MILLAR · TURK · FOTH

FUNDAMENTALS OF *Soil Science*

THIRD EDITION

C. E. MILLAR

Late Professor Emeritus of Soil Science
Michigan State University

L. M. TURK

Director
Agriculture Experiment Station
Michigan State University

H. D. FOTH

Associate Professor of Soil Science
Michigan State University

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Preface

Fundamentals of Soil Science was written primarily as a college textbook for use in the introductory or general course in soils. Also, it may be studied profitably by soil conservation technicians, agricultural agents, farmers, or anyone seeking a knowledge of the soil and of the principles underlying successful soil management.

The purpose of the book is fourfold: first, to give the reader the opportunity of becoming familiar with soils as natural units or entities and with their inherent characteristics; second, to develop in the student an understanding of the significance of fundamental soil properties; third, to set forth basic relationships between soils and plants; and last, to give the reader an understanding of the principles involved in the practical use and conservation of the soil.

General principles of soil science are emphasized and explained in simple terms, technical discussions, particularly of debatable points, being omitted. Special attention is given to progress which has been made in fundamental principles since the publication of the second edition of this book. The material dealing with the influence of the soil-forming factors on soil genesis has been consolidated and expanded. Other additions include material on the texture profile, the role of clay in organic matter accumulation, liquid fertilizers, and the relationship of *p*H to percentage of base saturation. Proven soil-management practices are referred to, but the details of practices have been omitted to a large extent.

It has been necessary to go somewhat into the fields of chemistry, botany, geology, physics, microbiology, crop production, and agricultural engineering because soil science is closely related to them.

Chapter sequence in the book provides a logical treatment of the subject. The arrangement of the material in the chapters is designed to assist the student in an effective study of the subject matter presented. For example, the "objectives" call attention to the main subdivisions of the material under discussion, and the "questions" bring out the pertinent points in the discussion.

We take pleasure in expressing appreciation to Dr. C. H. Spurway (deceased), Professor J. O. Veatch, Dr. G. J. Bouyoucos, and Dr. A. H. Mick for assistance in the preparation of the original edition of this book. In the first revision of the text valuable help was received from Professor W. T. McGeorge, University of Arizona; Dr. C. E. Kellogg, then with the Bureau of Plant Industry, Soils, and Agricultural Engineering; Dr. R. D. Hockensmith, Soil Conservation Service; and Dr. E. P. Whiteside, Dr. R. L. Cook, Dr. J. Q. Lynd, and other members of the Soil Science Department of Michigan State University. We also take pleasure in expressing appreciation for the valuable help received in preparing the second revision from Professor L. J. Braamse, Dr. L. S. Robertson, Professor I. F. Schneider, Dr. E. P. Whiteside, Dr. A. R. Wolcott, and other members of the Soil Science Department of Michigan State University.

C. E. MILLAR (Deceased)
L. M. TURK
H. D. FOTH

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Contents

1 Materials for Soil Development

Kinds and Composition of Mineral Parent Material 2
Characteristics of Minerals from Which Soils Are Derived 4
Igneous Rocks as Parent Material 8
Sediments as Soil Parent Material 9
Nature and Source of Organic Parent Materials 19

2 Processes of Soil Development

Processes of Disintegration 24
Chemical Processes of Soil Formation 25
Products and Results of Mineral Decomposition 28
Biological Activities and Soil Development 30
Synthesis and Translocation of Materials during Soil Development 32
Summary of General Changes Leading to Soil Development 35
The Soil Profile 37

3 Physical Properties of Soils

Soil Texture 42
A Textural Grouping of Soils 47
The Texture Profile 50
Soil Structure 52
Tillage Operations and Soil Properties 58
Porosity and Weight of Soil 67
Soil Color 70
Soil Temperature 73

4 Soil Moisture

Soil Water Which Yields to the Pull of Gravity 77

Soil Water Which Is Retained against the Pull of Gravity 87
Water in Relation to Plant Growth 98
Loss of Moisture from the Soil 102
Runoff Water 109

5 Origin and Classification of Soils

Soil Development in Relation to Time 111
Soil Development in Relation to Climate 114
Soil Development in Relation to Vegetation 117
Soil Development in Relation to Parent Material 120
Soil Development in Relation to Topography 124
A Systematic Classification of Soils 126
The Soil Survey 132
Some Important Great Soil Groups 136
Soil Groups in Relation to Population Density and Production of Food and Fiber 141

6 Chemical Properties of Soils

The Chemical Composition of Soils 147
The Colloidal Fraction of Soils 154
Other Chemical Properties of Soils 163

7 Soil Reaction

Soil Acidity and Conditions Giving Rise to Acid Soils 165
Conditions in Acid Soils Which Are Beneficial or Detrimental to the Growth of Plants 177
Conditions of Development and Effect of Neutral and Alkaline Soils on Plants 181

8 Lime and Its Use

The Need of Soils for Lime 186
Functions of Lime in the Soil 188
Forms of Lime 192
Lime Guarantees 198
Sources of Lime 201
The Use of Lime 205

9 Soil Organisms—Kinds, Numbers, Activities, and Relation to Soil Productivity

Nature and Extent of the Soil Population 217

Activities of Soil Microbes in Relation to the Growth of Higher Plants 229
The Role of Microorganisms in the Development of Soils 243
Relationships between Higher Plants and Soil Microorganisms and among Soil Microorganisms Themselves 246

10 Soil Organic Matter

Sources and Kinds of Soil Organic Matter 249
Decomposition of Organic Matter and Humus Formation 252
Effects of Organic Matter on Soil Characteristics and Productivity 263
Accumulation and Loss of Soil Organic Matter 266

11 Cover and Green-Manure Crops

The Effects of Cover and Green-Manure Crops 276
The Principal Cover and Green-Manure Crops and Their Regional Distribution 283
The Utilization of Cover and Green-Manure Crops 286
Effect of Green Manure on Yield of Crops 292

12 Farm Manures

Production of Manure 295
The Decomposition of Manure 301
Losses Occurring in Manure 305
Methods of Handling Manure 307
Field Management of Manure 311
Fertilizing Properties of Manure 314
Effects of Manure on the Soil 318

13 Nutrient Requirement of Plants

Elements Used by Plants 322
Effects of Nitrogen, Phosphorus, and Potassium on Plants and the Quantities Removed by Crops 328
Determining Soil-Nutrient Deficiencies 336

14 Fertilizers and Fertilizer Materials

Fertilizing Materials Supplying Nitrogen 345
Phosphatic Fertilizer Materials 349
Potassium Fertilizers 357
Mixed Fertilizers 362

15 Fertilizer Practices

Effects of Fertilizers on Soils 372
Effects of Fertilizers on Crops 376
Laws Controlling Fertilizer Sales 377
Purchase and Use of Fertilizers 381

16 Conserving Soil

Soil Conservation Defined 385
Reasons for Employing Conservation Practices 387
Controlling Erosion Caused by Water 393
Controlling Erosion Caused by Wind 409

17 Soil Fertility Maintenance and Productivity Rating of Soil

Maintaining Soil Fertility 420
Soil-Productivity Rating and Land Classification 428

18 Soils and Agriculture of Arid Regions

Characteristics and Utilization of Soil in Arid Regions 433
Development and Management of Saline and Alkali Soils 443

19 Irrigation

Water Supply and Land for Irrigation 455
Irrigation Practice 459

20 Soil Resources

Acreage of Farm Land in the United States 474
Acreages of Arable Land and Land Requirements 480
Land Policies of the United States 486

Glossary 491

Index 501

CHAPTER 1

Materials for Soil Development

Soils are developed; they are not merely an accumulation of debris resulting from decay of rock and organic materials. Soil formation is, accordingly, a constructive as well as a destructive process. Destructive forces predominate in the breaking down chemically and physically of minerals and plant and animal structures, with the resultant partial loss of the more soluble and volatile products. Particles of the original materials in various stages of decomposition also remain, together with newly developed compounds. The constructive forces develop new chemical compounds, both mineral and organic, and provide a new distribution or association of the materials so that the resultant soil has a characteristic structural and textural as well as chemical composition which influences plant growth. In other words, a soil is an entity—an object in nature which has characteristics that distinguish it from all other objects in nature.

Soils are developed from two classes of materials: (1) partially decomposed plant substance (organic material); and (2) rocks and minerals (mineral material). To a limited extent soils develop in a mixture containing considerable quantities of both organic and mineral matter. In discussing the parent materials from which soils are developed it is helpful to consider the following objectives.

► Objectives

A. Kinds and composition of mineral parent material.
B. Characteristics of minerals from which soils are derived.

C. Igneous rocks as parent material.
D. Sediments as soil parent material.
E. Nature and source of organic parent materials.

KINDS AND COMPOSITION OF MINERAL PARENT MATERIAL

Before the forces of soil development can be operative, it is necessary that raw materials on which they can work be present. Let us first study, therefore, parent materials from which soils are made. The mineral materials have been classified from a purely geological point of view, their mineralogical composition, texture, structure, and age being taken into account. Occasionally soil groups are incorrectly designated according to the geological classification of their parent material, and we carelessly speak of "granite soils" or "limestone soils." When we use these terms what we really mean is "soils developed from granite rocks" or "soils developed from limestone." In the consideration of mineral parent material, two questions suggest themselves.

► Questions

1. What is mean by "residual" and "transported" soils?
2. Which chemical elements make up a large part of the earth's surface?

Residual and Transported Materials

Soils have developed from the decay of hard rocks, consolidated sediments, or unconsolidated sediments exposed to soil-forming processes. Soils developed from hard rocks or consolidated sediments are often loosely termed *residual soils.* On the other hand, many soils have formed from stones, sand, silt, and clay which have been moved from their original sites and have not been consolidated after their deposition. Such soils are frequently called *transported soils;* more correctly speaking, they are soils that have developed in transported, unconsolidated material, because it is impossible for a soil to be naturally transported in its entirety. The general distribution of residual and transported soil materials in the United States is shown in Fig. 1.

Chemical Composition of the Earth's Crust

The solid crust of the earth (lithosphere) is made up largely of eight chemical elements. In fact, two elements, oxygen and silicon, compose some 75 per cent of it. On the other hand, many of the elements important in the growth of plants and animals occur in very small quantities. Needless to say, these elements and their compounds are not evenly dis-

Fig. 1. A generalized physiographic map of the United States. (Drawn from a map prepared by the Division of Soil Survey and presented in *U.S.D.A. Bull. 96.*)

Legend of Areas: 1. Pacific Coast region. 2. Northwest intermountain region. 3. Great Basin region. 4. Southwest arid region. 5. Rocky Mountain region. 6. Great Plains region. 7. Glacial lake and river terraces. 8. Glacial region. 9. Loessial deposits. 10. Limestone Valleys and Uplands. 11. Appalachian Mountains and Plateaus. 12. Piedmont Plateaus. 13. River flood plains. 14. Atlantic and Gulf coastal plains. 15. Loessial deposits over glacial material.

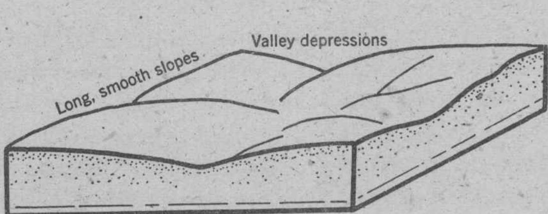

Fig. 2. A diagrammatic presentation of the mature topography of a residual-soil area. The long, smooth slopes and moderate valley depressions with well-developed drainages are characteristic. (Compare with Fig. 5.)

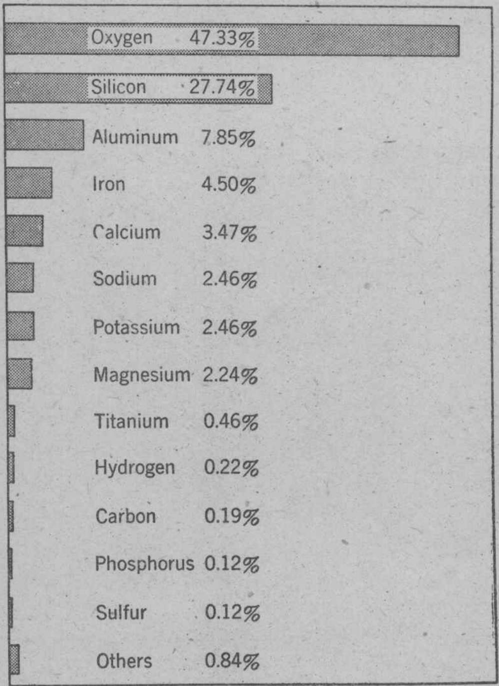

Fig. 3. Composition of the solid crust of the earth (lithosphere) to a depth of 10 miles. Note relatively small percentages of several elements essential for plant growth. (From F. W. Clarke, *U.S.G.S. Bull. 695.*)

tributed throughout the earth's surface. For example, in some places phosphorus compounds are so concentrated that they are mined, whereas in many other areas there is a deficiency of phosphorus for maximum plant growth. The composition of the lithosphere is shown in Fig. 3.

Differences in Soil Parent Materials

There were many variations in the original rocks from which soils were derived. Igneous, sedimentary, and metamorphic rocks all served as sources; and within these broad groups there are, of course, many differences in composition, structure, and ease of decomposition. A short discussion of igneous rocks and sedimentary materials will be given.

CHARACTERISTICS OF MINERALS FROM WHICH SOILS ARE DERIVED

Soils are composed very largely of fragments of rocks and minerals and of the products of their decomposition. A student should know at least some of the elementary facts concerning the composition and properties of minerals found most abundantly in soils. Three questions serve as guides in the study of soil minerals.

▶ Questions

1. Minerals represent what kinds of chemical compounds?
2. Into what groups are soil minerals divided?
3. What are the chief characteristics of the mineral groups?

Groups, Composition, and Characteristics of Minerals

Combinations of oxygen with silicon and iron, and sometimes with water also, give rise to such compounds as SiO_2 and $Fe_2O_3 \cdot 3H_2O$ and constitute one group of minerals called oxides. Basic compounds like $Ca(OH)_2$ and $Mg(OH)_2$ combine with CO_2 to form another mineral group, known as carbonates, which is very important in soil formation. By far the largest number of minerals belong to the silicate group, in which Ca, Mg, Na, K, Fe, and Al combine with the various silicic acids like orthosilicic (H_4SiO_4), metasilicic (H_2SiO_3), and polysilicic ($H_4Si_3O_8$). At times the Al is part of the negative radical forming aluminosilicates. Many of these compounds and the products formed from their decomposition take on water; that is, they become hydrated.

The name, chemical composition, and some information about occurrence, properties, and decomposition products of some of the most important and widely distributed minerals and rocks are listed below.

Oxide Group

Quartz	SiO_2	Very resistant to change; highly insoluble; very hard.
Hematite	Fe_2O_3	Red; hydrates with increase in volume to form $2Fe_2O_3 \cdot 3H_2O$.
Magnetite	Fe_3O_4	Dark brown; magnetic; resistant to change; not of wide occurrence.
Limonite	$2Fe_2O_3 \cdot 3H_2O$	Yellow; soft; resistant to change except in degree of hydration; widely distributed.
Other hydrated oxides of Fe	$2Fe_2O_3 \cdot H_2O$ $Fe_2O_3 \cdot H_2O$ $Fe_2O_3 \cdot 2H_2O$	Color varies from yellowish red to yellow with increase in hydration. Are supposed to account for red and yellow in soils. Are resistant to change other than in degree of hydration. Are of wide occurrence.

Carbonate Group

Calcite	$CaCO_3$, quite pure.	Well crystallized. Goes into solution readily as $Ca(HCO_3)_2$.
Dolomite	$CaCO_3 \cdot MgCO_3$	Important constituent of dolomitic limestone.
Magnesite	$MgCO_3$, purity varies.	Not of wide occurrence.
Siderite	$FeCO_3$, sometimes mined as an iron ore.	Not an important soil mineral. Found under poorly drained conditions. Combines with CO_2 and H_2O to form $Fe(HCO_3)_2$, which is soluble.

Feldspar Group

Microcline and orthoclase	$KAlSi_3O_8$	Orthoclase occurs in large quantities as a constituent of granite and gneiss.
Albite	$NaAlSi_3O_8$	The sodium and calcium feldspars form a part of many crystalline rocks like basalt, diabase, gabbro, diorite, and many lavas. The feldspars decompose fairly readily in the presence of H_2O and CO_2. The Ca goes to the carbonate or more soluble bicarbonate, and the Na and K to carbonates. Some SiO_2 is split off and may remain as insoluble SiO_2 or form silicic acids and soluble or colloidal hydrated silicates. Most of the Al and much Si go into the formation of hydrated aluminosilicates, of which kaolinite ($H_2Al_2Si_2O_8 \cdot H_2O$) is an example. The exact hydrated aluminosilicate formed depends on the conditions prevailing during decomposition. Compounds of this nature are important constituents of clay and play prominent roles in determining the properties of soils and the reactions that take place in them. Calcium feldspars decompose much more easily than do sodium and potassium feldspars.
Labradorite	$NaCaAl_2Si_6O_{16}$	
Anorthite	$CaAl_2Si_2O_8$	

Micas

Muscovite (white)	$H_2KAl_3Si_3O_{12}$	Break up into fine glittering scales which are sometimes mistaken for

Biotite (dark)	$(H, K)_2(Mg, Fe)_2$-$(Al, Fe)_2Si_3O_{12}$	gold when yellow. When much iron is present in biotite, it decomposes readily; otherwise the micas break up physically quite easily but decompose chemically very slowly. They are abundant ingredients of many rocks.

Other Silicates

Amphiboles (hornblende)	$Ca(Mg, Fe)_2Si_4O_{12}$ with $Na_2Al_2Si_4O_{12}$ and $(Mg, Fe)_2(Al, Fe)_2Si_2O_{12}$	The minerals are dark green in thin sections but appear black as they occur. Hornblende decomposes fairly readily because of its easy cleavage and high content of ferrous iron. On decomposition it produces a rust-colored clay which is a constituent of many red soils. Augite does not cleave so easily and often occurs as "black gravel" in soils.
Pyroxenes (augite)	$CaMgSi_2O_6$ with $(Mg, Fe)(Al, Fe)_2Si_2O_6$ There is considerable variation in the proportions of the different elements, especially of Ca, Mg, Al, Fe.	
Olivine	$MgFeSiO_4$	Decomposes in presence of moisture to form serpentine ($H_4Mg_3Si_2O_9$), liberating SiO_2 and FeO.
Leucite	$KAlSi_3O_{12}$	A constituent of many volcanic rocks but otherwise not an abundant mineral. It is of interest because of its high K content.
Talc (soapstone) and Serpentine	$3MgO \cdot 4SiO_2 \cdot H_2O$ $3MgO \cdot 2SiO_2 \cdot 2H_2O$	These two hydrated silicates of magnesium are found extensively in some regions. Both are soft, but serpentine in the absence of definite structure disintegrates slowly unless considerable ferrous iron is present. Talc cleaves readily and is very soft; so disintegration is accelerated. Both give rise to rather infertile soils.

Sulfides

Pyrite and Marcasite	FeS_2	These minerals are yellow, often mistaken for gold when small fragments are mixed with sand or gravel. They oxidize under suitable conditions, forming H_2SO_4. They are common constituents of rocks in some areas.