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Sheo Mohan Prasad *Editors*

Plant Responses to Soil Pollution

Springer

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Dedicated to Our Parents

Foreword

I am pleased to write the foreword for this book edited by Dr. Pratibha Singh, Dr. Sunita Kumari Singh, and Dr. Sheo Mohan Prasad. They have focused this book on an extremely important area of active research—the effects of soil pollutants on plants. Anything entering the environment in any form will reach the soil ultimately and the water table in turn and thus entering the food chain. Plants play a major role in the functioning of terrestrial and aquatic ecosystems and are important in order to achieve the goal of food security to feed the ever-increasing population. Unfortunately, the fast pace of development is leading to the addition of contaminants in soil, air, and water in the form of inorganic contaminants, metals, radionuclides, pesticides, and even chemical fertilizers, which proved to be a boon to farmers during the Green Revolution. With time, the pollutants accumulate and show biomagnification when they enter the food chain and become harmful for the health of plants, animals, and human beings. The effect of these soil pollutants on plants may include the accumulation of contaminants into the plant, including the edible portion of food crops, growth, morphology, physiological, and biochemical processes of plants, and productivity. It then also affects the health of other living beings on earth as plants are a source of food to them. This book highlights the side effects of modern agricultural management practices on the health of soil in terms of fertility and also increase in greenhouse gases from agricultural land leading to climate change. Nowadays, there is a need to remediate the soil and various ways of eco-friendly remediation techniques as given in this book, which further adds to the value of this book. I believe this book makes an important contribution to our understanding of the impact of soil contaminants on plants, and its focus on mechanistic studies and risk assessment will be of interest to researchers as well as policy makers.

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Preface

Soil pollution is one of the major aspects of pollution emerging from urban advancements including the fast pace of industrialization and uncontrolled exploitation of natural resources. Anything beyond the threshold limit becomes pollutants. Soil pollution minimizes the yield and quality of the crops and also alters soil biodiversity, soil organic matter as well as groundwater which in turn disturb the equilibrium of soil nutrients and its uptake by plants. The book discusses the grade of soil contamination, its origin, and its aftereffects on plants and their productivity status. Soil pertains to the multiphasic, heterogeneous environments, and successful remediation is dependent on an interdisciplinary approach involving disciplines such as microbiology, engineering, ecology, geology, and chemistry. In this volume, different kinds of soil contaminants and how the soil biota and plants which are the keystone of this ecosystem get affected at various levels are discussed in detail. How the soil pollutants enter the food chain, accumulate in the environment, and the techniques on remediation of problem soils are explained in the following chapters of the book.

Chapter 1. *Soil Acidification and Its Impact on Plants*: Soil is a living entity. The chapter well manifests the structure, function of soil, and the significance of pH based on which the acidity and alkalinity of soil is determined. pH plays an important role behind various soil functions like soil aggregate stability, nutrient availability, metal toxicity, and biological activities. The chapter explains the causes behind soil acidification which nowadays relate to various anthropogenic practices and natural biogeochemical cycles. The effects of acidity on the nutrient availability for plant in soil, metal toxicity, soil biological functions, and physiology of plants are discussed. The pathways of how soil acidity affect the plant community structure are described. It also tells about the strategies to be adopted to combat soil acidification.

Chapter 2. *Challenges to Organic Farming in Restoration of Degraded Land in India*: Degraded land is the indication of declined levels of productivity and economy of a country. In India, soil degradation has created very critical image in both rainfed and irrigated areas; it becomes more significant as it supports 18% of world's human population and 15% of world's livestock population with only 2.4% of global land area in which 29% land is degraded. This chapter discusses some possible opportunities and challenges of organic agriculture in degraded lands as a reformative measure.

Chapter 3. *Biochemical and Molecular Responses of Plants Exposed to Radioactive Pollutants*: Radioactive substances are unstable natural substances that decay and emit ionic radiation continuously in their surroundings. These are widely used in medicine, electricity, agriculture, industry, and research practices, which accumulate in the surroundings. Plants uptake these radionuclide wastes from soil and absorb from air. These radionuclides with high energy interact with metabolic pathways and alter the molecular nature of plants eventually altering the biochemical products. This chapter discusses the accumulation of radioactive substances in the environment, their interaction with plants, and their rational aspects.

Chapter 4. *Cadmium*: *A Threatening Agent for Plants*: Amid all heavy metals, cadmium is one of the most serious pollutants as it can potentially accrue in plants and reaches to the next trophic level. A wide range of anthropogenic activities like phosphate fertilizers, green wastes, and sewage bio-solids to the soil leads to the addition of cadmium to soil. This chapter discusses its transport, mechanism of action and regulatory network, and harmful aspects of cadmium exposure to plants and its effect on seed germination, growth, development, chlorophyll content, photosystem and photosynthesis, carbon assimilation, and reproduction. It also explains the mechanism adopted by plants for cadmium detoxification and the technique adopted to nullify the toxicity of cadmium in halophytes and other treated plants.

Chapter 5. *Effect of Soil Polluted by Heavy Metals: Effect on Plants, Bioremediation, and Adoptive Evolution in Plants*: Heavy metals pertain to the most threatening agent affecting the biotic components of ecosystem due to its toxicity. The sources of heavy metal pollution in soil and how it affects the plant growth are detailed in the chapter. It manifests the factors affecting the metals bioavailability. The toxic effect of a variety of heavy metals in soil and on plants is discussed. The chapter gives details on the different eco-friendly remediation strategies evolved in the form of bioremediation/phytoremediation and the mechanism of their action along adoptive evolution in plants.

Chapter 6. *Plant Responses to Sewage Pollution*: Sewage is an amalgamation of various liquid and solid substances comprising both pathogenic and nonpathogenic microorganisms. The use of sewage as organic manure may increase the risk of exposure of soil and ultimately flora to pollutants. Heavy metals on being introduced into the food chain show bioaccumulation. This chapter discusses the positive as well as negative responses of plants to sewage effluents. Vermi-composting may be a safe alteration for sewage sludge. The transformation of sewage sludge compost by vermi-composting may be one of the most efficient tools to diminish the threat of heavy metal contamination caused by direct use of sewage sludge.

Chapter 7. *Soil Pollution Caused by Agricultural Practices and Strategies to Manage Them*: Soil plays the role of a mother for all living beings on earth. It acts as a source of water and nutrients facilitating the plant growth. Modern agricultural practices have resulted in another source of soil pollution due to overuse of agrochemicals and irrigation. These resulted in global food security but invariably affect the structure and function of soil biotic components, thus affecting soil fertility in turn. Long-term applications of agrochemicals affecting the soil physical properties and the activity of living nexus are detailed in this chapter. Among agrochemicals, pesticides are the most influential as it is bioaccumulable and enters the food chain and the water table due to its persistency, affecting the environment and human health in turn. The chapter also briefs the strategies to be adopted for reduction of agrochemicals and promoting organic farming.

Chapter 8. *Inorganic Soil Contaminants and Their Biological Remediation*: Soil remediation is indispensable for the sustainable development and conservation of ecosystem. There are several physical, chemical, and biological methods to remediate the contaminated area, among which biological methods are inexpensive, effortlessly pertinent, environmentally safe strategies. This chapter discusses the type of inorganic contaminants, their sources and implications for soils, and biological remediation potential of organisms and also provides an overview of the recent developments in this area.

Chapter 9. *Phytoremediation of Pollutants from Soil*: Due to unbridled industrialization various organic pollutants which are highly toxic and carcinogenic are released into the environment. Phytoremediation is an emerging, eco-friendly and potentially very effective green technology that utilizes plants to extract, detoxify, and accrue the toxic pollutants from the environment. This chapter focuses on remediation strategies for contaminated soil by using a variety of plants in order to understand the cleanup of the environment in an effective way. On the basis of their properties, organic pollutants can be degraded in the rhizosphere of the plants followed by degradation, sequestration, or volatilization.

Chapter 10. *Impacts of Soil Contaminants on Human Health with Special Reference to Human Physiognomy and Physiology*: Soil serves as a habitat for a broad spectrum of macro- and microorganisms. Discharge of pharmaceutical, medical, industrial, sewage, and household wastes in soil results in the growth of various lethal microbes, ultimately leading to the outburst of human diseases. Nutrient inequities of soil collectively with the pathogenic biotic community result in detrimental impacts on the health of humans, plants, and animals. This chapter endeavors to deliver elaborate and comprehensive information on the interaction between urban soil pollution and human health issues.

Chapter 11. *Impact of Herbicide Use on Soil Microorganisms*: Economic viability and easy application make herbicide use indispensable in modern agriculture. The effect of herbicide use on soil microorganisms, especially mycorrhiza, bacteria, and actinomycetes, ranges from positive to negative to no effects. Several short-term studies have shown transient negative effects in the early period of application. The chapter briefs the national and international status of pesticides and their effects on soil microorganisms. Any change in biotic components will alter the soil function in terms of soil heterotrophic respiration, activity of OM decomposing and nutrient-cycling microbes, enzyme activity determining the soil health, and plant productivity. The studies referred to in the chapter encourage the study of the long-term effect of herbicides involving various herbicides in variable environment.

Chapter 12. *Biological Magnification of Soil Pollutants*: Increasing population and urbanization pose a serious threat to the environment due to the unscientific disposal of huge solid and liquid wastes to its precious water bodies and agricultural land. Wastes released from industries had been proved to cause toxicity as heavy metals accumulate at different trophic levels without their role in the biological system. This chapter summarizes the main sources of soil pollutants and their role in biological magnification along with their adverse role at different trophic levels.

Chapter 13. *Soil Pollution and Human Health*: Disproportionate fertilizers and pesticide usage spoil groundwater through runoff and leaching. Accumulation of contaminants in soil may lead to their subsequent translocation to the food chain. Contaminants even at low levels may cause harm to human health and the environment. This chapter discusses the sources and assessment of soil contaminants, green technologies, policies, and the impact of pollution on human health.

Chapter 14. *Emission of Greenhouse Gases from Soil: An Assessment of Agricultural Management Practices*: Increase in the levels of greenhouse gases is a serious threat in the present scenario to both living beings and their niches. The agriculture sector has now become a potent contributor to emissions of greenhouse gases from soil to atmosphere and thus contributing to climate change. The chapter describes greenhouse gases and their characteristics. The methodology adopted in this chapter to draw conclusions was wide literature review with emphasis on developing countries over a period of 12 years from 2005 to 2016. The chapter provides information on the sources of greenhouse gases, position of agriculture in greenhouse gas emissions, and the role played by different agricultural management practices in the evolution of greenhouse gases. The chapter further discusses how environmental factors affect greenhouse gas emissions from soil and their effect on agriculture in turn and suggests different mitigation strategies to be adopted depending on the crop type and the environment.

Overall, this book provides all valuable information related to different kinds of soil pollutants, biomagnifications, their effect on soil and plants in terms of soil fertility, productivity, morphology, growth, physiology, and metabolism of plants along with biochemical changes. It also provides information on the evolution of greenhouse gases from soil on account of various agricultural management practices further leading to climate change in turn. The book also becomes the source of various remediation techniques adopted nowadays. It will definitely be useful for scientists, academicians, researchers as well as graduate and postgraduate students of different universities across the globe.

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Chapra, Bihar, India — Sunita Kumari Singh
Prayagraj, UP, India — Sheo Mohan Prasad

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About the Editors

Pratibha Singh has been working as DST—Women Scientist b (WOS b) in the Department of Botany at the University of Allahabad, India. Her areas of expertise include sustainable agriculture and the side effects of abiotic stresses present in the environment on soil and plants. The research work aims towards a holistic approach to achieving sustained soil fertility and productivity along with maintenance of plant health in terms of physiology and biochemistry in tropical croplands. Dr. Singh obtained her PhD in Botany from Banaras Hindu University, Varanasi, India. She received several fellowships from UGC, CSIR, and DST during her doctoral and postdoctoral programs. She has authored several scientific publications and two textbooks with reputed international publishers. She has participated in many national and international conferences and has presented her work in the form of both oral and poster presentations. She bagged several prizes as young scientist and won the best oral presentation award in an international conference. She has also delivered an invited talk at Malaya University, Kuala Lumpur, Malaysia. Dr. Singh is also the life member of Blue Planet Society and the Society for Science and Nature.

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Abbreviations

AM	Arbuscular mycorrhizal fungi
ANC	Acid neutralizing capacity
APEDA	Agricultural and Processed Food Products Export Development Authority
APOD	Ascorbate peroxidase
APOX	Ascorbate peroxidase
APX	Ascorbate peroxidase
ATP	Adenosine triphosphate
BD	Soil bulk density
BAF	Bioaccumulation factor
BNC	Base neutralizing capacity
BOD	Biological oxygen demand
CAT	Catalase
CDF	Cation diffusion facilitator
CEC	Cation exchange capacity
CEU	Continuing education unit
CFCs	Chlorofluorocarbons
Chernobyl NPP	Chernobyl Nuclear Power Plant
CPI	Crop pollution index
CRIDA	Central Research Institute for Dryland Agriculture
DAA	Days after application
DCP	2,4-dichlorophenols
DDT	Dichlorodiphenyltrichloroethane
DH	Dehydrogenase
DHAA	Dehydroascorbic acid
DNA	Deoxyribonucleic acid
DSBs	Double-stranded breaks
DTT	1,1,1-trichloro-2,2-bis p-chlorophenyl ethane
ECe	Soil electrical conductivity
EDTA	Ethylene diamine tetraacetic acid
EFSA	European Food Safety Authority
EMS	Ethyl methane sulfonate
EPA	Environmental Protection Agency

ESP	Exchangeable sodium percentage
ESRL	Earth System Research Laboratory
ETs	Economic thresholds
FAO	Food and Agriculture Organization
fb	followed by
FGD	Flue gas desulfurization
FMD	Foot and mouth disease
G6PDH	Glucose-6-phosphate dehydrogenase
GDP	Gross domestic product
GHGs	Greenhouse gases
GR	Glutathione reductase
GSH	Glutathione
GST	Glutathione S-transferase
GWP	Global warming potential
HFCs	Hydro-fluorocarbons
HMs	Heavy metals
ICAR	Indian Council of Agriculture Research
IPM	Integrated pest management
IQ	Intelligence quotient
IR	Ionizing radiation
IRT	Iron-regulated transporter
ISRO	Indian Space Research Organisation
IUCN	International Union for Conservation of Nature
K_{sat}	Saturated hydraulic conductivity
MDA	Malondialdehyde
MDGs	Millennium development goals
MIF	Micro irrigation fund
MRLs	Maximum residue limits
MTs	Metallothioneins
NABARD	National Bank for Agriculture and Rural Development
NADPH	Nicotinamide adenine dinucleotide phosphate
NAM	National Agriculture Market
NAPCC	National Action Plan on Climate Change
NGOs	Non-governmental organizations
NIH	National Institutes of Health
NORM	Naturally occurring radioactive materials
NPK	Nitrogen phosphorus potassium
NRA	Nitrate reductase
NWDPRA	National watershed development project for rainfed areas
OC	Organic carbon
OEC	Oxygen evolving complex
OM	Organic matter
OsHMA	*Oryza sativa* heavy metal ATPase
OsNRAMP	*Oryza sativa* natural resistance-associated macrophage proteins
OPT	Oligopeptide transporter

PAGE	Polyacrylamide gel electrophoresis
PAHs	Polycyclic aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
PCP	Pentachlorophenols
PCs	Phytochelatins
PFCs	Per-fluorocarbons
PMFBY	Pradhan Mantri Fasal Bima Yojana
PE	Pre-emergence
POD	Peroxidase
POE	Post emergence
POPs	Persistent organic pollutants
POX	Guaiacol peroxidase
PPCPs	Pharmaceuticals and personal care products
PSCs	Pollution safe cultivars
RADP	Rainfed Area Development Programme
RAPD	Random amplification of polymorphic DNA
RNA	Ribonucleic acid
ROS	Reactive oxygen species
SAR	Sodium absorption ratio
SOC	Soil organic carbon
SOD	Superoxide dismutase
SOM	Soil organic matter
SQ	Soil quality
SSA	Sub-Saharan Africa
TBARS	Thiobarbituric acid reactive substances
TCE	Trichloroethylene
TERI	The Energy and Resources Institute
TN	Total nitrogen
TPH	Total petroleum hydrocarbon
TWI	Tolerable weekly intake
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNEP	UN Environment Programme
USNRC	United States Nuclear Regulatory Commission
USSR	Union of Soviet Socialist Republics
WAA	Weeks after application
WDCGG	World Data Centre for Greenhouse Gases
WFPS	Water-filled pore space
WHO	World Health Organization
WSC	Water splitting complex

1 Soil Acidification and its Impact on Plants

Durgesh Singh Yadav, Bhavna Jaiswal, Meenu Gautam, and Madhoolika Agrawal

Abstract

Acidic soils are widespread covering nearly 40% of the world's total arable land area. However, soils of certain regions are naturally acidic but an increase in soil acidification as a result of accelerating anthropogenic activities is becoming a global issue. High emissions of acid precursors (nitrogen, sulfur, and carbon dioxide) in the atmosphere are chiefly responsible for acid precipitation, which in turn is a pre-eminent factor for soil acidification. Long-term application of nitrogen fertilizers is a major contributor in acidification of agricultural soil. Soil acidification is an important edaphic stress, which leads to cation leaching, instability in the soil aggregate structure, increases metal toxicity, lowers the soil nutrient availability, and consequently affects the soil biological properties and plant performances. The present chapter aimed to assess the consequent effects of soil acidification on plants and the plant community structure. It includes causes, processes, plants' responses, and remedial measures to combat soil acidification due to increasing pollution. Different plants may show different sensitivity to acidity and have diverse an optimal pH range for nutrient uptake. Besides, depletion of basic cations (Na, Ca, Mg, and K) due to leaching and increased solubility of toxic metals (Al and Mn) in soil restrict the plant's access to water and nutrients, thereby causing severe injury to roots, a reduction in crop yield, and an increase in plant susceptibility to pathogens. Plant diversity, species richness, and occurrence of species are significantly influenced by acidification of soil. Alteration in the plant community structure, in turn, may affect the ecosystem structure and functions. Acidification of soil could plausibly be ameliorated by nutrient management practices and by addition of acid-neutralizing substances.

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Keywords

Soil acidification · Plants · Crops · pH · Atmospheric depositions · Biodiversity

1.1 Introduction

The term "soil" has been derived from the Latin word "solum", which means part of the earth's crust that has been changed as a result of soil-forming processes. Soil (also known as the pedosphere) is the material, which slowly develops as a thin layer on the earth's surface over time. It is mainly composed of organic matter, weathered mineral particles, living organisms, liquids, and gases; hence is one of the most important earth's natural resources essential for living beings (Bhattacharyya and Pal 2015). Soil is a zone of plants' growth where plant nutrients are stored through the interaction of diverse factors such as water, air, sunlight, rocks, flora, and fauna.

Depending upon various biotic and abiotic factors in different regions across the globe, there are broadly 12 classes of soil, viz. alfisols, andisols, aridisols, entisols, gelisols, histosols, inceptisols, mollisols, oxisols, spodosols, ultisols, vertisols, and others (rocky lands, shifting sand, and ice/glacier) (Fig. 1.1, Table 1.1).

1.1.1 Properties and Functions of the Soil

General physicochemical properties of the soil include texture (percentage of silt, clay, and sand in soil), temperature, pH, salinity, bulk density, porosity, moisture

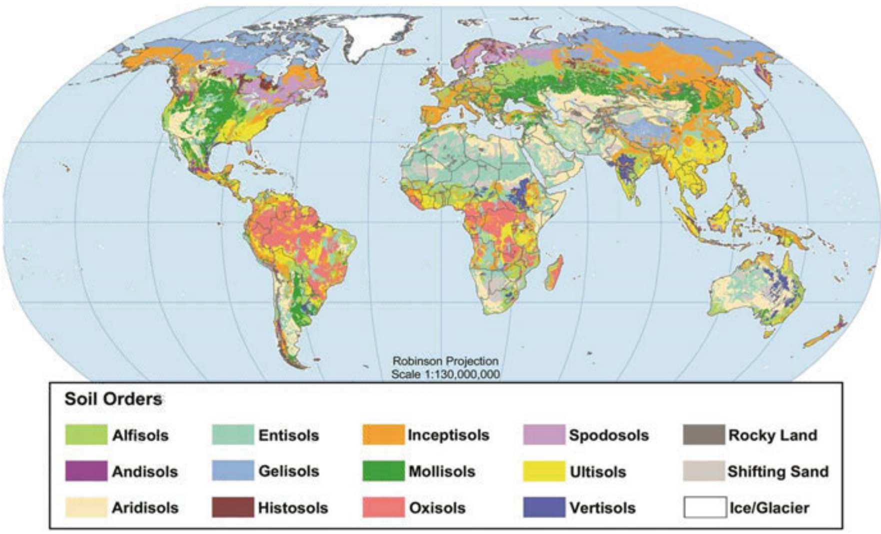


Fig. 1.1 Types of the soil in various regions of the world (Source: Soil Survey Division 2005)

Table 1.1 Key characteristics and occurrence of different classes of soil in various parts of the world

No.	Class	Key characteristics	Regions
1.	Alfisols	Commonly found in cool to hot humid areas, especially under forest and savannah grassland vegetation. Fertile with moderate to high base saturation Clay in subsoil horizons Covers about 10% of the world's ice-free land area	Europe, Russia, southern part of the USA, Mississippi, and Ohio river valleys in the USA
2.	Andisols	Form in volcanic ash and cinders Not extensively weathered High natural fertility and productivity High organic matter, low bulk density and can easily be tilled. Covers 1% of the world's ice-free land area	Limited geographic distribution
3.	Aridisols	Generally light in color and extensively found in tropical latitudes, rain shadow areas, and arid climates. Low organic matter with lime and salt accumulations Water deficient with low productivity High potential for land degradation due to overgrazing Occupies 12% of the world's ice-free land area	South-western and northern part of the USA, Australia, and many middle east regions
4.	Entisols	Little or no profile development in deep regolith Found at the site of unstable environments (floodplains, sand dunes, or those found on steep slopes) Vary in productivity potential	Geographically extensive and commonly found with aridisols
5.	Gelisols	Soil associated with permafrost and have limited profile development Soil organic matter on surface Productivity limited by short growing season Covers approximately 9% of the world's ice-free land area	Northern regions of Russia, Canada, and Alaska
6.	Histosols	Organic peat lands or boggy soils Consist of more than 20% organic materials by mass Found in cool and marshy areas Extent of the world's ice-free land area is 1%	Found mainly in geographically high latitude areas or other marshy wetlands

(continued)

Table 1.1 (continued)

No.	Class	Key characteristics	Regions
7.	Inceptisols	Found in the beginnings of soil profile development Variable productivity potential Covers 10% of the world's ice-free land area	Mainly in mountainous regions but occur almost everywhere
8.	Mollisols	Mineral soils developed under grassland vegetation Rich in organic matter Very fertile due to high clay and organic matter contents Extent of the world's ice-free land area is 7%	Eastern Europe, Russia, China, southern, and northern part of the USA
9.	Oxisols	In hot and humid climates with high annual rainfall Highly-weathered soils dominated by iron and aluminum oxides Low in fertility and high in soil acidity Physically stable soils with low shrink-swell properties Covers 8% of the world's ice-free land area	Equatorial latitudes
10.	Spodosols	Form in sandy materials under coniferous forest vegetation Associated with a wet and cool climate Coarse textured, high leaching potential, high organic matter, Fe and Al oxides contents. Acidic in nature and low soil fertility. Extent of the world's ice-free land area is 4%	Northern Europe, Russia, and north-eastern part of the USA
11.	Ultisols	Intensely weathered soils of humid areas Subsurface clay accumulations Low in fertility and high in soil acidity Covers 8% of the world's ice-free land area	Occur extensively in the south-eastern part of the USA, China, Indonesia, and equatorial regions of Africa
12.	Vertisols	High content of clay minerals, Dark colored with variable organic matter content (1–6%) Typically form in limestone/basalt/ topographic depressions Commonly formed in warm, subhumid, or semi-arid climates Extent of the world's ice-free land area is 2%	North-Eastern Africa, India, and Australia with smaller areas scattered worldwide.

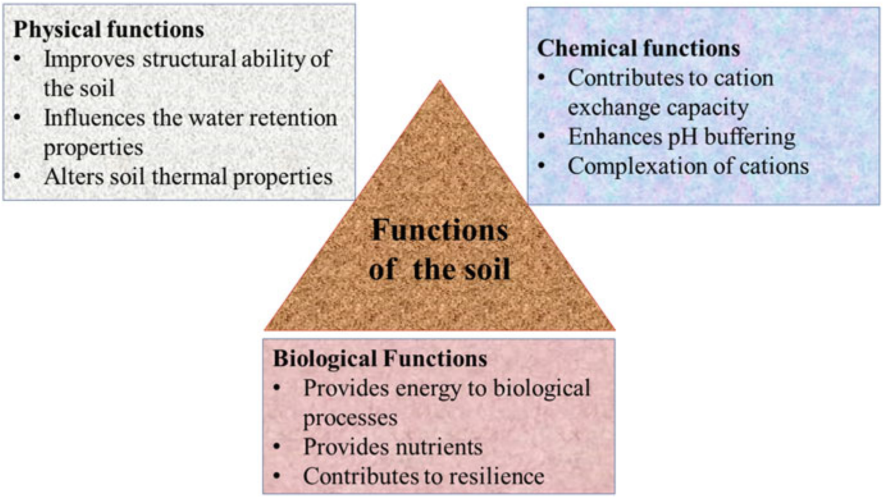


Fig. 1.2 Physicochemical and biological functions of the soil

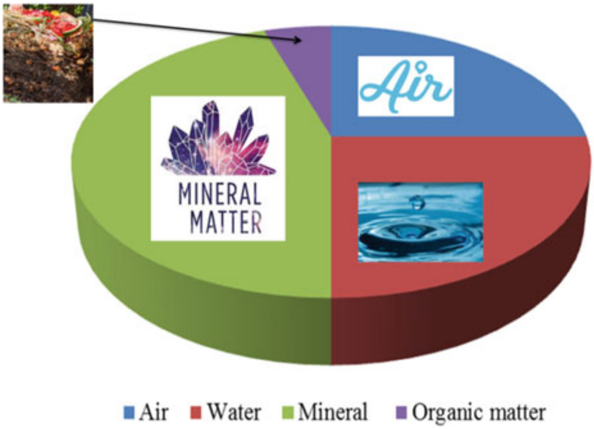
content, particle size, water-holding capacity, exchangeable cations (Ca^{2+}, Na^{+}, Mg^{2+}, K^{+}, Al^{3+}, and Fe^{3+}), cation exchange capacity, sodium exchangeable percentage, total nitrogen (N), available nitrogen (nitrate-N and ammonia-N), available phosphorous, total phosphorous, total organic carbon, organic and inorganic carbon, total and bioavailable metal(oid) contents (aluminum, Al; iron, Fe; zinc, Zn; nickel, Ni; selenium, Se; boron, B; copper, Cu; cobalt, Co; magnesium, Mg; manganese, Mn; cadmium, Cd; chromium, Cr; arsenic, As; and lead, Pb), humic acid, organic, and inorganic pesticides (Pandey et al. 2014; Gautam et al. 2017; Albers et al. 2019). Besides, microbial biomass, total enzymatic activities, activities of enzymes (dehydrogenase, peroxidase, alkaline phosphatase, polyphenol oxidase, urease, catalase, and nitrogenase), root exudates, soil basal respiration, and metabolic quotient are certain widely used biological parameters to assess the health of the soil (Choudhary et al. 2013; Pandey et al. 2014; Gautam et al. 2018).

The soil functions within an ecosystem vary greatly from one place to another depending upon the parent material, position on the landscape, age of the soil, climatic variables, and animals' and plants' diversity (Fig. 1.2) (Schoonover and Crim 2015).

Soil functions are thus crucial for the biosphere and its main ecological roles include:

(a) **Support for structures**: The soils are widely used in making causeways and roads, as a foundation for buildings and bridges as well as for the establishment of agriculture crops and forestry.
(b) **Medium for plant growth**: The soil consists of four main components, viz. mineral matter (45%), organic matter (5%), water (25%), and air (25%) (Fig. 1.3). It is a source of physical support (root anchorage), air (ventilation),

Fig. 1.3 Major components of the soil



water (holds rainwater, surface, and groundwater so that it can be utilized by plant roots), temperature moderation (acts as insulation for plants from extreme hot and cold conditions), protection from xenobiotics (removes toxic gases, decomposes, and absorbs organic/inorganic toxins), and supply nutrients (essential for their growth and development).

(c) **Regulate water supply**: The soil plays a pivotal role in cycling of freshwater. Water ending up into the water-body, i.e., lakes, rivers, estuaries, and aquifers, either traveled over the surface or through the soil. Soil filters and regulates water supply by restoration after precipitation. Management of the land area thus has a significant influence on the purity and amount of water that finds its way to aquatic systems.

(d) **Habitat for organisms**: Soil offers a shelter to billions of organisms (predators, prey, producers, consumers, and parasites). It provides a range of niche and habitat as well as types of habitats, which determine the specific organisms residing into it such as.

- Water-filled pores for swimming organisms like roundworms.
- Air-filled pores for insects and mites.
- Areas enriched in organic matter for various algae, fungi, parasites, lower, and higher plants.
- Areas with varied acidic, basic, and temperature regions for extreme dwellers.

(e) **Recycle wastes**: The soil system plays a significant role in nutrient cycling as soils have the ability to incorporate great quantities of organic waste, which then form humus. It converts the mineral nutrients of the wastes into utilizable constituents and has the ability to return carbon into the atmosphere in the form of CO_2. Plant residues and manures added to the soil increase nutrient concentrations, thereby enhancing the soil fertility.

1.1.2 Significance of pH

The pH is the measure of alkalinity and acidity of the soil (Fig. 1.4). Based on pH, the soil can be categorized into the following classes: extremely acid (≤4.4), very strongly acid (4.5–5.0), strongly acid (5.1–5.5), moderately acid (5.6–6.0), slightly acid (6.1–6.5), neutral (6.6–7.3), slightly alkaline (7.4–7.8), moderately alkaline (7.9–8.4), alkaline (8.5–9.0), and strongly alkaline (≥9.0). The pH scale (Fig. 1.4) shows various types of soils and their comparative relation with acidic and basic constituents based on their pH. Soil pH is one of the prime parameters that govern the soil aggregate stability, nutrient availability, metal toxicity, and biological activities (Goulding 2016).

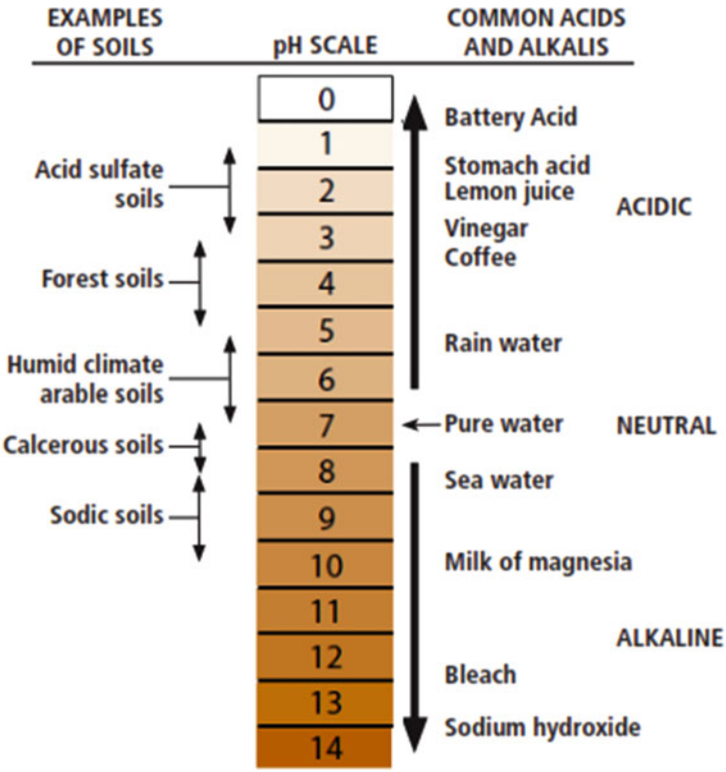


Fig. 1.4 The pH scale (Source: McCauley et al. 2009)

1.2 Soil Acidification

The soil acidification is a process where pH of the soil decreases over time. It is defined as a decrease in acid-neutralizing capacity (ANC) or an increase in base-neutralizing capacity (BNC) resulting in an increase in acid strength as represented by a decrease in soil pH (Blake 2005):

$$\text{Soil acidity } (+\Delta\text{BNC}) = -(\text{soil alkalinity}) = \Delta\text{ANC}$$

Pedogenic acidification processes in aerated soils are (1) an addition of strong acid (H_2SO_4 and HNO_3) into soil through acid deposition, (2) release of many organic acids and H^+ ions into the soil by plants and soil microbes and (3) uptake of basic cations by biota.

Soil acidification under natural conditions mainly occurs due to weathering of parent materials having high silica (rhyolite and granite), and sand with low buffering capacities and in regions with high precipitation (McCauley et al. 2009). Precipitation leads to leaching of base-forming cations with a simultaneous lowering of soil pH. Naturally occurring acidic soils are commonly found in areas at higher elevation, mining sites containing pyritic (Fe and elemental S) minerals, forest soils, and in areas where soils are formed from the acid-forming parent material. The process of soil acidification nowadays has been accelerated by human-induced activities such as agricultural practices, mining, metallurgical processes, etc. For instance, almost 5,00,000 ha of agricultural and rural land have acidified in Queensland (Rolfe et al. 2002). Intensive agricultural practices in coastal areas with a high precipitation rate are most at the risk of soil acidification (Duan et al. 2016). Soil acidification is a consequence of a dramatic increase in anthropogenic acid deposition originating chiefly from atmospheric sulfur dioxide (SO_2) and nitrogen oxides (NO_x) during agricultural fertilization and fossil fuel combustion (Zhao et al. 2009; Yang et al. 2012).

Soil acidification may have a negative impact on the entire ecosystem because soil is a fundamental interface where the atmosphere, lithosphere, hydrosphere, and biosphere meet. Any undesirable change in the baseline properties of soil affects a range of natural resource functions, which include soil micro-flora and fauna, vegetation structure, terrestrial animals, aquatic biota, atmospheric constituents, weed control, infrastructure, and human health (Singh and Agrawal 2004; Yang et al. 2015; Chen et al. 2016; Stevens et al. 2018). Some of these have wide community impacts through soil degradation and include the loss of native biodiversity that may impact on recreation and tourism (Singh and Agrawal 2007; Tian and Niu 2015).

1.2.1 Causes of Soil Acidification

Acidification of soil is accomplished through protons (H^+), which release into the soil mainly by atmospheric acidic substances, cation assimilation by plants,