Khalid Rehman Hakeem · Javaid Akhtar
Muhammad Sabir *Editors*

Soil Science: Agricultural and Environmental Prospectives

Springer

Soil Science: Agricultural and Environmental Prospectives

Khalid Rehman Hakeem • Javaid Akhtar
Muhammad Sabir
Editors

Soil Science: Agricultural and Environmental Prospectives

Springer

Editors
Khalid Rehman Hakeem
Universiti Putra Malaysia
Selangor, Malaysia

Muhammad Sabir
Institute of Soil and Environmental Science
University of Agriculture Faisalabad
Faisalabad, Pakistan

Javaid Akhtar
Institute of Soil and Environmental Science
University of Agriculture Faisalabad
Faisalabad, Pakistan

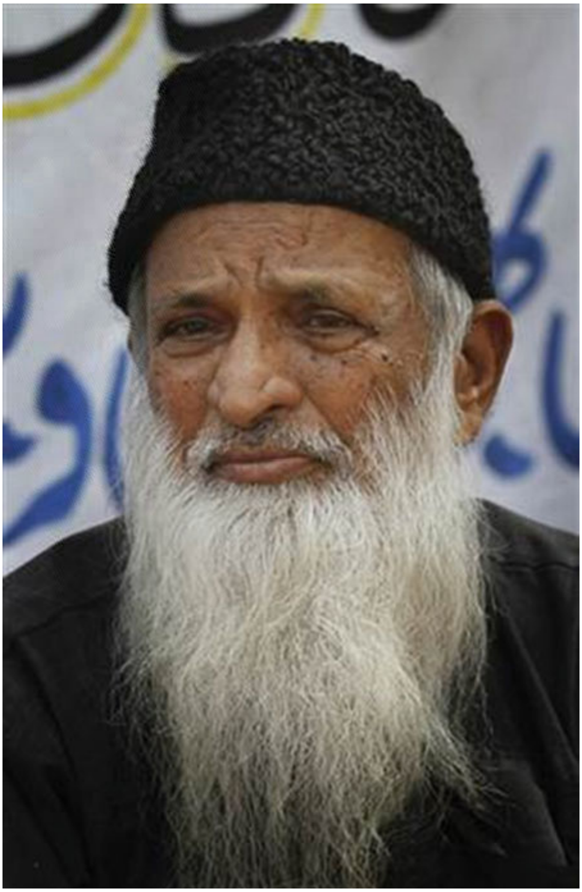
ISBN 978-3-319-34449-2 ISBN 978-3-319-34451-5 (eBook)
DOI 10.1007/978-3-319-34451-5

Library of Congress Control Number: 2016947711

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG Switzerland

This book is dedicated to Abdul Sattar Edhi
(Popularly known as the Angel of Mercy*)*



(1928–2016)

A prominent Pakistani philanthropist, social activist, ascetic, humanitarian and the founder of the Edhi Foundation in Pakistan

Foreword

The soil scientists currently are striving hard toward the transformation of agriculture into a more sustainable enterprise. All modern technologies are needed like geographical information systems, global positioning systems, as well as computer applications in crop production and natural resource management. During the last two decades, suggestions for a new type of soil science have come to the forefront, with more attention being paid toward a soil care approach in a closer contact with the society. There is a greater need for the young researchers to look back, note the achievements, and try to learn from the past. The authors in this book have tried to look forward by presenting the shifts in research foci. They have focused on the identity of soil science, directions for the future on a global scale, and the environmental and agricultural aspects in this field. The contributors here have also tried to actualize views on the soil science. Several well-known colleagues from different parts of the world have participated in this attempt and the book has been completed.

Our mother soil is not just a dust; it is a vital resource sustaining the miracle of life on this planet. The researchers in this field have a very important task to increase crop productivity but at the same time prevent our soils from erosion and pollution. Yes, the "green revolution" of the 1960s was a success of researchers working in the field of soils. Today, many of these workers are striving hard to find the ways of feeding the world's people in an agriculturally, environmentally, and economically sustainable way. In this sense, fundamental understanding of soil biology, chemistry, pedology, and physics has to be applied to the environmental problems caused by production.

The researchers in this field have to use geographic information systems (GIS) to analyze different aspects of soils and create soil maps for managing the soils for sustainable crop production as well as other products. There is a need for researchers in this field to get involved in creating environmental impact statements, erosion control, mine reclamation, and industrial site restoration. It all comes primarily under an applied agricultural field that is the soils.

Soil researchers have to apply their basic understanding of soils to many environmental problems, together with the concerns about soil, water, and air pollution. The book presents 18 chapters from an array of scientists.

Chapter 1 gives an appraisal of conservation tillage on the soil physical properties and highlights the information on tillage systems like *conventional tillage*, *intensive tillage*, and *conservation tillage*, the principles of conservation agriculture, comparison of tillage systems, conservation tillage effects on soil physical properties, and constraints in the adoption of conservation tillage.

Chapter 2 discusses the *degraded soil origin, types, and management and presents a detailed information on the* causes of land degradation, processes of land degradation, soil erosion, soil salinization, waterlogging, decline in soil fertility, types of land degradation, soil salinity, causes of salt-affected soils, impact of salt-affected soil on plants, reclamation of salt-affected soils, management of salt-affected soils, soil erosion, conservation technologies, soil acidity, effects of soil acidity on crop production, and finally agroforestry.

Chapter 3 summarizes the nitrogen management in rice-wheat cropping system in salt-affected soils with emphasis on the extent and nature of salt-affected soils, relationship between soil properties and salinity/sodicity, ionic and osmotic stresses, salinity stress at the cellular level, salinity impact on the N metabolism, interaction of salinity and N fertilization, the interactive effect of salinity and Ca^{2+}, and NUE in wheat and rice under saline conditions. At the end, contributors are presenting an important aspect in the soils that is nitrate leaching followed by salinity/sodicity and N management.

The management of acid sulfate soils for sustainable rice cultivation in Malaysia, constraints in acid sulfate soils, aluminum toxicity, and iron toxicity have been covered in Chap. 4.

In Chap. 5, approaches to remediate petroleum hydrocarbon-contaminated soils have been presented with emphasis on the health hazards of petroleum contamination, approaches to remediate petroleum contamination, physical approaches, chemical approaches, biological approaches, bioremediation, phytodegradation/phytotransformation, phytostabilization, phytovolatilization, and advantages and disadvantages of phytoremediation, and at the end, plant-assisted bioremediation and microbial-assisted phytoremediation have been discussed.

In Chap. 6, environmental impacts of nitrogen use in agriculture and mitigation strategies have been evaluated. The information includes nitrogen in the environment, nitrate leaching from soils, nitrate-related regulations, contribution of water and food to NO_3 ingestion, nitrate-related ecological issues in aquatic ecosystems, physical transport mechanisms of NO_3, factors involved in the NO_3 leaching environments, options to minimize NO_3 leaching, and fertilizer/soil/irrigation-based management options and strategies.

The topic on potassium for sustainable agriculture has been covered in Chap. 7, which deals with the potassium dynamics in soils, in plants, and in agriculture, environmental stresses due to K, sustainable soil fertility and K, human health and K interactions, and finally K evaluation in the soils.

Chapter 8 gives an overview of weathering and approaches to evaluation of weathering indices for soil profile studies with emphasis on physical/chemical weathering, relationship between physical/chemical weathering, quantification of weathering, the criteria applied in evaluating the utility of weathering indices, and applications of weathering indices.

The pesticide pollution in the agricultural soils of Pakistan has been discussed in Chap. 9. It covers the classification and the use of pesticides, the history of pesticides, pesticide use in the world and agricultural sector of Pakistan, major crops in Pakistan and pesticide use, pesticide occurrence in agricultural soils of Pakistan, groundwater and surface water pollution by pesticides in Pakistan, fate of pesticides in soils, toxicity of pesticides in soil, risk associated with pesticide use, and integrated pest management in Pakistan.

The problems and solutions related to the iron biofortification of cereals grown under calcareous soils have been summarized in Chap. 10. The information presented includes the status and forms of Fe in soil, iron deficiency in calcareous soils, strategies to overcome iron deficiency, significance of iron for plants, severity of iron deficiency in crops, strategies to overcome Fe deficiency in plants, organic amendments and nutrient availability, iron and human health, strategies to combat deficiency in humans, approaches for iron biofortification, nutritional factors affecting Fe bioavailability, and finally the models used for determination of iron bioavailability.

Chapter 11 discusses boron toxicity in salt-affected soils and effects on plants. Main features of this chapter are salinity, oxidative stress and plant growth, physiological responses as well as physiological and biochemical mechanisms of plants for salinity tolerance, forms of boron, sources and toxicity in soils and plants, toxicity symptoms in plants, toxicity effects on plant growth and physiology, activity of antioxidant enzymes in response to boron toxicity, photosynthetic features under boron toxicity, environment salinity and boron toxicity, and physiological and biochemical aspects.

In Chap. 12, silicon, a beneficial nutrient under salt stress, and its uptake mechanism and mode of action are presented, with details on the uptake in cereals, distribution in the mature cereal plant, silicon-mediated mechanisms improving salinity tolerance, and future prospects/missing links.

The topic of extensive research on the soil microflora has been evaluated in Chap. 13, which includes information on the effect of environment on soil microflora, advantages, and anthropogenic activities responsible for deteriorating effects on soil microflora.

Chapter 14 presents an overview of the arbuscular mycorrhizal fungi – a boon for plant nutrition and soil health. It includes detailed information on the host specificity, structural features of these mycorrhizae and their role to maintain a plant-soil nutrient balance, rhizosphere, concept and molecular signaling in the context of promoting mycorrhizal symbiosis, symbiotic relationships, their benefits in the context of sustainability of agroecosystems, sustainable soil health, biota, and soil structure and management.

An overview on the *Azotobacter chroococcum* – a potential biofertilizer in agriculture – has been discussed in Chap. 15. It covers information on the research on *A. chroococcum spp*. in crop production, its significance in plant nutrition and contribution to soil fertility and use as microbial inoculant, synthesis of growth-promoting substances, stimulation of rhizospheric microbes, protection from phytopathogens, improvement of nutrient uptake, and ultimately biological nitrogen fixation.

Sources and composition of wastewater, threats to plants and soils, industrial/domestic wastes, pesticides and insecticides, hospital/pharmaceutical wastes, nutrients, and impacts on soil and plant health are the main features discussed in Chap. 16.

Chapter 17 describes commonly used and emerging cost-effective amendments for heavy metal immobilization. There is a dire need to develop procedures to determine immobilization efficacy that could be used to assess the in situ short- and long-term environmental stability of metal immobilization.

In the last chapter, climate change and its impacts on carbon sequestration, biodiversity, and agriculture have been evaluated in the light of the difference between weather and climate, greenhouse effect/gases, global warming potential of greenhouse gases, non-greenhouse influences of climate, and global warming and its impacts in the future and on soil carbon sequestration.

The title selection of this volume is a highly challenging one, as it involves the "soils," the most complicated biomaterial present on earth. A science-oriented approach vis-a-vis an emphasis on a healthy ecosystem approach in crop production and sustainability of natural resources has been presented at length. The information gathered from this book will be helpful in the understanding of fundamental properties of and processes in soils, both of which have agricultural and environmental benefits.

I trust this book will serve its purpose, and when read carefully, it will stimulate thinking among the young researchers.

Dr. Münir Öztürk (M.Sc., Ph.D., D.Sc.)
Fellow of the Islamic World
Academy of Sciences
Professor (Emer.) of Ecology
& Environmental Sciences
Ex-Chairman Botany Department
and Founder Director Centre for Environmental Studies,
Faculty of Science, Ege University,
35100 Bornova- Izmir, Turkey
Consultant Fellow, Faculty of Forestry,
Universiti Putra Malaysia, Selangor-Malaysia
Distinguished Visiting Scientist, ICCBS,
Karachi University, Pakistan
http://ege.academia.edu/MunirOzturk
Citations: http://scholar.google.com.pk/citations?user=ooL4g4wAAAAJ&hl=en

Preface

Soil is a natural resource which supports life on earth. It provides a natural medium for plant growth, raw material for industries, and energy production. Soil is composed of mineral grains that come from weathering of the rocks which finally constitute soil particles like sand, silt, and clay. Soil formations are very slow processes which took place over thousands of years as a result of physical, chemical, and biological processes. Human interventions, climate, and living organisms are involved in this extremely slow process which ensues in soil formation. Soil is the largest reservoir of biodiversity which contains almost one-third of all living organisms. Soil performs different functions ranging from provision of livelihood and habitats of humans, animals, plants, and soil organisms to sustainability of environmental quality.

Being a natural and universal sink for the variety of the pollutants, soil occupies the pivotal position in the environment and maintaining its quality. The soil plays an important role in purification and recycling of air, water, and nutrients and thus maintains different natural cycles with ensuring the sustainability of life on earth. Soil purifies and transforms nutrients and other chemical substances and thus maintains the quality of groundwater, provides plants with nutrients, and affects the climate. Soil is the primary production factor for agriculture and forestry. Fertile soils provide the basis for the entire food chain, and thus the soil is inevitable for sustaining life on earth. However, its improper use and the underestimation of its importance are a matter of serious concern which may have dire consequences over a period of time. Environmental pollution is affecting soil productivity and thus its capacity to sustain life on earth. Different types of pollutants are added into soils like agricultural nutrients and pollutants, as well as local contamination and pollution at abandoned sites. In addition to pollutant load, soil sustainability is threatened by soil erosion caused by wind and water. Soil erosion not only depletes soil fertility but also affects environmental quality. Soil erosion is the result of intensive agriculture and unscientific management of soil resources.

In this book, we have tried to integrate literature focusing on the issue related to soil productivity, different practices to manage these issues, and then the role of the soil in environmental and agricultural sustainability. The chapters in this book highlight importance of soil as a natural resource for agricultural productivity and environmental sustainability.

We are highly grateful to all our contributors for readily accepting our invitation and for not only sharing their knowledge and research but for venerably integrating their expertise in dispersed information from diverse fields in composing the chapters and enduring editorial suggestions to finally produce this venture. We greatly appreciate their commitment. We are also thankful to Prof. Munir Ozturk for his suggestions and writing the foreword for this volume.

We thank the Springer International team for their generous cooperation at every stage of the book production.

Selangor, Malaysia Khalid Rehman Hakeem
Faisalabad, Pakistan Javaid Akhtar
Faisalabad, Pakistan Muhammad Sabir

Contents

An Appraisal of Conservation Tillage on the Soil Physical Properties

Sartaj A. Wani, Tahir Ali, M. Nayeem Sofi, M. Ramzan, and Khalid Rehman Hakeem

Contents

Abstract Farming systems today have many implications than before because of the growing concerns about agricultural sustainability and environment. Soil management is aimed at the maintenance of optimal soil physical quality for crop

S.A. Wani (✉) • T. Ali • M.N. Sofi
Division of Soil Science, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar, 190001 Srinagar, Jammu and Kashmir, India
e-mail: sartajmess@gmail.com

M. Ramzan
Department of Botany, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

K.R. Hakeem (✉)
Faculty of Forestry, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
e-mail: kur.hakeem@gmail.com

K.R. Hakeem et al. (eds.), *Soil Science: Agricultural and Environmental Prospectives*, DOI 10.1007/978-3-319-34451-5_1

production. The conventional tillage practices resulted in losses of soil, water and nutrients, and degraded the soil with low organic matter content and a fragile physical structure. The conservation tillage in its many and varied forms holds promise for the sustainability of agricultural productivity and environment by reducing greenhouse gas emissions, improvement in dynamic soil physical properties in general like soil aggregate stability, structure, soil strength, bulk density etc, that provides key information about the soil quality. All these aspects are reviewed with some detailed information on the benefits of conservation tillage. The aim of the present review is to analyze and discuss the conservation tillage and its impacts on physical aspects of soil health.

Keywords Conservation tillage • Soil • Sustainability • Physical Properties

1 Introduction

The greatest challenge to the world in the years to come is to provide food to burgeoning population, which would likely to rise 8909 million in 2050 and there is urgent need to increase in total food production on sustainable basis, without compromising on natural resources and environment. The growth rate in agriculture has been the major detriment in world food production. Today farming systems have more obvious and detectable social, ecological, economic and environmental implications than ever before because of the growing concerns about agricultural sustainability and the environment (Shrestha and Clements 2003). Maintenance of soil quality would reduce the problems of land degradation, decreasing soil fertility and rapidly declining production levels that occur in many parts of the world which not only lack the basic principles of good farming practices but weak technical know-how as well. The global importance of soil conservation and the control and mitigation of land degradation (Derpsch 2005) are more highly recognized now than at any time in the past. This is because rising populations and rising incomes in the middle classes, as well as increased capacity of human interventions to cause ecosystem degradation, are now of such magnitude that for the first time in history how we manage the land can impact directly on global environmental goods and services. This grave concern on environmental values is the major driving force on the geopolitical agenda for soil conservation and this is expected to increase in the future as society better understands the important linkages between soil quality and the environment (Dumanski 2015).

The importance of conserving soil resources and reducing soil erosion came first to national attention in the United States during the 'Dust Bowl' period in the early 1930s, when the combination of drought, intensive tillage practices, crop failure and wind-driven erosion of millions of acres of farmland occurred in the Great Plains of the US (Chauhan et al. 2006 and Gajri et al. 2009). In the subsequent decades, several conservation tillage production systems and other latest technical management services emerged in the mid-west and the south-east US, to address the soil loss concerns. Similarly, yet somewhat later, recognition of the importance of controlling soil erosion losses has also been a major driver for the development of conservation tillage systems (Coughenour and Chamala 2000). The introduction of Paraquat herbicide became the source of chemical foundation for no-tillage farming, which led the scientists to think that crop could be drilled into soil with minimum of tillage or no- tillage at all, when weeds are controlled chemically (Gajri et al. 2009). Conservation tillage was practiced in 1995 on about 40 × 106 ha or 35.5 % of planted area in USA. Because of the important role that surface cover or roughness has in mitigating soil erosion losses, the concept of conservation tillage during this time eventually became linked with the specific management goal of maintaining at least 30 % crop residue on the soil surface after planting.

Soil tillage one of the basic and important components of agricultural production technology, greatly influencing agricultural sustainability through its effects on soil processes, soil properties, and crop growth. Soil tillage is one of the very important factors in agriculture that would affect soil physical properties and yield of crops (Rashidi and Keshavarzpour 2008). The tillage would aim to create a soil environment favorable to the plant growth and development. Among different crop production factors, tillage contributes up to 20 % (Khurshid et al. 2006). An important effect of soil tillage on sustainability is through its impact on the environment e.g. soil degradation, water quality, emission of greenhouse gases from soil-related processes (Kassam et al. 2010). As a sub-system of a crop production system, different practices in tillage can be used to achieve many agronomic objectives, like soil conditioning, weed or pest suppression, crop residue management, incorporation or mixing (placement or redistribution of substances such as fertilizers, manures, seeds, residues, sometimes from a less favourable location to a more favourable spatial distribution), segregation (consolidation of rocks, root crops, soil crumb sizes), land forming (changing the shape of the soil surface e.g. ridging, roughening and furrowing).

Degradation of soil structure in some situations leads to a continuous soil compaction of fine particles with low levels of organic matter. Such soils are more prone to soil loss through water and wind erosion eventually resulting in desertification, as experienced in USA in the 1930s (Biswas 1984). The conventional soil tillage system practices resulted not only in loss of soil, water and nutrients in the field, but degraded the soil with low organic matter content and a fragile physical structure, which in turn led to low crop yields and low water and fertilizer use efficiency (Wang et al. 2007). The impact of tillage on soil, environment etc. depends on the combination of tillage operations and their timing in the tillage system to provide specific functions in given situations. The genetic yield potential of a crop cannot be realized even when all the other requirements are fulfilled unless the soil physical environment is maintained at its optimum level. No doubt, if these soils are managed properly for good physical health, the yield potential of different crops can be increased significantly (Indoria et al. 2016). However, the soil physical management technologies are location specific and the benefits from their adoption are greatly depend on the rainfall intensity, slope and texture of the soil besides the prevailing crop/cropping system (Indoria et al. 2016). Therefore, scientists and policy makers put emphasis on alternative form of conservation tillage systems. Conservation tillage increases the amount of crop residue left in the soil after harvest, thereby reducing soil erosion and increasing organic matter, soil aggregation, water infiltration and water holding capacity compared with conventional tillage systems (Basic 2004). Reduced tillage, mulching and crop rotation have the potential of reversing physical, chemical and biological degradation of soils (Dexter 2004) under different climatic conditions and soil types (Daraghmeh et al. 2009). Compared to conventional tillage, there are several benefits from conservation tillage such as economic benefits to labour, cost and time saved, erosion protection, soil and water conservation (Glab and Kulig 2008) and increases of soil fertility or reduce nutrient loss (Wang and Gao 2004; Limousin and Tessier 2007). One of the most successful soil management techniques in agricultural land is no-tillage management (NT), and it is being applied worldwide (Barbera et al. 2012; Lieskovský and Kenderessy 2014). Therefore, the first step in making sustainable production management decisions is to understand the practices associated with each tillage system. The different tillage systems are described below.

2 Tillage Systems

2.1 Conventional Tillage

Conventional tillage is a tillage system using cultivation as the major means of seedbed preparation and weed control. Conventional tillage is defined by the *Conservation Tillage Information Center* in West Lafayette, Indiana, USA (CTIC 2004) as any tillage and planting system that leaves less than 15% residue cover after planting, or less than 560 kg per hectare of small grain residue equivalent throughout the critical wind erosion period. It is based on mechanical soil manipulation involving a sequence of soil tillage, such as mouldboard ploughing followed by one or two harrowings, to produce a fine seedbed and also the removal of most of the plant residue from the previous crop.

2.2 Intensive Tillage

Multiple field operations or practices with implements such as a mould board, disk, and/or chisel plough are used to describe intensive tillage systems. Then a finisher with a harrow, rolling basket and cutter can be used to prepare the seed bed. Intensive tillage systems leave less than 15 % crop residue and cover less than 560 kg/ha of small grain residue on the surface. These types of tillage systems are often referred to as conventional tillage systems but as reduced and conservation tillage systems have been more widely adopted, it is often not appropriate to refer to this type of system as conventional.

2.3 Conservation Tillage

Conservation tillage (CT) is defined by the Conservation Tillage Information Center (CTIC 1993) as any tillage and planting system that covers 30% or more of the soil surface with crop residue after planting, to reduce soil erosion by water. The FAO definition of conservation tillage canters on avoiding mechanical soil disturbance, maintaining continuous soil cover, and adopting diverse cropping systems (Kassam et al. 2014). It is the collective umbrella term which is given for no-tillage, direct-drilling, minimum tillage, ridge tillage (Baker et al. 2002). Main aim of conservation tillage is to boost agricultural production by increasing the efficiency of farm resources, and facilitating to reduce land degradation through integrated management of available land, water, and natural resources combined with external inputs (SoCo 2009). However, the success or failure of conservation tillage depends on the use of herbicides, crop residue and efficiency of planting equipments to place seed in soil below the residues.

Conservation tillage systems is being practised worldwide and currently about 100 million ha has been adopted throughout the world. Six countries have more than 1 million ha area under no tillage systems. South America has the highest adoption rates, and has more area under permanent no-till and permanent soil cover. United States has the maximum area under conservation agriculture, followed by Brazil, Argentina, Canada, Australia and Paraguay. Adoption of no-tillage systems for sowing of winter-season crops including wheat planted after rice has shown tremendous increase in South Asia in the last few years (Fig. 1). The CTIC (1993) has sub-divided the conservation tillage into following four systems:

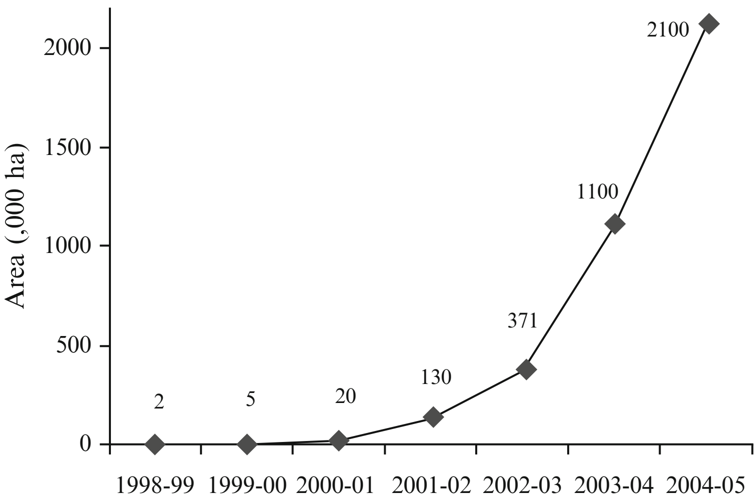


Fig. 1 Increase in area under zero-till winter season crops including wheat planted after rice in South Asia

2.3.1 No-Tillage (No-Till, Zero-Till, Slot Planting, Sod Planting, Eco-fallow, Chemical- Fallow, Direct Drilling)

Several variations of minimum tillage systems are in use globally, varying in degree from almost no tillage to nearly full conventional tillage (Unger 1984). The CTIC defines no-till as a system in which the soil is left undisturbed from harvest to planting except for nutrient injection. Tillage is essentially eliminated with no-till system. The only tillage that is used is the soil disturbance in a narrow slot created by coulters or seed openers (Conservation Tillage Systems and Management 2000). Planting or drilling is accomplished in a narrow seedbed or slot created by coulters, row cleaners, disk openers in row chisels or roto-tillers. Compared to other tillage systems, no-till also minimizes fuel and labour requirements. Pre-emergence or post-emergence surface applications of one or two herbicides properly timed is sufficient to control weeds. Recent advancements in herbicides make weed control with no-till easier than it used to be. Early pre-plant applications, longer-lasting residual herbicides and a wide variety of post-emerge products are helping assure weed control success with no-till (Lal 1998). Residue, when uniformly spread, increases water infiltration and reduces soil moisture evaporation as shown in Fig. 2 (Gajri et al. 2009). In a long-term tillage study, higher soil moisture under no-till corn production was observed throughout the growing season. Significantly less evaporation occurred under no-till early in the growing season. This conservation of soil water may carry the no-till crop through short drought periods without severe moisture stresses developing in the plants. However, the extra water conserved under no-till can occasionally be detrimental under conditions in which excessive soil water contributes to denitrification losses. Soil compaction in no-tillage soils was not found to be a problem. Saturated hydraulic conductivity measurements suggest better water movement in no-tillage compared with existing system of

Fig. 2 No-till leaves the maximum crop residue for soil protection

conventional tillage. In 2011, South America had 44 % of the total global area under no-tillage, followed by North America i.e. 32 %. Europe had 1.35 million ha under no-tillage which is about 1% of the total global area (Friedrich et al. 2012).

2.3.2 Reduced Tillage

Reduced tillage system that is less intensive than conventional systems. Under this conservation tillage system, the number of tillage operations is minimized by either the elimination of one or more tillage operations or combining together of primary and secondary tillage operations. Only those tillage operations are operated and performed that are absolutely necessary for crop production under a given set of soil, crop and climatic conditions (Gajri et al. 2009). Land preparations and seeding is completed in one operation. Ploughing is normally eliminated, but the total field surface is still worked by tillage equipment. The crop residues are retained on the soil surface for as long as possible if the objective is to conserve soil and soil moisture during rainy season. Under irrigated conditions, reduced tillage may be practiced after removing residues from the surface. This tillage practice has largely been adopted in alluvial soils of Indo-Gangetic Plains, where wheat is planted with minimum tillage operations in the lean fields the surface (Gajri et al. 2009) Figs. 4, 5, 6.

2.3.3 Ridge Tillage

Ridge tillage or Ridge-till is a reduced disturbance planting system in which crops are planted and grown on ridges formed during the previous growing season and by shallow, in-season cultivation equipment. In ridge-till, the soil is also left undisturbed from harvest to planting except for possible fertilizer injection (Gajri et al. 2009). The ridge beds are established and maintained through the use of specialized cultivators and planters designed to work in heavy crop residues (Fig. 2). Tillage is generally very shallow, disturbing only the ridge tops. Planting is completed in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. A band application of herbicide behind the planter provides weed control in the row (Opara-Nadi 1993). Ridge tillage is primarily intended for the production of agronomic row crops like corn, soybeans, cotton, sorghum and sunflower. Level or gently sloping fields, especially those with poorly drained soils are well suited to ridge systems. A ridge tillage system is an excellent choice for soils that are often too wet. Ridges in the ridge-till system work quite well to provide drainage on poorly drained soils. Ridge-tillage system reduces erosion by leaving the soil covered with residue until planting. After planting, 30–50 % residues may be left, but it is not uniformly distributed on the surface (Fig. 3).

Fig. 3 Ridge-till system with crops planted on ridges

2.3.4 Stubble Mulch Tillage

Mulch tillage or Mulch-till is a category that includes all conservation tillage practices other than no-till and ridge-till. Mulch tillage is described as a tillage system in which a significant portion of crop residue is left on the soil surface to cover soil surface (SCSA 1987). It is usually accomplished by substituting chisel plows, sweep cultivators, or disk harrows for the moldboard plow or disk plow in primary tillage. This change in implements is attractive because residues are not buried deep in the soil and good aerobic decomposition is thus encouraged (Gajri et al. 2009). Weed control is accomplished with herbicides and/or cultivation.

3 The Principles of Conservation Agriculture

Conservation agriculture emphasizes that the soil is a living body, essential to sustain quality of life on the surface of earth. Conservation tillage in particular recognizes the importance of the upper 0–20 cm of soil as the most active zone, but also the zone most vulnerable to erosion and degradation. Most environmental functions and services that are essential to support terrestrial life are concentrated in the micro, meso, and macro fauna and flora which live and interact in this zone.

The principles of conservation agriculture and the activities to be supported are described as follows:

- *Maintaining permanent soil cover and promoting minimal mechanical disturbance of soil through zero tillage systems, to ensure sufficient residual biomass to enhance soil and water conservation and control soil erosion*. This improves soil aggregation, soil biological activity and soil biodiversity, water quality and increases soil carbon sequestration. It greatly enhances water infiltration,

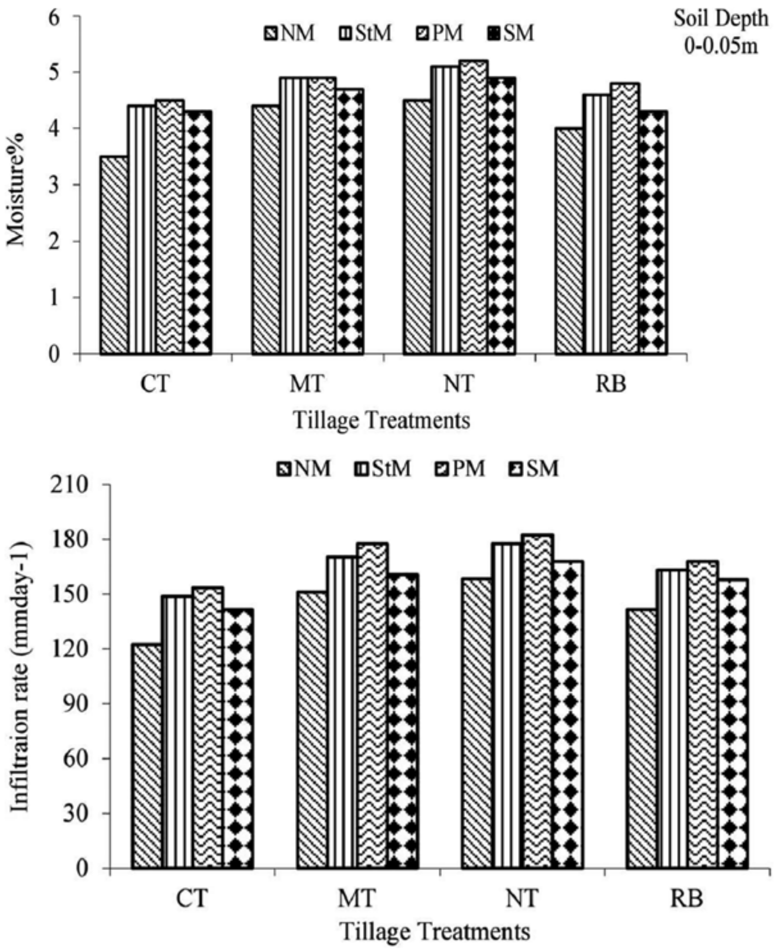


Fig. 4 Effect of tillage & water management practices on soil water content at harvesting of maize (3 years average), were, *CT* Conv. Till., *MT* Min. Till., *NT* No Till., *RB* Raised bed, *NM* No Mulch, *StM* Straw mulch, *PM* Polythene Mulch and *SM* Soil Mulch

improves efficient water use efficiency and maintains optimum temperature, moisture and increased insurance against drought.

- *Promoting a healthy, living soil through crop rotations, cover crops and involving integrated pest management technologies.* These practices reduce requirements for pesticides and herbicides, control off-site pollution. The objective is to create a healthy soil microenvironment that is naturally aerated, better able to receive, hold and supply plant available water, maintain nutrient cycling and better able to decompose and mitigate pollutants.
- *Promoting application of fertilizers, pesticides, herbicides and fungicides in balance with crop requirements.* By feeding the soil medium rather than fertilize the crop to be grown, will reduce chemical pollution, improve water quality and maintain the natural ecological integrity of the soil, while optimizing crop productivity and economic returns.

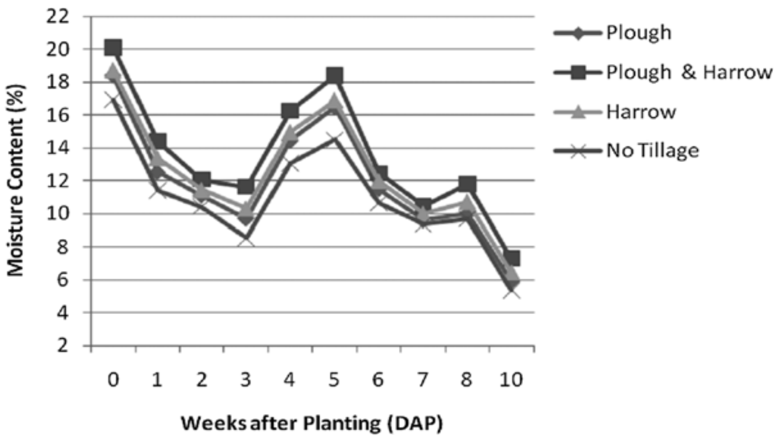


Fig. 5 Effect of tillage practice on moisture content: 0–10 cm (2009)

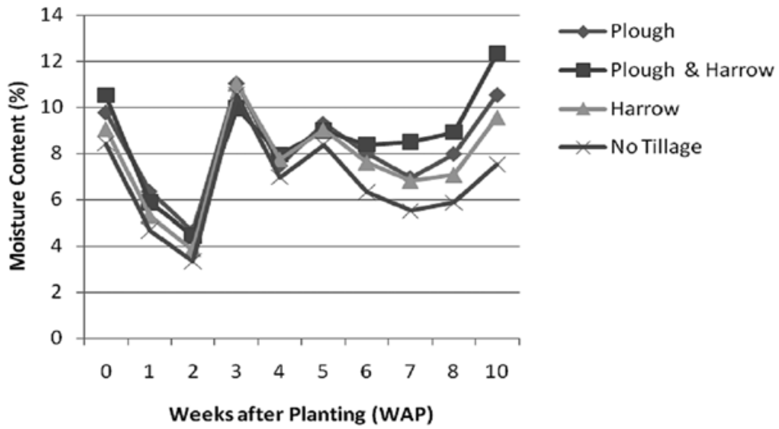


Fig. 6 Effect of tillage practice on moisture content: 0–10 cm (2010)

- *Promoting precision placement of inputs to reduce costs, optimize efficiency of operations, and prevent environmental damage.* Site specific treatment of problems, increased economic and field operation efficiencies, improved environmental protection and reduced (optimized) input costs. Precision is exercised at many steps in field operations especially during seed, fertilizer and spray placement; permanent wheel placement to stop random compaction.
- *Promoting legume fallows (including herbaceous and tree fallows where suitable), composting and the use of manures and other organic soil amendments.* This improves soil structure and biodiversity and reduces the need for inorganic fertilizers; improves soil physical properties and soil biodiversity.
- *Promoting agroforestry for fiber, fruit and medicinal purposes.* Agroforestry (trees on farms) provides many opportunities for value added production, efficient utilization of soil resources, contour hedges for erosion control, to conserve and enhance biodiversity.

4 Comparison of Tillage Systems

Typical advantages and disadvantages of different tillage systems are shown below. This information is useful in determining the suitability of tillage systems or combinations of systems for various situations. The most important advantage of conservation tillage is to control considerably soil erosion effectively and economically and the resulting sedimentation as well, a major water pollutant. Compared to the commonly used disk system, no-till saves about 1–1/2 gal/ac in fuel and 20 min of labour/ac. Labour savings allow a larger area to be farmed without additional equipment or help. Conservation tillage systems therefore represent alternatives at a time when economics require flexibility in crop production.

Comparison of selected tillage systems and typical field operations

System	Typical field operations	Major advantages	Major disadvantages
Mouldboard plough	Fall or spring plough; plough one or two spring disking	Suited for poorly drained Major soil erosion. Well-tilled seedbed.	Fuel and labour costs maximum, Soil moisture loss high, field cultivations; Timeliness considerations, very good incorporation.
Chisel plough	Fall chisel; one or two spring diskings or field cultivations; plant; cultivate. than fall plow or fall disk	Less wind erosion and fuel requirements Well adapted to poorly drained soils. Good to excellent incorporation.	Erosion controls less but significant soil moisture loss. Medium to high labour because of rough surface.
Disk	Fall or spring disk; spring disk and/or field cultivate; plant; cultivate.	Less erosion than from cleanly tilled systems. Well adapted for lighter to medium textured, well-drained soils. Good to excellent incorporation.	Little erosion control. High soil moisture loss
Ridge-till	Chop stalks (on furrow irrigation); plant on ridges; cultivate for weed control and to rebuild ridges.	Excellent erosion control if on contour. Well adapted to wide range of soils. Excellent for furrow irrigation. Ridges warm up and dry out quickly. Fuel and labour costs	No incorporation Narrow row soybeans and small grains not well suited. No forage crops. Machinery Low modifications required
Strip-till	Fall strip-till; spray; plant On cleared strips; post emergent spray as needed.	Clears residue from row area to allow pre-plant soil warming and drying. Injection of nutrients directly into row area. Well suited for poorly drained soils.	Cost of pre plant operation Strips may dry too much, crust, or erode without residue. Not suited for drilled crops. Potential for different nitrogen fertilizer losses
No-till	Spray; plant into undisturbed surface; post emergent spray	Maximum erosion control. Soil moisture conservation as needed. Minimum fuel and labour costs.	No incorporation increased dependence on herbicides. Limitations with poorly drained soils

5 Conservation Tillage Effects on Soil Physical Properties

Effects of conservation tillage on soil properties vary and these variations depend on the particular system chosen. No-tillage management affects the pedological, hydrological and geomorphological processes (García-Orenes et al. 2009; Gao et al. 2014). Conservation tillage improved soil structure thereby enhancing nutrient recycling, water availability and biodiversity while reducing water and wind erosion and improving surface and ground water quality (Lahmar 2010). Soil physical properties in general have significantly improved under different types of conservation tillage (Wang et al. 2005). According to (Lal 1997), and generally with no-till physical properties are more favourable than tillage-based systems. No-till (NT) systems, which maintain high surface soil coverage, have resulted insignificant change in soil properties especially in the upper few centimetres (Anikwe and Ubochi 2007). Macro-porosity hence soil aggregation are increased substantially with build-up of active organic matter fraction and consolidation of other macro and micro organisms. Infiltration and internal drainage are generally improved, as is soil water-holding capacity. Infiltration capacity at optimum rate in no-till managed soils is generally quite desirable for long term water retention, but under high infiltration rate it may lead to more rapid leaching of nitrates and other water-soluble nutrient related chemicals. Residue-covered soils are generally cooler and moister. This is an advantage in the hot part of the year, but may be detrimental to early crop growth in the cool spring of temperate regions.

In cool regions, adoption of conservation tillage has hinders due to restricted soil drainage leading to soil conditions as wetter and cooler than with conventional tillage and hence yield levels may be low. Reduced yields have discouraged the adoption of conservation tillage in these regions. However, limited pre-planting tillage over the crop rows or ridge tillage are conservation tillage systems that allow at least part of the soil to warm faster and largely overcome these problems.

5.1 Soil Structure and Soil Aggregation

Soil aggregation can be improved by management practices that decrease agro-ecosystem disturbances, improve soil fertility, increase organic inputs, increase plant cover, and decrease soil organic carbon decomposition rate. The stability of soil structure and soil aggregates is strongly linked with physical protection of soil organic matter within soil aggregates (Bachmann et al. 2008). The stability of aggregates depends on the strength of intra-aggregate bonds and distribution of possible failure zones related to the geometries of air filled pores, small cracks, strength of mineral-organic bonds and other cementing agents between soil particles (Bronick and Lal 2005; Kodesova et al. 2009). Better aggregation and improved pore size distribution (Bhattacharyya et al. 2006a) was observed by the adoption of zero tillage. In Gottingen, Germany, Jacobs et al. (2009) found that minimum tillage

Table 1 Effect of different tillage treatments on soil structure (mean of 2006 and 2007)

Tillage	Aggregate proportion in size class (%)				MWD
	>2 mm	2–1 mm	1–0.25 mm	<0.25 mm	
NT	56.45a	25.62b	16.57c	1.36b	2.47a
RT	46.86b	27.43ab	23.30b	2.41a	2.20b
CT	25.96c	30.46a	41.81a	1.78ab	1.63c

Letters indicate results of LSD test. *NT* no tillage, *RT* ridge tillage, *CT* conventional tillage

(MT), compared with CT, did not only improve aggregate stability but also increased the concentrations of SOC and N within the aggregates in the upper 5–8 cm soil depth after 37–40 years of tillage treatments. Zhang et al. (2012) reported the soil aggregate distribution and mean weight diameter (MWD) under different tillage systems at the depth of 0–20 cm (Table 1).

5.2 Bulk Density, Porosity and Penetration Resistance

Studies showed that macropore connectivity increased under NT, which allowed for increased water infiltration. There were inconsistent responses in total porosity and soil bulk density as compared with conventional tillage practices (Stubbs et al. 2004). Macropores typically are characteristic features of root channels, earthworm made holes, and other continuous non uniform channels. The population of earthworms is generally higher under NT systems than under full-width tillage systems (Blanco-Canqui and Lal 2007). Total porosity, which is directly related to bulk density, tends to be lower under NT, at least initially. Studies by Jiang et al. (2007) showed that micropores (<10 μm) will increase under NT, even in soils that have a clay pan. In areas being converting from CT to NT, bulk density will increase and typically will not decrease unless there is an increase in soil organic matter or proportion of macro-porosity. Practices such as adding residue mulch, growing winter cover crops with fibrous rooting systems, and including small grain in the rotation along with no-till increase porosity (Villamil et al. 2006; Blanco-Canqui and Lal 2007; Jemai et al. 2013). Raczkowski et al. (2012) conducted an 8-year NT study in North Carolina on sandy soils under a rotation of low-residue cotton, soybeans, and peanuts along with high-residue corn and sorghum. This study showed that NT resulted in higher bulk density, lower macroporosity, and higher microporosity compared to CT. These results were expected because low-residue crops were used and the area was in a thermic soil temperature regime under a humid climate, in which residue decomposes quickly.

Penetration resistance (kPa) of the soil can be regarded as a factor determining the quality of its structure and depends on its physical and mechanical properties. Tillage increased bulk density and penetration resistance of the soils significantly as

Table 2 Effect of different tillage treatments on soil physical properties (mean of 2006 and 2007)

Treatments	Soil bulk density (gcm^{-3})	Soil penetration resistance (k Pa)	Soil moisture content (%)
CT	1.41 c	560 c	19.6 a
RT	1.47 b	815 b	18.4 b
MT	1.50 ab	1105 a	17.1 c
NT	1.52 a	1250 a	16.8 c

CT Conv. Till., *RT* Reduced till. *MT* Minimum Till., *NT* No till

compared to zero-tillage (Carman 1997; Zhang et al. 2013). Rashidi and Keshavarzpour (2008) observed that the highest soil bulk density of 1.52 g cm^{-3} was obtained for the NT treatment and lowest (1.41 g cm^{-3}) for the CT treatment. The highest soil penetration resistance of 1250 kPa was obtained for the NT treatment and lowest (560 kPa) for the CT treatment. The highest soil moisture content of 19.6 % was obtained for the CT treatment and lowest (16.8 %) for the NT treatment shown in Table 2.

5.3 Soil Strength and Stability

The term ‘strength’ describes the level of stress or pressure that a soil can resist without undergoing irreversible deformation or change in shape while as ‘stability’ is used to describe the ability of soil to retain a coherent structure in the presence of free water. Both strength and stability are necessary if the soil is to retain its structure against imposed or external stresses. These imposed stresses may be natural such as raindrop impact or floods or may be anthropogenic such as those imposed by vehicular traffic. A complication with soil is that its strength must not be too great otherwise; plant roots and other organisms will not be able to penetrate. Aggregate stability improved with only 3 years of NT on sandy piedmont soils in Georgia under thermic and humid climatic conditions, which cause a more rapid breakdown of organic matter (Franzluebbers and Stuedemann 2008). Brock (1999) reported that water-stable aggregates cannot be sustained with CT since the residue cover is not sufficient to protect against surface crusting and that long-term NT is needed to increase aggregate stability. Conservation tillage encourages microbial activity through increase in organic matter thereby leading to increased soil aggregate stability (Table 3).