BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

Managing soil health for sustainable agriculture

Volume 1: Fundamentals

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SCIENCE PUBLISHING

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Introduction

There has been growing concern that both intensive agriculture in the developed world and rapid expansion of crop cultivation in developing countries is damaging the health of the soils which are the foundation of farming. Healthy soils are also critical for addressing finite resources for food production, an expanding global population, climate change, ecosystem services, environmental quality, and the overall quality of life which depends on food security. At the same time, we are discovering much more about how complex soils are as living biological systems and the need for biological solutions to effective soil management. These issues are addressed in the two volumes of *Managing soil health for sustainable agriculture*:

- Volume 1: Fundamentals
- Volume 2: Monitoring and management

Volume 1 reviews the latest research on soil science. After an overview of the role of soil as a provider of ecosystem services, the book reviews soil structure and chemistry as well organic matter, soil microorganisms and fauna. The third part of the book discusses soil dynamics, from water and nutrient cycles to soil erosion mechanisms.

Part 1 Overview

The first part of the volume offers an overview of different aspects of soil health. Chapter 1 offers a general overview of soil health, charting the shift from a utilitarian focus on soil quality for crop production to a more holistic concept of soil health which sees soil as an ecosystem in which soil biology, moderated by physical and chemical properties, is central to its functionality. This concept highlights the potential difference between performance and inherent potential. The chapter looks at the implications of this broader concept of soil health for different ways of measuring soil health, whether in terms of its physical and chemical properties, functional performance, soil organic carbon or biological status.

Building on the foundation provided by Chapter 1, Chapter 2 provides an overview of the range of ecosystem services provided by soil. Ecosystem services provided by soil can be supporting (e.g. provisioning primary production and biodiversity) or regulatory (e.g. erosion control, water infiltration, nutrient retention, atmospheric gas regulation, and pest control). The chapter explains how ecosystem services benefit human welfare through these functions, addressing the soil's role in such areas as the production of food, fiber and energy, erosion control, carbon storage, pest control and biodiversity.

The subject of Chapter 3 is the critical nexus of soil health and climate change. A healthy soil has the capacity to sustain biological activity, maintain environmental quality and promote plant and animal health. The chapter reviews the impact of changing climate on the key components of soil health, including soil physical, chemical, and biological properties and such risks as increasing acidity and salinity. The chapter also reviews some of the key management practices that have been demonstrated to improve soil health and deliver climate benefits, including conservation agricultural techniques such as zero/minimum tillage, retention of crop residues, rotations and cover crops which both protect soil from the effects of climate change and improve its capacity to store carbon.

As highlighted earlier, soil function is an interplay of physical, chemical, and biological processes, with soil microbes playing a direct role in driving soil chemical and physical processes that are important for overall ecosystem function. Building on the foundations of the previous chapters, Chapter 4 provides an overview of how best to achieve soil conservation and regeneration through integrated soil health management. After highlighting some of the known impacts of management strategies on soil health, the chapter introduces an Integrated Soil Health Management (ISHM) framework that may be used to design, implement, and evaluate management decisions for soil conservation and regeneration.

The final chapter in Part 1, Chapter 5, provides an overview of the economics of soil health. Soil heath management practices and systems can be important tools for farmers to realize on-farm benefits associated with decreased erosion, improving levels of soil organic matter, and improved soil structure and function. The chapter describes existing research on the economics of soil health, with a particular focus on the adoption of soil health management practices by farmers. The chapter covers such issues as the costs and benefits of soil health practices, public benefits from soil health and soil health management practices, and barriers to the adoption of soil health practices by farmers. The chapter provides some detailed case studies and evaluates the role of government regulations, policies and incentive programs.

Part 2 Soil structure and composition

The theme of the second part of the volume is soil structure and composition. The focus of Chapter 6 is on the role of soil texture and structure in soil health. The chapter examines the relationship between particle size and soil health, affecting such areas as cation exchange capacity, hydraulic conductivity, gas transport function and mechanical strength. The chapter then considers what determines optimum particle size and the relationship between soil health and soil aggregate formation.

Moving from soil texture to its chemical composition, Chapter 7 begins by reviewing the use of key chemical indicators for soil health such as pH, salinity and sodicity. It then focuses on research on major nutrients such as nitrogen, phosphorus and potassium. In each case, the chapter discusses what we know about its function in plant growth, fixation in soil, loss mechanisms and factors affecting availability to plants. The chapter also discusses other nutrients such as calcium, magnesium and sulfur. Building on this foundation, the chapter discusses management practices to improve nutrient availability and reduce the reliance on inorganic fertilizers. The chapter includes a case study from India that show how integrated nutrient management can be used to optimize soil health.

The theme of Chapter 8 is the role of soil microorganisms in soil health. Soil is a complex environment that supports the largest, most diverse and resilient microbial community on the planet, essential for nutrient cycling and plant growth. The details of many soil microorganisms remain unknown, but the recent improvements in molecular methods for microbial ecology have made it possible to view the soil microbiome as a whole, providing information on its responses to changes in land-use and microbially-mediated functions relevant to agricultural sustainability and major geochemical cycles. The chapter discusses the contribution of soil microorganisms to nutrient cycling in soil, and the impact of human activities on the soil microbiome. The chapter considers the influence of the microbiome on crop health and yields and discusses the potential for future exploitation of the soil microbiome.

The final chapter of the section, Chapter 9, addresses the role of soil fauna in soil health and the delivery of ecosystem services. Soil fauna includes microscopic organisms such as nematodes (microfauna), mites and springtails (mesofauna), up to larger invertebrates such as worms, spiders, ants, termites and beetles (macrofauna) and vertebrates (megafauna) such as amphibians, reptiles and mammals. The chapter explains how their activity is important for soil health and can result in various ecosystem services, including provision of food and primary production, nutrient cycling and organic matter dynamics, water availability, gas exchanges, soil formation, pollination and seed dispersal. The chapter classifies soil fauna and reviews currently available information on soil fauna biodiversity and functional roles worldwide, their role in soil health and the importance of management in determining soil fauna communities.

Part 3 Soil dynamics

The third part of the volume addresses the theme of soil dynamics. Chapter 10 considers the role of soil hydrology in soil health. Soil hydrology stands at the forefront of soil health due to its critical importance in regulating physical, chemical, and biological processes in soils. Not only do the interactions between soil and water affect a number of soil processes and properties, soil hydrology also links closely to soil types and landscape features as well as management practices that are closely tied to soil health. The chapter discusses various soil hydrologic processes and properties that influence soil health along with crop growth, ecosystem services, and environmental impacts. The chapter describes how soil physical, chemical, and biological processes are often mediated by soil hydrologic conditions. The chapter relates these processes and properties to soil hydrologic functions in the context of soil health and management.

Complementing the preceding chapter's focus on soil hydrology, the focus of Chapter 11 is nutrient cycling in soils. Sustainable agricultural systems must enable profitable production of sufficient high-quality crops to meet human demand, while simultaneously minimising off-site impacts. Although simple chemical equilibria play a part, nutrient cycling processes in soil are largely the outcome of biochemical processes resulting from the activity and interactions of a huge diversity of soil organisms. The chapter outlines the underlying concepts of nutrient cycling, before giving reviewing current research on carbon, nitrogen, phosphorus other nutrient cycles in soil.

Building on the themes of the two previous chapters, Chapter 12 offers an overview of plant-soil interactions. Plant-soil interactions are the prime mechanism for integrating the impacts of the aerial environment, animals (including plant shoot symbionts and pathogens), plant shoot physiology, plant root physiology and structure, the soil microbiome and soil chemistry and structure into what is commonly termed soil health. The chapter addresses three aspects of this chain: interactions of the shoot with the roots, interactions between the roots and the microbiome, and interactions between the root system and physical and structural characteristics of the soil.

The subject of the volume's concluding chapter, Chapter 13, is mechanisms of soil erosion and degradation. The chapter offers an overview of soil erosion processes, focusing on the most common kind (erosion by water). However, the chapter also deals with other mechanisms of soil erosion, before going on to consider the consequences of erosion. The chapter relates soil erosion to crop productivity and sustainable agriculture, and examines the role of soil conservation in mitigating soil erosion.

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