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Managing soil health for sustainable agriculture

Volume 2: Monitoring and management

Edited by Dr Don Reicosky, Soil Scientist Emeritus
USDA-ARS and University of Minnesota, USA

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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 2 discusses key methods for monitoring soil health and provides a comprehensive review of techniques to manage soil health, from no-till and conservation tillage techniques to the use of rotations, intercropping and cover crops. The volume also contains detailed case studies of ways of supporting smallholders in maintaining soil health in regions such as Africa, Asia and South America.

Part 1 Soil monitoring

The first part of the volume reviews soil classification, sampling and ways of monitoring soil dynamics. The focus of Chapter 1 is on the use of indices and databases in soil health assessment and inventory. It is increasingly appreciated that the soil resource embodies significant natural capital supporting valuable ecosystem services. The chapter explores the challenges for comprehensive soil health assessment, giving an account of soil health assessment frameworks and indices and indexing systems in active use. The chapter looks at practical on-farm assessment of soil health, methods of mapping soil health and the use of soil property databases.

Moving on from the use of indices and databases, Chapter 2 examines the use of soil sampling for soil health assessment. A successful soil health study or project requires thorough planning. Accurate results in soil health assessment can be difficult to obtain due to complications from spatial, temporal and managerial variability. A well-planned soil health sampling design will ensure that the resulting data are representative of the sample population and study objectives. The chapter focuses on three crucial stages of a successful soil health study: defining objectives and generating hypotheses, designing a suitable sampling plan, and collecting data.

Focussing in on one specific aspect of soil health monitoring, Chapter 3 looks at biological indicators of soil health in organic cultivation. Soil is a living ecosystem that is home to billions of microbes that help animals, plants and humans cycle carbon and mineral nutrients to sustain life. The chapter outlines the metrics of soil health, including chemical and physical indicators, as well indicators for soil organic carbon and biologically active carbon. The chapter also provides an overview of biological indicators of soil health,

including phospholipid fatty acid methyl esters, nitrification and denitrification, and the use of functional gene copies of bacterial nitrifiers.

Moving on from the assessment of soil content to the issue of soil contamination, Chapter 4 examines the impact of heavy metal contamination on soil health. Heavy metal pollution often results in the degradation of soil health. Contamination of heavy metals above threshold values can destroy soil's natural ability to perform ecosystem services, a change which can be irreversible. Heavy metal contamination of soils is a global challenge that needs to be resolved by the joint efforts of governments and scientific communities. The chapter summarizes the literature regarding sources, impacts, indicators, risk assessment, remediation, and the future problems of heavy metals in relation to soil and human health, and provides directions for the improvement of soil management and the development of effective pollution control strategies.

The final chapter of the section considers the modeling soil organic matter (SOM) dynamics as a soil health indicator. After examining the basics of SOM, the chapter explores current issues and developments in SOM modeling, including the relationship between soil biological processes and ecosystem dynamics, conceptual versus measurable SOM pool structure, and dynamic linkages with soil physical properties. The chapter looks ahead to future trends in soil health monitoring and decision support services, including the use of SOM models in land management applications and the rapid evolution of feedback between modeling and decision support services.

Part 2 Managing soil health

The second part of the volume surveys key techniques for managing soil, from no-till and conservation tillage techniques to the use of rotations, intercropping and cover crops as well as manure and compost management. The focus of Chapter 6 is on drainage requirements to maintain soil health. The effective management of soil water conditions is essential for ensuring healthy plant growth and optimum yield. Drainage is the primary technique by which producers keep soil water conditions at or near optimum for plant growth. A well-designed drainage system may result in a number of benefits including: better soil aeration, less flooding in low areas, less surface runoff, better soil structure, better root development, higher yields and improved crop quality. The chapter offers a brief summary of the history, purpose and practice of land drainage. The chapter reviews the literature on the impact of excess water and drainage on different aspects of soil health, including physical, chemical, and biological properties and processes.

Complementing the previous chapter's focus on drainage requirements, Chapter 7 considers the management of irrigation for soil health in arid and semi-arid regions. Irrigated arid and semi-arid regions of the world account for upwards of 40% of global crop production. Managing soil health while simultaneously increasing water use efficiency in these areas is challenging, but critical to future global food security. The chapter describes production practices such as no-tillage and surface residue preservation that maximize both water infiltration into soil and soil water retention, reduce runoff and evaporation, and thereby increase the productive flow of water via transpiration. The chapter summarizes recent examples of soil health management of irrigated and dryland arid and semi-arid environments, including examples of cost-benefit trade-offs associated with reduced-disturbance no-tillage systems and the use of cover crops.

The subject of Chapter 8 is the effects of crop rotations and intercropping on soil health, particularly in optimising nitrogen fixation and, in particular, soil organic matter (SOM) which is widely seen as central to soil health. The chapter reviews the range of research on the advantages, design, implementation and effectiveness of rotations and intercropping programs, particularly those incorporating legumes. Complementing Chapter 8, Chapter 9 considers the use of cover crops to promote soil health. Key management principles for improving soil health include keeping soil covered, providing living roots for as much of the year as possible, increasing biodiversity, and reducing disturbance of the soil. Cover crops contribute to achieving all of these principles. In addition to their contributions to soil health, cover crops help with weed and pest management, provide habitat and food for pollinators and wildlife, and contribute to environmental benefits such as reduced erosion, water and sediment loss as well as run-off.

The subject of Chapter 10 is optimising the use of fertiliser to maintain soil health. The chapter examines management of mineral fertilisers and organic manures in relation to its effects on soil health in terms of soil organic carbon and nitrogen, soil acidification and soil microbiology. The chapter discusses the optimisation of nitrogen, phosphorus and potassium fertiliser use, together with their interactions and interdependency. Moving from fertiliser to manure, Chapter 11 considers the use of manure and compost management to maintain soil health. The chapter examines the mechanisms of how manure and compost improve soil health and the continued role of livestock and their manure in the future of sustainable agriculture. The chapter includes a detailed case study which highlights the legacy effect of manure application on crop yield and soil health.

Complementing the focus of the previous two chapters on fertiliser and manure, Chapter 12 looks at pesticide use and biodiversity in soils. Pesticides are applied to agricultural systems in high quantities relative to other synthetic compounds and therefore have considerable effects on soil microbial communities and their functions. Although pesticides undergo considerable evaluation for efficacy in controlling target pests in agroecosystems and in non-agricultural sites, effects on soil and environmental organisms and their activities receive minimal attention beyond specific environmental impacts required by regulatory agencies. Limited research has found that pesticides used in agricultural management systems influence both structural and functional biodiversity in soils, which are important components of soil health. The chapter presents the mechanisms by which pesticides affect soil microbial diversity and describes management systems developed to limit impacts of pesticides on soil and environmental health.

The focus of Chapter 13 is conservation grass hedges and soil health parameters. Grass hedges, narrow (less than 2 m) strips of tall and stiff-stemmed perennial grass planted within croplands, are an innovative conservation practice to improve the health of the soils. Integrating grass hedges with food crops is a potential strategy to reduce erosion, improve soil health and wildlife habitat, and improve overall soil productivity. The chapter reviews current research on grass hedges and their soil benefits, to better understand the potential of grass hedges for managing water erosion as well improving soil health in agricultural lands. The chapter covers such issues as erosion, soil properties, food, feed, and fuel production and impact of grass hedges on biodiversity or wildlife habitat. Finally, the chapter explains the factors affecting the performance of grass hedges.

The subject of the final chapter in Part 2, Chapter 14, is managing soil health in organic cultivation. Although organic standards do not refer directly to soil health, organic agriculture has the potential to improve soil health and environmental services by promoting soil conservation and reducing greenhouse gases. The chapter presents

findings from a field experiment which continuously monitored the soil health of an organically managed production system between 2003 and 2014. The experiments focus on intensive organic vegetable crop production systems typical of experienced fresh market growers. The research sought to evaluate short and long-term effects of various different management systems, including crop rotations, cover crops and animal amendments. The chapter discusses the impact of these measures in terms of nutrient release, soil health, greenhouse gas emissions and ecosystem structure and function.

Part 3 Regional strategies in the developing world

The final part of the volume discusses ways of supporting smallholders in maintaining soil health in regions such as Africa, Asia and South America. Chapter 15 looks at the key challenges and strategies for supporting smallholders in maintaining soil health. There is no single method to engage with smallholder farmers to manage soil health, as they are a diverse group scattered across multiple geographies, soil types, agro-ecologies, cropping systems, and cultures. However, systematically understanding the key challenges and motivations among selected groups of smallholder farmers can provide insights into targeted approaches to address the challenges. The chapter characterises smallholder farmers before describing the key constraints and challenges they face, including financial, labor, agronomic input, behavioral, and knowledge-access constraints. The chapter examines the key levers that can assist smallholders in maintaining soil health.

The specific regional focus of Chapter 16 is maintaining soil health in Africa. Sub-Saharan Africa (SSA) has a wide variety of natural ecosystem resources, including soils, vegetation, water and genetic diversity. However, land degradation in SSA is intensifying at an alarming rate, and this region also has the lowest agriculture and livestock yields of any region in the world. This is accompanied by the world's highest rates of deforestation and malnutrition. The chapter examines the different types of land degradation as well as their ecological, economic and social consequences. The chapter also addresses the relationships between soil quality, soil health, and food security, and then reviews strategies for maintaining soil health in the region.

Moving from Africa to China, the focus of Chapter 17 is a case study from China of organic amendments to improve soil health and crop productivity. The chapter focuses on three long-term fertilization experiments in China which aimed to improve soil fertility, maintain soil health and increase crop productivity. The chapter examines the impact of the different fertilization techniques used on both crop yield and long-term soil health.

Moving from China to South America, Chapter 18 deals with soil health assessment and maintenance in Central and South-Central Brazil. Brazil has evolved from a food-insecure country in the early 1970s to one of the most important food producers and exporters in the world. Production has increased steadily and productivity gains have fostered a significant land-saving effect. However, wide variations in the landscape, soils, climate, and plant diversity present challenges in applying soil health principles for enhanced management practices. These challenges have been overcome by the application of conservation agriculture (CA), an integrated, holistic farming system that improves soil functioning and consequently crop growth and yield. The chapter outlines monitoring and agronomic strategies that are being used to ensure that soil health is being maintained or improved rather than degraded by more intensive cultivation.

The volume's final chapter, Chapter 19, is about maintaining soil health in dryland areas. Drylands cover 40 per cent of the global terrestrial space and are home to 2 billion people. Land use is dominated by rangelands, much less by croplands, while barren areas with sparse vegetation mixed with rock outcrops are widespread. In spite of their hostile nature, drylands host 50 per cent of global livestock and 30 per cent of crops. The chapter addresses critical research issues needed to maintain soil health in the drylands. These include nutrient cycling, preservation of soil biota, carbon sequestration, erosion control, rainwater harvesting and irrigation efficiency. The chapter examines the options for improving dryland soil health and provides a detailed case study from Egypt.

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