report*. Rome, Italy: Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils.
- Filippelli, G.M., and M.A. Laidlaw. 2010. The Elephant in the Playground: Confronting Lead-Contaminated Soils as an Important Source of Lead Burdens to Urban Populations. *Perspectives in Biology and Medicine* 53, no. 1: 31–45.
- Frossard, E., M. Bucher, F. Mächler, A. Mozafar, and R. Hurrell. 2000. Potential for Increasing the Content and Bioavailability of Fe, Zn and Ca in Plants for Human Nutrition. *Journal of the Science of Food and Agriculture* 80, no. 7: 861–879. [https://onlinelibrary.wiley.com/doi/abs/10.1002/\(SICI\)1097-0010\(20000515\)80:7%3C861::AID-JSFA601%3E3.0.CO;2-P?casa_token=y0SxDWWkrMAAAAAA:UrrJSPaXfaElvNz_ISGKLoN_dlow9qPl_Aw0qJwm4pQluFoLshgN2rV4ThKSSXkLcvGS9jwZ24QGLHg](https://onlinelibrary.wiley.com/doi/abs/10.1002/(SICI)1097-0010(20000515)80:7%3C861::AID-JSFA601%3E3.0.CO;2-P?casa_token=y0SxDWWkrMAAAAAA:UrrJSPaXfaElvNz_ISGKLoN_dlow9qPl_Aw0qJwm4pQluFoLshgN2rV4ThKSSXkLcvGS9jwZ24QGLHg).
- Goswami, K. 2020. Covid-19: 4 Unbelievable Environmental Changes Seen in India since Lockdown. *India Today*. <https://www.indiatoday.in/education-today/gk-current-affairs/story/covid-19-4-vital-environmental-changes-evidenced-in-india-since-lockdown-1673726-2020-05-02>.
- Grusak, M.A., M.R. Broadley, and P.J. White. 2016. Plant Macro- and Micronutrient Minerals. In *ELS*, 1–6. John Wiley & Sons, Ltd. doi: 10.1002/9780470015902.a0001306.pub2
- Holcombe, M., and S. O'Key. 2020. Satellite Images Show Less Pollution over the US as Coronavirus Shuts down Public Places. *The Mercury News*. <https://www.mercurynews.com/2020/03/23/satellite-images-show-less-pollution-over-the-us-as-coronavirus-shuts-down-public-places/>.

- Howard, A. 1943. *An Agricultural Testament*. New York: Oxford University Press.
- IPCC. 2019. *Special Report on Climate Change and Land*. Ed. P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D.C. Roberts, P. Zhai, et al. Geneva, Switzerland: Intergovernmental Panel on Climate Change. <https://www.ipcc.ch/srcccl/>.
- Jack, A. 1998. *Nutrition under Siege*. Vol. 1. Becket, MA: One Peaceful World.
- Johnson, D.W., and J.T. Ball. 1990. Environmental Pollution and Impacts on Soils and Forests Nutrition in North America. *Water, Air, & Soil Pollution* 54, no. 1 (March): 3–20.
- Johnston, A.E. 1986. Soil Organic Matter, Effects on Soils and Crops. *Soil Use and Management* 2, no. 3: 97–105.
- Jones, D.L., P. Cross, P.J.A. Withers, T.H. DeLuca, D.A. Robinson, R.S. Quilliam, I.M. Harris, D.R. Chadwick, and G. Edwards-Jones. 2013. REVIEW: Nutrient Stripping: The Global Disparity between Food Security and Soil Nutrient Stocks. *Journal of Applied Ecology* 50, no. 4 (August 1): 851–862. doi:10.1111/1365-2664.12089.
- Kim, J., N.M. Mason, S. Snapp, and F. Wu. 2019. Does Sustainable Intensification of Maize Production Enhance Child Nutrition? Evidence from Rural Tanzania. *Agricultural Economics* 50, no. 6 (November 29): 723–734. <https://onlinelibrary.wiley.com/doi/abs/10.1111/agec.12520>.
- Kishore, G.M., and C. Shewmaker. 1999. Biotechnology: Enhancing Human Nutrition in Developing and Developed Worlds. *Proceedings of the National Academy of Sciences of the United States of America* 96, no. 11: 5968–5972. <https://www.pnas.org/content/96/11/5968.short>.
- Lal, R. 2009. Soil Degradation as a Reason for Inadequate Human Nutrition. *Food Security* 1, no. 1 (February): 45–57.
- Lal, R. 2013. Soil and Sanskriti. *Journal of Indian Society of Soil Science* no. 61: 267–274.
- Lal, R. 2020. Soil Science Beyond COVID-19. *Journal of Soil and Water Conservation* 75, no. 4: 1–3.
- Lal, R., U. Safrieli, and B. Boer. 2012. Zero Net Land Degradation. *UNCCD Position Paper for Rio+20*. Bonn, Germany.
- Lal, R., P. Smith, H.F. Jungkunst, W.J. Mitsch, J. Lehmann, P.K.R. Nair, A.B. McBratney, et al. 2018. The Carbon Sequestration Potential of Terrestrial Ecosystems. *Journal of Soil and Water Conservation* 73, no. 6: A145–A152.
- Lal, R., and B.A. Stewart (Eds.). 2017. *Urban Soils*. CRC Press. doi: 10.1201/9781315154251
- Loneragan, J.F. 1997. Plant Nutrition in the 20th and Perspectives for the 21st Century. *Plant and Soil* 196: 163–174. doi: 10.1023/A:1004208621263
- Long, C. 1999. Is Chemical Farming Making Our Food Less Nutritious. *Organic Gardening* 46(6): 12.
- Mahajan, N.C., K. Mrunalini, K.S. Krishna Prasad, R.K. Naresh, and L. Sirisha. 2019. Soil Quality Indicators, Building Soil Organic Matter and Microbial Derived Inputs to Soil Organic Matter under Conservation Agriculture Ecosystem: A Review. *International Journal of Current Microbiology and Applied Sciences* 8, no. 2: 1859–1879.
- Mahato, S., S. Pal, and K.G. Ghosh. 2020. Effect of Lockdown amid COVID-19 Pandemic on Air Quality of the Megacity Delhi, India. *Science of The Total Environment* 730: 139086. <http://www.sciencedirect.com/science/article/pii/S0048969720326036>.
- Marschner, H., V. Römheld, W.J. Horst, and P. Martin. 1986. Root-induced Changes in the Rhizosphere: Importance for the Mineral Nutrition of Plants. *Zeitschrift Für Pflanzenernährung Und Bodenkunde* 149, no. 4: 441–456.
- Martos, S., S. Mattana, A. Ribas, E. Albanell, and X. Domene. 2020. Biochar Application as a Win-Win Strategy to Mitigate Soil Nitrate Pollution without Compromising Crop Yields: A Case Study in a Mediterranean Calcareous Soil. *Journal of Soils and Sediments* 20, no. 1 (January 1): 220–233.
- Mayer, A.M. 1997. Historical Changes in the Mineral Content of Fruits and Vegetables. *British Food Journal* 99(6): 207–211. doi: 10.1108/00070709710181540.
- Monroe, R. 2020. What Does It Take for the Coronavirus (or Other Major Economic Events) to Affect Global Carbon Dioxide Readings? *Scripps Institution of Oceanography*. <https://scripps.ucsd.edu/programs/keelingcurve/2020/03/11/what-does-it-take-for-the-coronavirus-or-other-major-economic-events-to-affect-global-carbon-dioxide-readings/>.
- Nguyen, M.-L., F. Zapata, and G. Dercon. 2010. “Zero-Tolerance” on Land Degradation for Sustainable Intensification of Agricultural Production. In: Zdruli P., M. Pagliai, S. Kapur, A. Faz Cano (eds.), *Land Degradation and Desertification: Assessment, Mitigation and Remediation*, 37–47. Dordrecht: Springer Netherlands.
- Nieder, R., D.K. Benbi, and F.-X. Reichl. 2018. *Soil Components and Human Health*. Heidelberg: Springer Netherlands.
- Ogen, Y. 2020. Assessing Nitrogen Dioxide (NO₂) Levels as a Contributing Factor to Coronavirus (COVID-19) Fatality. *Science of the Total Environment* 726 (April): 138605.

- Ohno, T., and G.M. Hettiarachchi. 2018. Soil Chemistry and the One Health Initiative: Introduction to the Special Section. *Journal of Environmental Quality* 47, no. 6 (November): 1305–1309. <https://www.ncbi.nlm.nih.gov/pubmed/30512058>.
- Oliver, M.A., and P.J. Gregory. 2015. Soil, Food Security and Human Health: A Review. *European Journal of Soil Science* 66, no. 2 (March 1): 257–276. <http://doi.wiley.com/10.1111/ejss.12216>.
- Page, K.L., Y.P. Dang, and R.C. Dalal. 2020. The Ability of Conservation Agriculture to Conserve Soil Organic Carbon and the Subsequent Impact on Soil Physical, Chemical, and Biological Properties and Yield. *Frontiers in Sustainable Food Systems*. <https://www.frontiersin.org/article/10.3389/fsufs.2020.00031>.
- Prusiner, S.B. 1982. Novel Proteinaceous Infectious Particles Cause Scrapie. *Science* 216, no. 4542: 136–144.
- Prusiner, S.B. 1998. Prions. *Proceedings of the National Academy of Sciences of the United States of America* 95: 13363–13383. National Academy of Sciences.
- Radwan, S.S., H. Al-Awadhi, and I.M. El-Nemr. 2000. Cropping as a Phytoremediation Practice for Oily Desert Soil with Reference to Crop Safety as Food. *International Journal of Phytoremediation* 2, no. 4: 383–396.
- Rennenberg, H., C. Herschbach, and A. Polle. 1996. Consequences of Air Pollution on Shoot-Root Interactions. *Journal of Plant Physiology* 148, no. 3–4 (January 1): 296–301.
- Reuters. 2020. Global CO2 Measurement Hits Record High in May Despite Pandemic Induced Lockdown. *News 18*. <https://www.news18.com/news/world/global-co2-measurement-hits-record-high-in-may-despite-pandemic-induced-lockdown-2653289.html>.
- Semenchuk, P.R., E.J. Krab, M. Hedenström, C.A. Phillips, F.J. Ancin-Murguzur, and E.J. Cooper. 2019. Soil Organic Carbon Depletion and Degradation in Surface Soil after Long-Term Non-Growing Season Warming in High Arctic Svalbard. *Science of The Total Environment* 646: 158–167.
- Singh, G. 2015. Agriculture Diversification for Food, Nutrition, Livelihood and Environmental Security: Challenges and Opportunities. *Indian Journal of Agronomy* 60, no. 2: 172–184. <http://www.indianjournals.com/ijor.aspx?target=ijor:ija&volume=60&issue=2&article=001>.
- Vanek, S.J., A.D. Jones, and L.E. Drinkwater. 2016. Coupling of Soil Regeneration, Food Security, and Nutrition Outcomes in Andean Subsistence Agroecosystems. *Food Security* 8, no. 4 (August 1): 727–742.
- Villagra, E.L., M.G. Minervini, E.Z. Brandán, and R.R. Fernández. 2012. Effects of Mineral Nutrition and Biofertilization on Lettuce Production under Conventional and Soilless Culture. *Acta Horticulturae* 947, no. 947 (May 1): 395–400. https://www.actahort.org/books/947/947_51.htm.
- Watson, C.A., D. Atkinson, P. Gosling, L.R. Jackson, and F.W. Rayns. 2002. Managing Soil Fertility in Organic Farming Systems. *Soil Use and Management* 18, no. s1 (September 1): 239–247. doi:10.1111/j.1475-2743.2002.tb00265.x.
- WHO. 2019. Malnutrition Is a World Health Crisis. *World Health Organization: Nutrition*. <https://www.who.int/nutrition/topics/world-food-day-2019-malnutrition-world-health-crisis/en/>.
- Yang, X.E., W.R. Chen, and Y. Feng. 2007. Improving Human Micronutrient Nutrition through Biofortification in the Soil-Plant System: China as a Case Study. *Environmental Geochemistry and Health* 29, no. 5: 413–428.

2 Health of Soil, Plants, Animals, and People

Kathi J. Kemper, Ye Xia, Jeffrey Lakritz, and Rattan Lal
The Ohio State University

CONTENTS

2.1	Overview.....	13
2.2	One Health.....	14
2.3	Soil Health.....	15
2.3.1	Soil and Life.....	15
2.3.2	Soil Health.....	15
2.3.3	Soil Health and Human Health.....	17
2.3.4	Soil Management and Human Health.....	18
2.4	Plant Health.....	18
2.4.1	Soil Health and Its Indicators in Agriculture System.....	18
2.4.2	Plant Pathogens and Their Caused Destructive Diseases on Plants.....	19
2.4.3	Agricultural Practices Affect Plant and Soil Health.....	21
2.4.4	Plant- and Soil-Associated Microbiomes for Plant Growth and Health.....	22
2.5	Animal Health.....	23
2.5.1	Livestock Production-Soil and Plant Health.....	23
2.5.2	Effects of Soil on Animal Health.....	23
2.5.3	Effects of Plants on Animal Health.....	29
2.5.4	Effect of Animals on Soil and Plant Health.....	30
2.6	Human Health.....	33
2.6.1	Human Activity Impacts Soil Health.....	33
2.6.2	Soil Impact Physically.....	34
2.6.3	Soil Impact on Human Nutrition.....	34
2.6.4	Toxic Compounds in Soil Impact Human Health.....	35
2.6.5	Soil Pathogens.....	36
2.6.6	Soil as Source of Modern Antibiotics and Other Benefits.....	37
2.7	Conclusions.....	38
	References.....	38

2.1 OVERVIEW

This chapter is based on the concept of “One Health,” a global, collaborative, multidisciplinary effort to attain optimal health for plants, animals, people, and the environment. “One Health” recognizes the fundamental interconnectedness of ecosystems, plants, animals, and humans (Figure 2.1). The health or toxicity of one affects all.

1. Healthy soil is a vital, living ecosystem that sustains productive populations of soil organisms. Healthy soil contains nutrients that sustain all land-based plant, animal, and human life; it is also the source of some of our most important antibiotics. On the other hand, soil that has been compacted, eroded, contaminated (e.g., with toxic heavy metals), or which

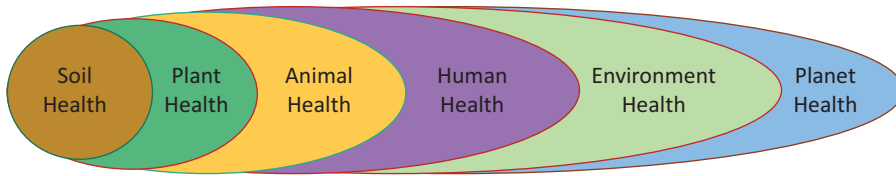


FIGURE 2.1 Relationships between ecosystem, plant, animal, and human health. The “One Health” concept: the continuum between the health of the soil, planet, and its ecosphere (e.g., hydrosphere, atmosphere, biosphere, and pedosphere).

has been subjected to pesticides or imbalances of healthy and pathogenic organisms (e.g., helminths, protozoa, bacteria, fungi, and viruses), reduces the viability of plants, animals, and humans. Optimal agricultural and forestry practices can also promote soil’s role as a carbon sink, offsetting anthropogenic increases in atmospheric carbon dioxide.

2. Healthy plants are critical for ecosystem and for the security of food for animal and human beings. Unhealthy plants cannot provide optimal nutrients for livestock or humans; plants contaminated with heavy metals (e.g., arsenic) or pathogenic organisms (e.g., *E. coli* or *Salmonella*) can be toxic for humans and livestock.
3. Healthy animals promote healthy soil, contribute nutrients to healthy plants, and promote optimal human nutrition. Livestock consume significant amounts of grain and produce methane, a potent greenhouse gas; animal waste can also contaminate food crops with pathogenic organisms leading to human illnesses.
4. The human population has grown from 2.5 billion in 1950 to over 7 billion today, and is expected to exceed 9 billion by 2050, accelerating expanding needs for healthy crops and livestock. At the same time, the amount of land available to grow food has been contracted by expanding cities, rising sea levels, desertification, and salinization as the climate crisis escalates; furthermore, rising CO₂ levels promote rapid carbohydrate accumulation in plants without concomitant increases in protein and essential minerals, leading to a relative decrease in the nutritional value of crops and animals that feed on those crops. Human behaviors such as mining, agriculture, and industry can result in toxic dumping that adversely affects the health of soil, plants, and animals and reduces biodiversity. Human health is inextricably linked to the health of the soil as well as the diverse plants and animals with whom we share this planet, and humans can act to protect this ecosystem or destroy it.

2.2 ONE HEALTH

“One Health” (Figure 2.1) has been defined as “the collaborative effort of multiple disciplines—working locally, nationally, and globally—to attain optimal health for people, animals, plants, and our environment” (King et al. 2008). “One Health” has a rich history. In the Bible, Moses (Anon. 2002) recommended that the people observe as they entered Canaan,

See what the land is like and whether the people who live there are strong or weak, few or many. What kind of land do they live in? Is it good or bad? How is the soil? Is it fertile or poor? Are there trees on it or not? Do your best to bring back some fruit of the land.

(Numbers 13:18–20)

For example, in the 19th century, prominent human biomedical researchers such as the microbiologist, Robert Koch, and immunologist, Paul Ehrlich, worked in the fields of both animal and human medicine (Shomaker, Green, and Yandow 2013). The father of cell biology, Rudolf Virchow, also recognized the relationship between human and animal health and passed it along to his student, Sir William Osler, who brought the concept to North America. Sir Albert Howard, President

of the National Academy of Sciences in India, said in the early 20th century, “Health of soil, plants, animal, and people is one and indivisible” (Howard 1943, 1945). The concept of “One Health” has continued into the 21st century by both veterinarians and physicians who recognized that many animal illnesses have much to teach physicians about human health.

The US Centers for Disease Control and Prevention (CDC) has a “One Health” office (<https://www.cdc.gov/onehealth/index>), recognizing approximately six out of every ten infectious diseases in humans are spread from animals. For example, nearly 75% of infectious diseases emerging in the past 30 years that affect humans originated in animals. These include HIV/AIDS (from West African primates), global influenza H1N1 pandemic (from swine), SARS (from Chinese bats and palm civets), and Covid-19 (Coronavirus Disease 2019). In addition, the “One Health” Commission (<https://www.onehealthcommission.org>) is rooted into the understanding of the *interdependence* of human and natural systems, and addressing the loss of biodiversity, pollution, climate change, ecosystem function, and the social determinants of health, including social justice. The “One Health” Commission is a partnership of multiple organizations including the American Medical Association, the American Public Health Association, the Association of American Medical Colleges, the American Veterinary Medical Association, and the Association of American Veterinary Medical Colleges. As awareness of the impact of climate change on human health has grown, the concept of “One Health” has expanded to include not only animal and human health but also the health of ecosystems.

The relationships between ecosystems, plant, animal, and human health are complex and interconnected (Figure 2.1). The driving force of all ecosystems is plant-based photosynthesis, which uses the sun’s energy to convert atmospheric CO₂ to energy-rich compounds, which can then transfer solar energy via carbon-based compounds to other organisms within the ecosystem (Reicosky and Janzen 2018). Although the flow of carbon-based energy drives ecosystem function, the reserve of stored soil carbon provides resilience to the system, serving as a buffer of energy and nutrients and sustaining the system during stresses and shortfalls (Reicosky and Janzen 2018). The ecosystem (of which soil is a vital component) affects human health both directly and indirectly. For example, waterborne illnesses kill an estimated 2.5 million people globally annually. While some of these illnesses come directly from contaminated water, some come indirectly from contaminated soil, which contaminates water, thereby affecting food plants and livestock.

2.3 SOIL HEALTH

2.3.1 SOIL AND LIFE

Soil is the essence of all terrestrial life. Charles Kellogg (1938) stated that “essentially all life depends upon the soil—There can be no life without soil and no soil without life; they have evolved together.” The rhizosphere, root-soil interphase at the nanoscale, is the only site in the universe which possesses the divine powers of resurrecting death into life. In “A Sand County Almanac,” Wendell Berry (1977) reiterated that “The soil is the great connector of our lives, the source and destination of it all.” Aldo Leopold (1949) opined that “Land, then, is not merely soil; it is a fountain of energy flowing through a circuit of soils, plants, and animals.” John Muir (1838–1914) emphasized the importance of interconnectivity by stating that “When we try to pick out anything by itself, we find it hitched to everything else in the Universe” (Muir 1911). It is this interconnectivity, indicating that everything is connected to everything else (Commoner 1971), which is depicted in Figure 2.1 from the scale of a pedon to that of the planet.

2.3.2 SOIL HEALTH

Terms “soil quality” and “soil health,” often used interchangeably, are indeed different (Lal 2016). Soil quality denotes soil functions or what it does (Doran and Werner 1990; Doran and Zeiss 2000; Doran 1990). In comparison, soil health is defined as the “capacity of soil to function as a vital living

system to sustain biological productivity, maintain environment quality, and promote plant, animal, and human health (Doran, Sarrantonio, and Liebig 1996; Doran and Zeiss 2000). In essence, soil health is the biological component of soil quality (Figures 2.2 and 2.3).

Soil quality can be quantified by measurements of soil properties and processes. In comparison, soil health is still a qualitative aspect, and efforts need to be made to quantify its attributes and

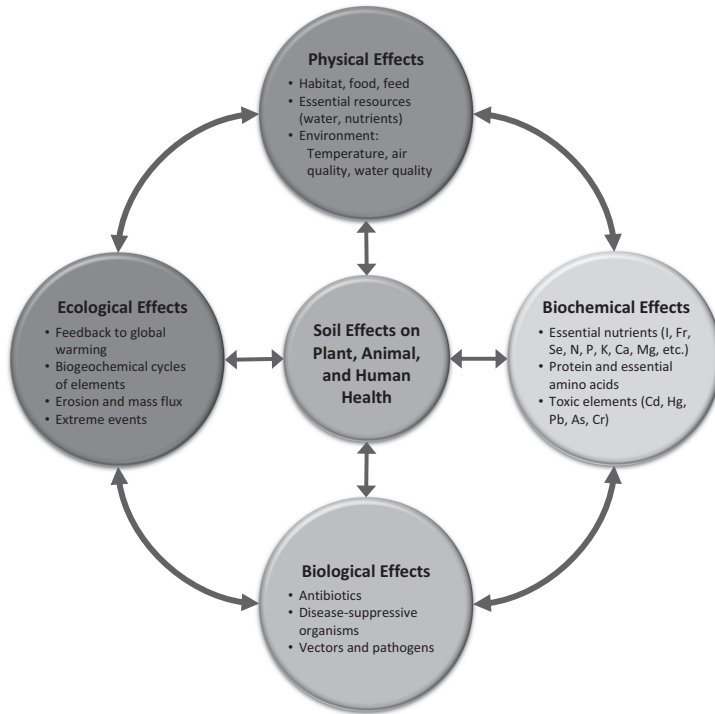


FIGURE 2.2 Soil effects on plant, animal, and human health (Kemper, Lakritz, and Lal 2017).

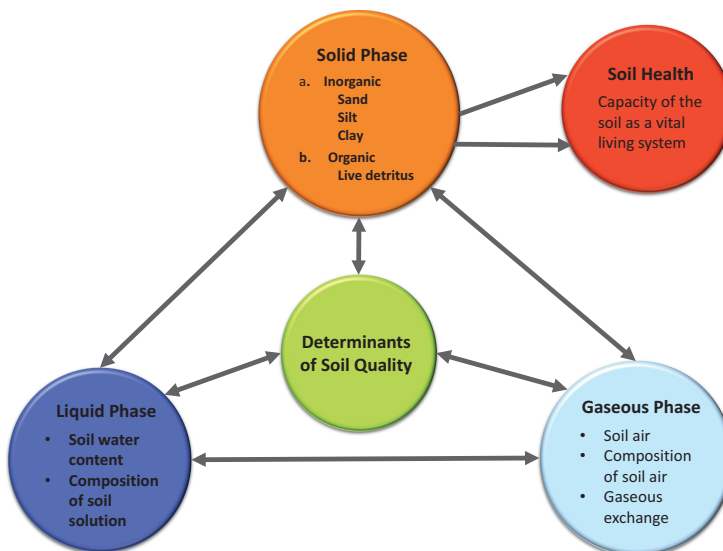


FIGURE 2.3 Relationship between soil quality and soil health.

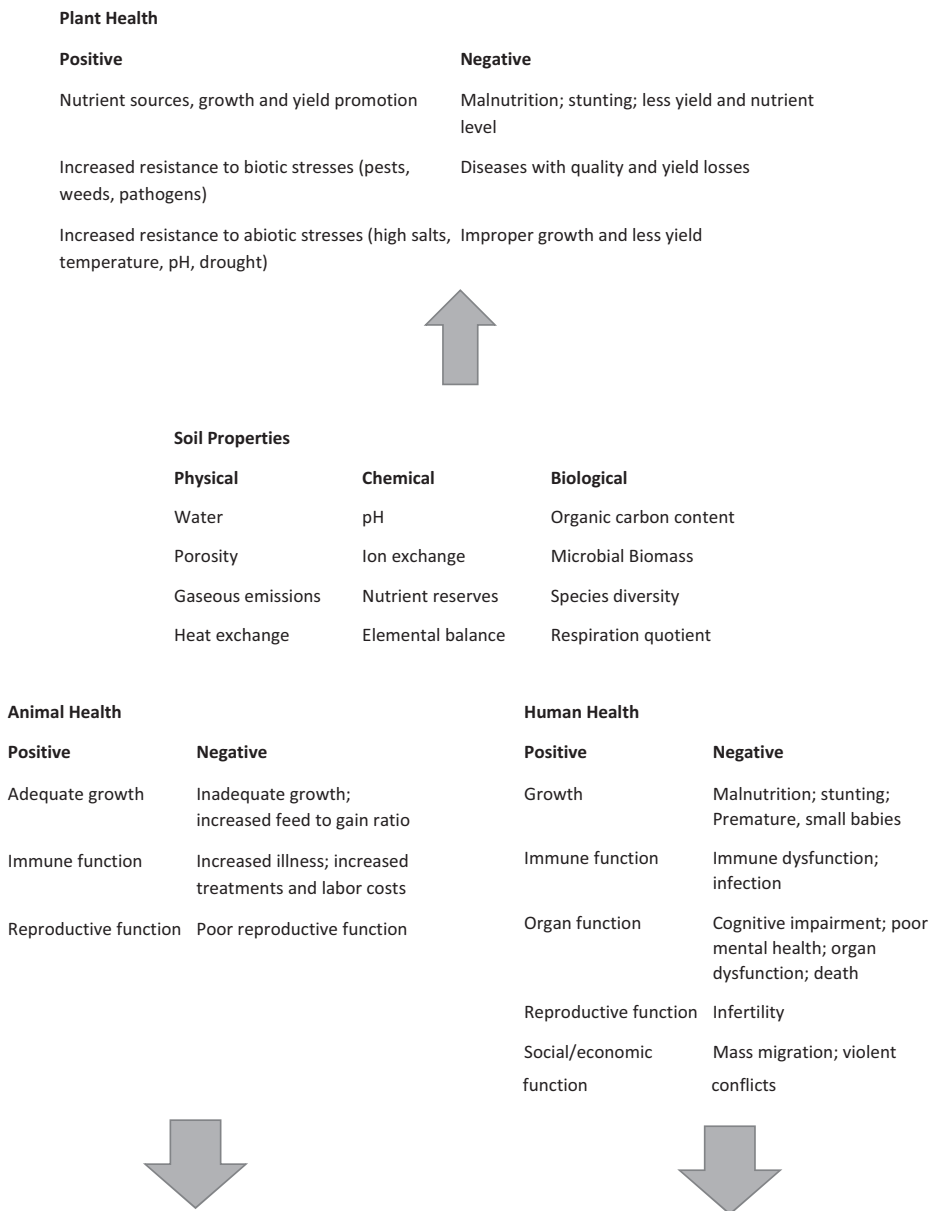


FIGURE 2.4 Positive and negative effects of soil properties on plant, animal, and human health (Kemper, Lakritz, and Lal 2019).

indicators. However, being a biological component, it is highly dynamic and strongly influenced by natural and anthropogenic perturbations. Soil health has important positive and negative effects on the health of plants, animals, and human health (Figure 2.4).

2.3.3 SOIL HEALTH AND HUMAN HEALTH

There is a strong interest in managing human health by a holistic approach of managing the environment in which humans live. Thus, there is a growing interest in linking human health to that of soil health. Soil health can be managed through specific land uses (e.g., arable, pastoral, silvicultural,

urban, recreational, and industrial) (Figure 2.5). Because of the rapid, growing interest in managing human health through systemic treatments of the causes, some recent publications are focused on important thematic issues, including (i) the framework for “One Health” research (Lebov et al. 2017), (ii) cycling of microbial communities (van Bruggen et al. 2019), (iii) soil chemical properties (Ohno and Hettiarachchi 2018), (iv) soil processes and human health (Brevik and Burgess 2014), and (v) the rationale for the focus on soil–human health connection (Shafer 2018), and many others.

Among numerous reasons for linking soil health to human health are based on the truism that soil is the (i) basic media for growing plants and raising livestock, (ii) reservoir of biodiversity and of the germplasm, (iii) store of water, (iv) filtration and purification of water, (v) foundation of all civil structures, (vi) archive of human and planetary history, (vii) moderator of climate, (viii) source/sink of greenhouse gases, (ix) basis of earth’s future, (x) the source of raw material for many, (xi) media for recycling nutrients, and (xii) source of esthetic and spiritual values. For these and many other reasons, 2015 was declared the U.N. Year of the Soil (FAO 2015), 2015–2024 is declared the Decade of the Soil (IUSS 2015), and the World Soil Day is celebrated on the 5th of December (IUSS 2002).

2.3.4 SOIL MANAGEMENT AND HUMAN HEALTH

Soil is finite, highly variable over time and space, and is fragile to natural and anthropogenic perturbations. Anthropogenic perturbations that affect human health include (i) plowing, (ii) vehicular traffic, (iii) irrigation, (iv) use of agricultural chemicals, (v) surface mining for minerals and topsoil, (vi) farming operations, and (vii) development of infrastructure. These and other land uses can also affect human health through human-induced degradation of soil quality. Other stressors on ecosystems, plant, animal, and human health include climate change, rapid population growth, urbanization, economic disparities, pollution, destruction of habitat and loss of biodiversity, international conflict and political destabilization, and rapid human migration (Table 2.1).

2.4 PLANT HEALTH

2.4.1 SOIL HEALTH AND ITS INDICATORS IN AGRICULTURE SYSTEM

Soil health not only relates to the physical, chemical, and biological properties of soil but also to its impact on plant growth and productivity in agriculture systems (Aziz, Mahmood, and Islam 2013;

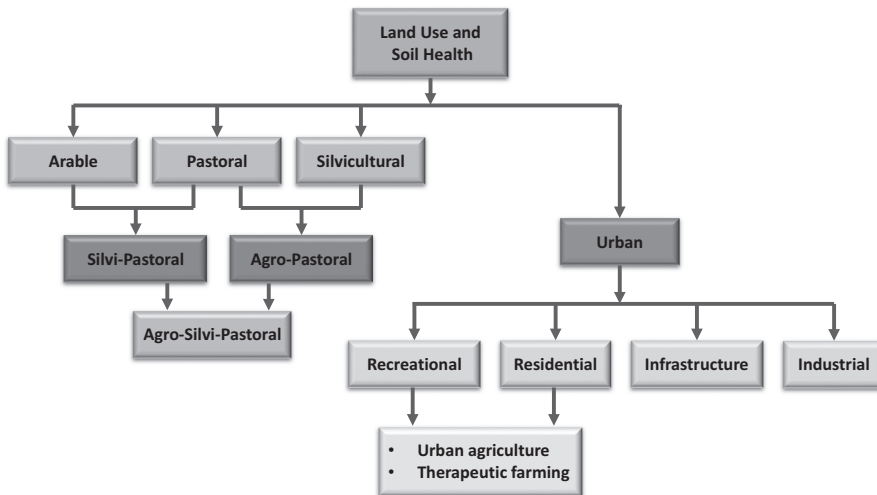


FIGURE 2.5 Strategies of managing soil health through specific functions or land uses.

TABLE 2.1
Stressors on Ecosystems, Plant, Animal, and Human Health

1. Climate change, warming, ocean acidification and sea-level rise, severe storms, flooding; fires
2. Rapid human population growth from over 7 billion to an anticipated 9.5 billion by 2050
3. Urbanization
4. Economic disparities
5. Pollution
6. Habitat destruction and loss of biodiversity
7. International conflict, terrorism, political destabilization, revolution
8. Rapid human migration (e.g., refugees from climate, conflict, and famine) and international travel allowing rapid spread of diseases

Bal et al. 2013; Yucel et al. 2015). Soil health is strongly influenced by the concentration and composition of the soil organic carbon (SOC) and nitrogen (Lal 2007).

Improved soil health helps to enhance the resilience of croplands to extreme weather events and biotic stress, and directly impacts the local jobs and the economic stability of rural communities (Clay et al. 2015). In conventional systems, however, soil health is often a lesser priority amid others, such as higher yields, protection of crops from pests and diseases, and most importantly net income. Commonly, the accepted indicators of soil health include a combination of microbial biomass, biodiversity and efficiency, aggregate stability, drainage and water retention, nutrient cycling, active and passive pools of soil organic matter (SOM), soil enzyme activities, etc. (Romig, Garlynd, and Harris 1997; Islam and Weil 2000; Aziz, Mahmood, and Islam 2013). Of all the indicators, SOM is a composite indicator of healthy soil and contributes to food security and ecosystem resilience (Zebarth et al. 1999; Islam and Weil 2000; Aziz et al. 2015; Lal 2017). The balance among the natural processes of primary production, decomposition, and transformation contributes to the SOM formation (Wilson 1991). SOC, through its impact on soil health and crop productivity, has a high societal value (Lal 2014).

Agricultural management practices known to improve the SOM and overall soil health include but are not limited to the no-till, crop rotation, cover crops, soil amendments, and beneficial microbes, such as the plant growth promotion bacteria and arbuscular mycorrhizal fungi (AMF) (González et al. 2003; Slepeticene 2001). Soil organic amendments have been used as the source of organic matters and essential nutrients (Celik, Ortas, and Kilic 2004; Tejada et al. 2008). Soils with high and labile organic matter may provide a better environment for enhanced microbial diversity and efficiency. In addition, soil with high organic matter contents has a greater abundance of water-stable aggregates with higher exchange capacity for plant nutrients. Complex organic nutrients need to be broken down by diverse microbes for plants to utilize them efficiently (Tejada et al. 2008). A higher SOM content also improves the water-infiltration and water-holding capacity, providing plant resilience to drought and other stresses to stabilize long-term farm economics (Celik, Ortas, and Kilic 2004; Lal 2007, 2017).

2.4.2 PLANT PATHOGENS AND THEIR CAUSED DESTRUCTIVE DISEASES ON PLANTS

There are many microbial pathogens that can infect different plant species in the greenhouse and field conditions, which can cause huge yield and economic losses. Of all the problems related to the pathogen-caused plant diseases, those caused by the soilborne pathogens can be the most frustrating ones (Table 2.2). In the fields, the destructive soilborne pathogens, such as *Rhizoctonia* spp., *Sclerotinia* spp., *Pythium* spp., *Fusarium* spp., and *Verticillium* spp., could cause infections on plants separately or together (Gao et al. 2014). These pathogens can survive in the soil even when their usual host crops are no longer present. For example, *Rhizoctonia solani* is a soilborne pathogen

and can cause severe disease pressure and huge yield losses on tomato plants and many other plant species (Meyer et al. 2006). The related destructive plant disease symptoms caused by these soil-borne pathogens include but are not limited to the damping-off of seedlings, aerial blights, root rots, and stem cankers on the plants. Currently, many plant species are short of resistant varieties to confer resistance to most of the soilborne pathogens; therefore, the chemical control by the fungicide/bactericide application is the main approach (Stevens et al. 2003). However, the long residue of these chemicals can lead to the harmful effects on human health and environment. To reduce chemical applications, the combined use of fungicides/bactericides with proper agricultural practices could potentially enhance the efficacy of the related disease controls (Hüberli et al. 2015). Many studies have shown that plant diseases caused by the soilborne pathogens, such as the *R. solani*, could also

TABLE 2.2
Soilborne Infectious Diseases of Plants, Animals, and Humans

Category	Examples in Plants	Examples in Animals	Examples in Humans
Helminths	Phylum Nematoda, nematodes, such as root-knot nematode (<i>Meloidogyne</i> species); cyst nematode (<i>Heterodera</i> species); Sting Nematode; needle nematodes (<i>Longidorus africanus</i>); stubby root nematodes (<i>Paratrichodorus</i> species)	Nematodes—Hookworm (<i>Bunostomum phlebotomum</i>); Trichostrongylid nematodes (<i>Haemonchus contortus</i> , <i>Trichostrongylus</i> spp., <i>Ostertagia ostertagia</i> , <i>Cooperia</i> spp.), Trichuriasis, <i>Ascaris suum</i> , <i>Dictyocaulus viviparus</i> , <i>Protostrongylus</i> spp., <i>Muellerius</i> spp.	Ascariasis (roundworms), Echinococcosis, Hookworm, Strongyloidosis (threadworms), Trichuriasis (whipworms), Trichinellosis (Trichinosis)
Protozoa	Naked amebae, testate amebae, flagellates, ciliates, microsporidia, and sporozoans	<i>Eimeria</i> spp., <i>Entamoeba histolytica</i> , Cryptosporidiosis, Giardiasis	<i>Entamoeba histolytica</i> (Amebiasis), Cryptosporidiosis, Cyclosporiasis, Giardiasis, Toxoplasmosis
Fungi (oomycetes)	<i>Microdochium</i> , <i>Sclerotinia</i> , <i>Fusarium</i> , <i>Rhizoctonia</i> , <i>Verticillium</i> , <i>Monosporascus</i> , <i>Aphanomyces</i> , <i>Bremia</i> , <i>Phytophthora</i> , <i>Pythium</i> , <i>Macrophomina</i> , <i>Plasmodiophora</i> and <i>Spongospora</i>	Endophytes (<i>Neotyphodium coenophialum</i>), <i>Trichophyton verrucosum</i> , Histoplasmosis, Blastomycosis, Cryptococcosis, Coccidioidomycosis, Aspergillosis, Mucormycosis	Aspergillosis, Blastomycosis, Coccidioidomycosis (Valley fever), Histoplasmosis, Sporotrichosis, Mucormycosis, Nocardia
Bacteria	<i>Rhizobium radiobacter</i> (<i>Agrobacterium tumefaciens</i>), <i>Erwinia</i> , <i>Rhizomonas</i> , <i>Streptomyces</i> , <i>Pseudomonas</i> and <i>Xanthomonas</i> for short time in soil.	<i>Listeria monocytogenes</i> , <i>Salmonella</i> spp., <i>E. coli</i> , <i>Campylobacter</i> spp., <i>Yersinia enterocolitica</i> , <i>Enterococcus</i> spp., <i>M. avium</i> , spp. <i>pseudotuberculosis</i> , Clostridial intoxications (<i>Clostridium chauvoeii</i> , Cl. novyi Type D, Cl. Septicum, Cl. Sordelli, Cl. Perfringens Type C, Cl. Perfringens Type D, Cl. Tetani, Cl. Botulinum, <i>Bacillus anthracis</i> , Leptospirosis, Dermatophilosis, <i>Actinobacillus ligneresii</i> , <i>Actinomyces bovis</i> , <i>Brucella abortus</i>	Actinomycosis, Anthrax, <i>Bacillus cereus</i> , <i>Campylobacter</i> , <i>Clostridium botulinum</i> (Botulism), <i>C. perfringens</i> (gas gangrene), <i>Clostridium tetanus</i> , <i>Coxiella burnetti</i> (Q fever), <i>Escherichia coli</i> (Enterohemorrhagic, Enterotoxigenic, Verotoxigenic, and Enteropathogenic types), Legionella, Leptospirosis, <i>Listeria monocytogenes</i> , Lyme disease, Melioidosis, <i>Pseudomonas</i> , Salmonellosis (including typhoid fever and non-typhoid salmonella infections), Shigellosis, Tularemia, <i>Yersinia pestis</i> (plague)

(Continued)

TABLE 2.2 (Continued)**Soilborne Infectious Diseases of Plants, Animals, and Humans**

Category	Examples in Plants	Examples in Animals	Examples in Humans
Viruses	Lettuce necrotic stunt virus (LNSV); Beet necrotic yellow vein virus (BNYVV; genus <i>Benyvirus</i>), Potatomop-topvirus (PMTV; genus <i>Pomovirus</i>); <i>Furovirus</i> (type species soilborne wheat mosaic virus); <i>Bymovirus</i> (type species Barley yellow mosaic virus); Peanut clump virus (PCV; genus <i>Pecluvirus</i>); infection of lettuce big-vein associated virus (LBVaV; genus <i>Varicosavirus</i>); Mirafiori lettuce big-vein virus (MiLBVV; genus <i>Ophiovirus</i>); Viruses of the genera <i>Tombusvirus</i> (cucumber necrosis virus; CNV), <i>Carmovirus</i> (i.e., melon necrotic spot virus, MNSV); Grapevine Fan leaf virus (GFLV, genus <i>Nepovirus</i>); Tobacco rattle virus (TRV, genus <i>Tobravirus</i>).	Coronavirus, <i>Vesicular stomatitis</i> , <i>Rotavirus</i> , Contagious ecthyma virus, Goat pox, Peste des petitis ruminants,	Enteroviruses (poliovirus, coxsackieviruses, and echoviruses), <i>Hantavirus</i> (hantavirus pulmonary syndrome or hemorrhagic fever with renal syndrome)

be suppressed by either adding SOM for general suppression, or/and specific microbial antagonists by beneficial microbes, such as the bacteria *Bacillus* species (Weller et al. 2002; Stone, Scheuerell, and Darby 2004) and AMF (Abdel-Fattah et al. 2011).

2.4.3 AGRICULTURAL PRACTICES AFFECT PLANT AND SOIL HEALTH

More and more studies have investigated the comparisons between conventional and sustainable farming systems, such as the organic farming system. These studies reveal that sustainable agricultural practices can influence soil composition and functions, which could be associated with higher biological efficiency and diversity of the soil-associated microbial communities (Monokrousos et al. 2006; Esperschütz et al. 2007; Araujo et al. 2009; R. Li et al. 2012). To conserve system biodiversity, including the soil microbes, sustainable practices excluding the pesticide use could reduce their impacts on the nontarget organisms (Kuepper and Gegner 2004). Our previous studies examined the culturable endophytic bacterial and fungal communities from four economically important crops, including corn, tomato, pepper, and melon, grown under low-input organic or conventional management practices. Our results showed that the plant culturable endophytic bacterial and fungal communities were significantly impacted by different agricultural production practices (conventional vs. organic farming system) (Xia et al. 2015, 2019).

The agricultural practices, such as crop rotation with cover crops and green manures, conservation tillage, and microbial products usage contribute to building an active, diverse, disease-suppressive soil associated with certain microbial communities, which have been shown to effectively reduce most of the major soilborne diseases and enhance plant tolerance to abiotic/biotic stress and yield within their respective agro-ecosystems (Marzano 2012).