PRINCIPLES AND APPLICATIONS OF SOIL GEOGRAPHY

Edited by

E. M. Bridges and D. A. Davidson

PRINCIPLES AND APPLICATIONS OF SOIL GEOGRAPHY

Edited by

E. M. Bridges and D. A. Davidson

Longman London and New York

Longman Group Limited
Longman House
Burnt Mill, Harlow, Essex, UK

Published in the United States of America
by Longman Inc., New York

First published 1982

British Library Cataloguing in Publication Data

Principles and applications of soil geography.
1. Soils
I. Bridges, Edwin Michael
II. Davidson, Donald Allen
631.4 S591 80–41509

ISBN 0-582-30014-2

Printed in Singapore by Kyodo Shing Loong Printing Industries Pte. Ltd

PREFACE

A textbook, published recently in the United States of America, contains the comment that 'these are exciting times in pedology'; the editors of this book share this enthusiastic viewpoint. A great deal of activity is taking place in the scientific study of the soil and as a result, many papers and books are being written upon the subject.

As university teachers, the editors appreciate the need for a university or college textbook for undergraduates which deals with the underlying principles of soil geography and which introduces the practical applications of the subject. This book attempts an answer to the question: why an interest in soils? It explains man's involvement with soils and stresses his complete dependence on them for food supplies. The text describes how soil maps are made, how information from soil surveys is stored and manipulated and explains how such data may be used.

The authors of the chapters of this book can claim collectively about 200 years' experience in soil studies and can modestly be said to have a considerable expertise in the subject. The editors were conscious of the need to provide a coherent treatment of the subject and they assume the responsibility for the overall structure of the book, but the detailed form of separate chapters has been modified by contributors in conjunction with the editors to give the necessary coherence. The editors are extremely grateful to the contributors for their forebearance in the lengthy process of arriving at the present format and it is our hope that the result is a satisfactory account of current principles and applications of soil geography.

In the preparation of the separate chapters, several people have kindly read and commented upon draft manuscript material for individual contributors. The editors are pleased to acknowledge with gratitude the valuable assistance of B. W. Avery, E. Grant, R. Hartnup, D. Mackney, A. McBratney, J. M. Ragg, A. P. A. Vink and P. S. Wright. The editors also wish to acknowledge the assistance given by their wives, and particularly to Mrs Glenys Bridges, for compilation of the index. Sources of illustrative material are acknowledged elsewhere but initial drafting has been done by the cartographic staff at the University College of Swansea and the final diagrams were prepared by the publisher's staff. In conclusion, the editors wish to record their thanks to the staff of Longman for their help and encouragement during the preparation of this book.

E. M. Bridges University College of Swansea
D. A. Davidson University of Strathclyde
June 1980

CONTRIBUTORS

Dr D. A. Davidson, Senior Lecturer in Geography at the University of Strathclyde, holds the B.Sc. degree from the University of Aberdeen and the Ph.D. degree of the University of Sheffield. He was formerly a lecturer at St David's University College, Lampeter and has also lectured at Carleton University, Ottawa. He has studied relationships between soil and archaeology in Scotland and Greece and is author of *Soils and Land Use Planning* (Longman) and *Science for Physical Geographers* (Arnold). He is a member of the British Society of Soil Science, the Institute of British Geographers and the Institution of Environmental Science.

Dr E. M. Bridges, Senior Lecturer in the Department of Geography at the University College of Swansea, holds B.Sc. and M.Sc. degrees from the University of Sheffield and the Ph.D. degree of the University of Wales. Formerly a member of the Soil Survey of England and Wales, he has worked on surveys in the United Kingdom and Bahrain and has taught in the Universities of New England, Australia, the University of Khartoum and the University of the West Indies, Trinidad. He is author of *The Soils and Land Use of the District North of Derby* (Harpenden), *World Soils* (Cambridge University Press) and is a member of the British Society of Soil Science, the Institute of British Geographers and is a Fellow of the Royal Geographical Society.

Mr B. Clayden, Principal Scientific Officer with the Soil Survey of England and Wales at its Headquarters at Rothamsted Experimental Station, holds the degree of B.Sc. from the University of Sheffield. He worked on soil surveys in Somerset, Devon and Iraq before serving as Regional Officer for Wales, and now has a national responsibility for soil classification and correlation. He is author of *Soils of the middle Teign valley district of Devon* and *Soils of the Exeter district*, and joint author of *Soils in Dyfed I* and *The classification of some British soils according to the comprehensive system of the United States*, all published by the Soil Survey. He is a member of the British Society of Soil Science and the Quaternary Research Association.

Dr C. C. Rudeforth, Principal Scientific Officer with the Soil Survey of England and Wales, holds the degrees of B.Sc., M.Sc. (with distinction) and Ph.D. of the University of London. He is the Regional Officer for Wales in the Soil Survey of England and Wales and has worked on soil surveys in the north of England and Iraq. He is the author of *Soils of North Cardiganshire* (Harpenden), and is joint author of *Hydrological Properties of Soils in the River Dee Catchment* (Harpenden) and *Soils, Land Classification and Land Use of West and Central Pembrokeshire* (Harpenden). He is a member of the British Society of Soil Science.

Dr R. J. Huggett, Lecturer in the Department of Geography in the University of Manchester, holds the degrees of B.Sc. and Ph.D. of the University of London. After holding a school teaching post for a short period in Hertfordshire, he took up his present position. He is the author of *Systems Analysis in Geography* (Oxford) and a joint author of *Modelling Geography: a mathematical approach*. Dr Huggett is a member of the Mervyn Peake Society and of the Institute of British Geographers.

Mr M. G. Jarvis, Principal Scientific Officer with the Soil Survey of England and Wales holds the degree of B.A. from the University of Oxford. He is the Regional Officer for the Soil Survey of England and Wales in the south-east of England and has a particular interest in the application of soil surveys. He is the author of *Soils of the Wantage and Abingdon district* (Harpenden), joint author of the *Soils of Berkshire* and joint editor of *Soil Survey Applications* (Harpenden). He is a member of the British Society of Soil Science.

Professor H. D. Foth, Professor of Soil Science at Michigan State University, holds the degrees of B.S. and M.S. from the University of Wisconsin and the Ph.D. from Iowa State University. He is the author of *Fundamentals of Soil Science* and *Soil Geography and Land Use*, both published by Wiley. Professor Foth has received numerous teaching awards including the Agronomic Education Award, the Oahus Award and the Ensminger Distinguished Teacher Award. He is a fellow of the American Association for Advancement of Science, member of the Soil Science Society of America, the American Society of Agronomy, a Teacher Fellow of the National Association of Colleges and Teachers of Agriculture and is a member of the Association of American Geographers.

INTRODUCTION

The aim of soil geography is to record and explain the development and distribution of soils on the earth's surface. It is a branch of learning which lies between soil science and geography and is of particular importance to both subjects. One view of geography is that it focusses attention on the interaction of man and the physical environment. Nowhere is this more obvious or so vital as it is with the man–soil relationship. Soils are a major resource of all countries, and as the basis of agriculture they play an important role in the sustenance of mankind. The biology, physics and chemistry of soils, all of which converge in a study of soil fertility, are the concern of soil science. These studies merge to form soil geography.

Mankind's relationship with the soil is long and complex, reaching back to prehistoric times. For primitive cultures, the soil was simply an insignificant part of the total environment, but with the development of agriculture came the necessity for man to seek fertile soils and the technology with which to manage them. Except for a few very favoured locations, fertility of soils proved to be transitory, and agricultural systems evolved which attempted to prolong or enhance the productive capacity of the soil. By the nineteenth century, man's understanding of soils in temperate regions of the world was such that a sustained production of crops could take place, but in tropical regions much still remains to be learnt. At the present time, with virtually all the best soils already under arable cultivation, the need for a knowledge of the distribution of soils and their properties has been brought sharply into focus as further increases in agricultural productivity are sought from finite soil resources.

The professional skills of a soil surveyor enable him to record both vertical and horizontal variation of soils and their characteristics on a two-dimensional map. Soil maps are produced at many different scales for a wide variety of purposes and different users' requirements. It is important that the limitations and possibilities of the different scales are fully appreciated by soil map users. The information contained in the many soil maps and reports which are available constitute the material of soil geography. The arrangement of this material in meaningful categories draws the soil geographer into problems of soil classification, data handling and conceptual modelling, all of which are discussed in Chapters 1–5 of this book.

The last three chapters move away from the basic principles of soil survey and soil geography to discuss some of the applied aspects of the subject. These are discussed conveniently in two chapters, respectively concerned with agricultural and non-agricultural uses of soil survey data. Land classification, which follows from a knowledge of the soils, has become an important tool in farm management and land-use planning generally. It enables the best economic use to be made of the available soil resources. A dispassionate assessment of the facts of soil geography can often provide information which can help resolve disputes between those who wish to extend urbanization and those who wish to retain rural uses of land.

On a global scale, soil geography has recently received a great impetus with the production of the FAO/UNESCO Soil Map of the World. Previously, soil maps of the world had been compiled on an empirical basis, but the vast increase in knowledge in recent years has enabled soil scientists to produce this new map based on pedological criteria. This has enabled a more accurate estimate to be made of the extent of different soils throughout the world. In turn, this allows a more realistic approach to the determination of total world agricultural productivity as there is an established link between soil morphology and crop yields. With millions of people in developing countries under-nourished and a continually increasing world population, every effort must be made to obtain the maximum productivity from the world's soils. This must happen without causing the degradation or destruction of the soil mantle which is so essential for life on earth.

Soil geography has been a traditional but minor part of the courses offered in most university departments of soil science or geography. With the growth in knowledge during the last few years the stature of soil geography has increased. It is now widely acknowledged that it has a contribution to make to the world outside the academic and research institutions which have nurtured its development. Soil studies are one means of integrating large parts of physical geography in a way which is of immediate relevance to mankind and in this way gives coherence to geography as a whole. Interpretations of soil survey data have expanded the need for soil–geographical studies from a rather narrow agricultural base to be of wider applicability as forecast by Bartelli *et al.* (1966) and Simonson (1974).

ACKNOWLEDGEMENTS

The editors and publishers wish to acknowledge with gratitude the following journals and individuals who have kindly allowed diagrams and tables which first appeared elsewhere to be reproduced within these pages:

American Society of Photogrammetry for our Fig. 4.7; Catena for our Fig. 5.11; C.S.I.R.O. for our Fig. 2.4; Department of Regional Economic Expansion, Toronto, Canada for our Fig. 7.1; Earth Surface Processes for our Fig. 5.12; Elsivier Scientific Publications for our Fig. 4.10, 4.16, 4.17, 5.6, 7.6, 7.7, 7.8, 7.9, 7.10; F.A.O. for our Figs. 2.3, 6.12, 6.13; Geographical Association for our Fig. 2.1; Geographical Journal for our Figs. 2.2, 6.1 and 6.11. H.M.S.O., MOD and Institute of Civil Engineers for our Fig. 7.3; The International Development Research Centre, Ottawa for our Fig. 4.8; The International Institute for Land Reclamation and Improvement for our Fig. 6.9; The Journal of Soil Science for our Figs. 1.3, 4.4, 4.9, 4.13, 4.14, 4.15, and 5.4; Dr. W. Junk for our Fig. 1.4; The Land Resources Division of the Department of Overseas Surveys for our Fig. 2.5; Michigan Department of State Highways for our Figs. 7.4 and 7.5; The Ministry of Agriculture for our Figs. 6.4 and 6.5; Dr. F. C. Peacock for our Fig. 5.8; D. Reidel Publishing Company for our Fig. 4.12; Rothamsted Experimental Station and the Soil Survey of England and Wales for our Figs. 2.6, 2.7, 4.3, 6.2, 6.3, 6.6, 6.7, 6.8, and 7.2; Dr. D. S. Sasser for our Fig. 5.9; The Soil Science Society of America for our Figs. 4.5 and 4.11; The State Agricultural University, Wageningen for our Fig. 6.10; Dr. A. Warren for our Fig. 5.5; The Williams Wilkins Company, Baltimore, for our Fig. 5.7; The United States Department of Agriculture for our Figs. 8.1, 8.2, 8.3, and 8.4.

Agriculture Canada for our Table 3.8 from Table 8, publication 1646 *The Canadian System of Soil Classification* by the Canada Soil Survey Committee, by permission of the Minister of Supply & Services, Canada; George Allen & Unwin (Publishers) Ltd for our Table 3.11 from *The Soils of Europe* 1953 by Kubien, published by Thomas Murby; the author, Kurt W. Bauer for extracts from 'The Use of Soils Data in Regional Planning' as published in *Geoderma 10*; Canada Land Inventory for 'Capability Classes' from the *Land Capability Classification for Forestry, Report No 4* by R. J. McCormack; Commission de Pedologie et Cartographie, Ecole National Superior for our Table 3.12; Food & Agriculture Organisation of the United Nations for our Tables 3.9, 8.1, 8.4 and quotations from *A Framework for Land Evaluation* Soils Bulletin No 34; Forestry Commission for our Tables 7.1 and 7.2 from *Forest Record 69* by D. G. Pyatt; *Geoderma* and the authors for our Table 5.1 by A. J. Conacher and J. B. Dalrymple 1977, 5.2 and 5.3 by D. H. Yaalon 1975 and 7.10 by G. J.W. Westerveld and J. A. van den Hurk; The Geographical Society of New South Wales and the author Dr. Conacher for our Table 5.4 from *Australian Geographer* 12(3) 1973; International Institute for Land Reclamation and Improvement for our Table 2.3 adopted from Vink 1963, *ILRI Publication No. 10*; Michigan Department of Transportation for our Table 7.8 from *Field Manual of Soil Engineering* 1970; Office of Science & Technology Policy for our Table 8.2 adapted from *The World Food Problem*; Oxford University Press for our Tables 3.13 by Avery 1973 and 4.4 after Rudeforth 1975 from *Journal of Soil Science* (c) Oxford University Press; Relim Technical Publishers for our Table 3.14 by Stace et al, 1968; Scripta Publishing Co for our Table 3.10 by Rozov & Ivanova from *Soviet Soil Science* 1967 No 2 pp 147–156. Reprinted by permission; *Soil Science Society of America Journal* for our Table 5.5 by Smeck and Runge from Volume 35, 1971; Soil Survey of England & Wales for our Tables 2.4 by J. K. Coulter, 6.2 and 6.3 by D. Mackney and 6.4 by L. J. Hooper from *Technical Monograph No 4* 1974 edited by D. Mackney, our Table 2.5 compiled from *Field Handbook* (Hodgson 1974), our Table 6.1 by J. S. Bibby and D. Mackney compiled from *Technical Monograph No 1* and our Table 7.3 by Farquheson et al from *Soil Survey Special Survey No 11* 1978; The Williams Wilkins Co. and the authors Thorp and Smith for our Tables 1.1 from *Soil Science 99* 1965 and 3.2 from *Soil Science 67* 1949.

We are unable to trace the copyright owner of our Table 6.5 from Veldkamp and would appreciate any information which would enable us to do so.

CONTENTS

1

SOILS AND MAN IN THE PAST

D. A. Davidson

Ever since man has made land-use decisions, it has been to his advantage to assess the suitability of land for particular purposes. Indeed, his existence on earth is only possible through husbandry of plants and animals which in turn depend upon the physical resources. Modern agricultural systems of course have to operate within economic, social and political situations as well as environmental ones, but there is no doubt that the physical nature of land imposes varying constraints on agricultural development in different parts of the world. Such limitations become more apparent as population increases and as energy becomes progressively more expensive and difficult to obtain. The basic physical resources for agriculture are climate and soils; the former provides the necessary inputs of energy and moisture, whilst the latter supplies the medium in which crops grow in terms of physical support, moisture and nutrients. The studies of climate and soils are fundamental topics, as man is so dependent upon these resources.

Soil geography is interpreted as the study of the nature, formation and distribution of soils, and how soil characteristics and man's activities are interrelated. According to FitzPatrick (1971) 'pedology is the study of soils as naturally occurring phenomena, taking into account their composition, distribution and method of formation'. Thus pedology constitutes a substantial part of soil geography, but with the important addition that soil geography also examines the ecological relationship between man and soils. It is sometimes suggested that soils and man can be separated to allow the study of soils as naturally occurring phenomena. In practice this is extremely difficult since there are probably very few areas in the habitable world where man either in the past or present has not influenced soils. Thus, a very appropriate way to begin a book on soil geography is to examine the ways by which man through time has influenced soils. Such a focus underlines the symbiotic relationship between man and soils as well as stressing that many soil attributes are only explicable with reference to man's activities in the past. In order to examine how man has influenced soil conditions, an outline is given from prehistoric times until the present of man's effects on and use of soils.

1.1 PRE-NEOLITHIC COMMUNITIES AND SOILS

From our advanced technological stance, it is easy to forget the extent to which human prehistory is dominated by hunting-gathering societies of the Palaeolithic and Mesolithic periods. For this long period of the order of 3.5 million years, humans existed in nomadic or semi-nomadic bands in environments ranging from African savannas and open woodlands, to temperate forests and forest-tundra. In such societies, man evolved and adapted to the particular challenges and opportunities of his environment. At least in the early Palaeolithic, these small groups of widely dispersed people had virtually no effect on the natural environment (Butzer 1964). Little is known about the deliberate use of fire by man in Palaeolithic times though it is known that Pekin man tended fire in his caves. Man may have used fire to make clearings so that hunting was more successful. Fire also might have been employed to encourage the growth of certain food plants or to drive game. However, such suggestions must remain in the realm of speculation. Although the potential effect of fire must be recognized even in the Palaeolithic cultures (Stewart 1956), it can be suggested that Palaeolithic man had made at most only a highly localized impact on vegetation and thus soils through his use of fire.

At the economic level, the Mesolithic period was very similar to the preceding Palaeolithic; the distinguishing characteristic was the advanced development of a stone-working technology, expressed in the small highly worked flint implements called microliths. The gradual increase in population, combined with a better technology, led man to make the first clearly discernible impact upon the landscape. In Britain, researches by Dimbleby (1961, 1962), Simmons (1969a, b) and Smith (1970) indicate that Mesolithic man had a significant localized effect on the vegetation of such areas as the North York Moors and Dartmoor. Jones (1976) has observed inwash stripes of mineral material in a Mesolithic context in a peat-filled glacial drainage channel in north Yorkshire. Such sedimentation is correlated with adjacent forest clearance and resultant erosion. Mellars (1975) has argued that a deliberate policy of forest clearance by Mesolithic communities would have had clear benefits through improving the general health and reproductive rate of animals and by controlling the distribution of herds at different times of the year.

The possible consequences of deforestation in terms of soils are summarized in Fig. 1.1. It should be emphasized that the eventual outcome depends very much on the nature of the parent materials, the climatic regime, the new vegetation type, the slope of the land and the time period available for forest regeneration. In uplands, or on lower areas of glacial sands and gravels, the processes of soil degradation fol-

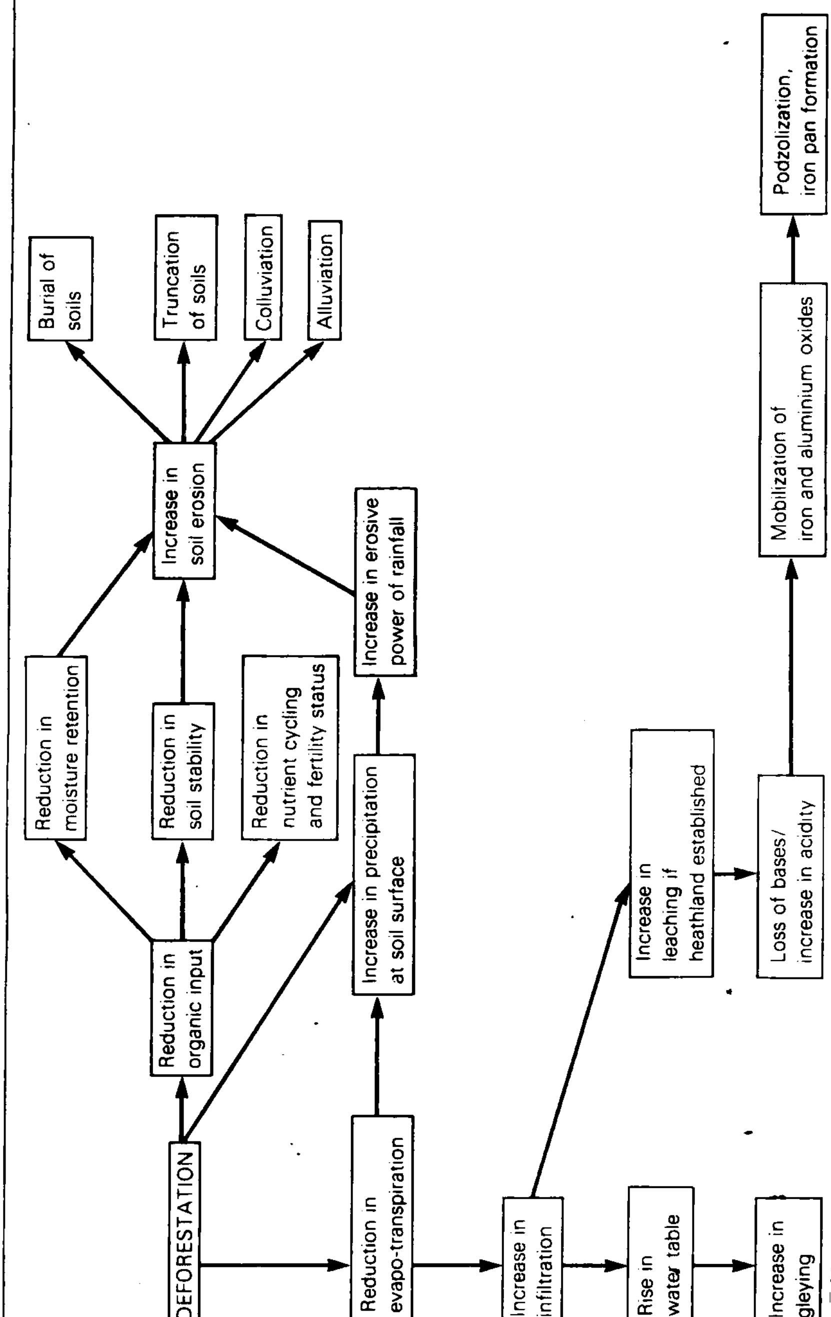

Fig. 1.1 Soil changes which may result from deforestation

lowing forest clearance can be of sufficient magnitude to cause the soils to tend towards quite different types. Changes in vegetation and soils are well exemplified in Britain by the Mesolithic site at Iping Common in Sussex (Keef *et al.* 1965). At this site the effect of Mesolithic man in the sixth millennium BC was to change the vegetation from a hazel woodland to a self-perpetuating heath. Such vegetational changes were mirrored in the local soil which changed from a brown earth in which earthworms were abundant to an acidic podzol with no earthworms (Evans 1975). Other heathlands also began to develop in Britain during the Mesolithic, albeit on a limited scale. Associated with such changes was podzolization – the development of acid soils with distinctive horizons, in particular a bleached horizon and the reddish brown illuvial horizons resulting from the release and downward movement of iron and aluminium oxides accompanied by humus. Another consequence of man's activities during the Mesolithic was to accelerate the spread of blanket bog on many uplands. The effect of deforestation would have been to raise the water-tables in these areas by the processes summarized in Fig. 1.1. Poor drainage conditions led to the development of peat bogs, but it should be stressed that the magnitude of man's role in inducing this change is open to debate. The increase in precipitation during the Atlantic period would also have led to the spread of upland bogs. Evans (1975) concludes, with reference to Britain, 'excepting the formation of blanket bog on many uplands and in the west during Atlantic times, it is unlikely that either Mesolithic man or climate had much influence on the degradation of soils over wide areas of the country, even although the effect locally may have been pronounced'.

1.2 NEOLITHIC COMMUNITIES AND SOILS

The Neolithic period marks the beginning of animal and crop husbandry, the earliest origins of which seem to have been in the Middle East during the 9th millennium BC. The first agricultural practices in Britain occurred during the 4th millennium BC. It is very easy to overemphasize the contrast between a Mesolithic and a Neolithic economy, but archaeological thinking now stresses the continuity of these cultures. Evans (1975), for example, sees in Britain no clear distinction in archaeological or environmental terms between Mesolithic and Neolithic communities of the 4th millennium BC. Nevertheless, the Neolithic is distinguished by man building at least semi-permanent settlements and beginning to manage the environment for his own benefit. Soils thus began to assume an importance to man through his concern to produce crops and rear livestock.

Agriculture would have been gradually introduced into forest clearings in the early Neolithic period. No doubt at first hunting and gathering continued to play significant roles in Neolithic economies. Clearance of trees may have been on a selective basis whereby trees were ring-barked and allowed to die slowly (Walker 1966). The intervening spaces were gradually opened up by cattle and particularly by pigs (Bradley 1978). Alternatively, complete clearance could have been achieved by fire or by cutting down all the trees. The change in vegetation, the application of wood ash, the effect of livestock and to a limited extent, the use of simple ards as ploughs necessarily led to changes in soil-forming processes (Fig. 1.2), but it would be wrong to consider that all such processes led to soil degradation. Many present-day soils support intensive agriculture without deterioration and the farmer's aim is to improve and maintain soil fertility. In the Neolithic era, a certain amount of mixing of the soil would have resulted from the use of the ard. These benefits, of course, are short-lived in a slash-and-burn agricultural system, with yields decreasing very quickly. Coles (1976) notes that clearances in Russia and Canada during historical times yielded uneconomic returns after the first year of cropping. He relates the rapid exhaustion to the thin layer of soil available to crops. The advantages of the wood ash quickly became dissipated and weeds assumed dominance. By the time the land was abandoned, it would have been in very poor condition in terms of fertility. Weedy land must have posed very serious problems since stone ards were unable to cut through such secondary vegetation.

In Britain the transition from the Mesolithic to the Neolithic period coincides with the change from Pollen Zone VIIa (the Atlantic) to Zone VIIb (the Sub Boreal) (Fig. 1.3). The distinguishing characteristic in the pollen record is the decline in elm pollen between these zones. There has been much discussion on the cause of this decline; some workers stress the role of climatic change given the apparent synchroneity of the decline over the British Isles whilst others emphasize the role of man in reducing elms through his selective gathering of leaf fodder for livestock. A review of such themes is provided by Bradley (1978), who also explores a hypothesis fusing both ideas, *viz.* climatic deterioration combined with man's rising numbers forced him to adopt a more settled and intensive form of land use. The implication is that the elm decline does not mark the beginning of the Neolithic clearances, but rather the beginning of a period of intensified agricultural activity. Thus small agricultural clearances must have been created during the 4th millennium BC in the Atlantic period, but they were of sufficiently small extent not to have been reflected in the pollen record.

Neolithic man certainly began to develop an awareness of soil character. There is a close correspondence between the spread of Neolithic settlements across central Europe and loessic soils, whilst a British example is the association on Anglesey of Neolithic sites and well-drained soils derived from glacial deposits (Grimes 1945). An insight into the mechanisms whereby pioneering agricultural communities selected particular

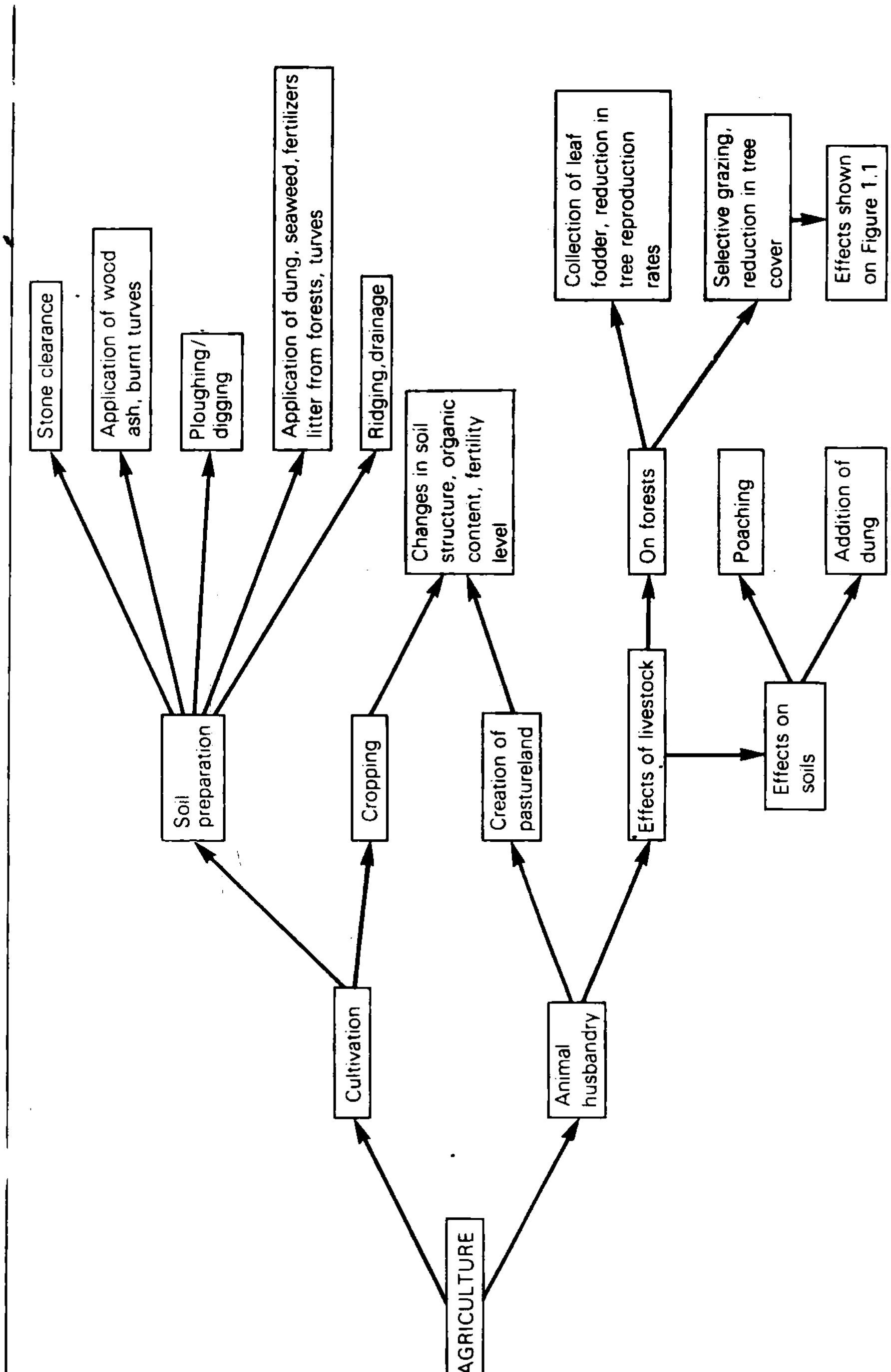

Fig. 1.2 Possible effects on soils following the introduction of agriculture