



Visual Soil Evaluation

Realizing Potential Crop Production
with Minimum Environmental Impact

Edited by **Bruce C. Ball** and **Lars J. Munkholm**

Visual Soil Evaluation

Realizing Potential Crop Production with Minimum
Environmental Impact

Edited by

Bruce C. Ball

SRUC, Edinburgh, UK

and

Lars J. Munkholm

Aarhus University, Tjele, Denmark

CABI is a trading name of CAB International

CABI
Nosworthy Way
Wallingford
Oxfordshire OX10 8DE
UK

CABI
745 Atlantic Avenue
8th Floor
Boston, MA 02111
USA

Tel: +44 (0)1491 832111
Fax: +44 (0)1491 833508
E-mail: info@cabi.org
Website: www.cabi.org

Tel: +1 (0)617 682 9015
E-mail: cabi-nao@cabi.org

© CAB International 2015. All rights reserved. No part of this publication may be reproduced in any form or by any means, electronically, mechanically, by photocopying, recording or otherwise, without the prior permission of the copyright owners.

A catalogue record for this book is available from the British Library,
London, UK.

Library of Congress Cataloging-in-Publication Data

Visual soil evaluation : realizing potential crop production with minimum environmental impact / editors, Bruce C. Ball (SRUC, Edinburgh, UK) and Lars J. Munkholm (Aarhus University, Tjele, Denmark).

pages cm

Includes bibliographical references and index.

ISBN 978-1-78064-470-7 (hardback : alk. paper) -- ISBN 978-1-78064-745-6 (pbk. : alk. paper) 1. Crops and soils. 2. Soils--Analysis. 3. Soils--Quality. 4. Soil structure. 5. Soil chemistry. I. Ball, Bruce C., editor. II. Munkholm, Lars J., editor.

S596.7.V57 2015
631.4--dc23

2015020427

ISBN-13: 978 1 78064 470 7 (hbk)
978 1 78064 745 6 (pbk)

Commissioning editor: Ward Cooper
Associate editor: Alexandra Lainsbury
Production editor: Tim Kapp

Typeset by SPi, Pondicherry, India
Printed and bound by Gutenberg Press Ltd, Tarxien, Malta

Visual Soil Evaluation

Realizing Potential Crop Production with Minimum
Environmental Impact

List of Contributors

- Bruce C. Ball**, SRUC Crop and Soil Systems Research Group, West Mains Road, Edinburgh, EH9 3JG, UK. bruce.ball@sruc.ac.uk
- Tom Batey**, 125 Blenheim Place, Aberdeen, AB25 2DL, UK. tombeth33@gmail.com
- Hubert Boizard**, INRA, UPR1158 Agro-Impact, Estrées-Mons, BP 50136, 80203 Péronne, France. hubert.boizard@mons.inra.fr
- Joanna M. Cloy**, SRUC Crop and Soil Systems Research Group, West Mains Road, Edinburgh, EH9 3JG, UK. joanna.cloy@sruc.ac.uk
- Anthony C. Edwards**, SRUC Crop and Soil Systems Research Group, Craibstone, Aberdeen, AB51 6FA, UK. Tony.Edwards@sruc.ac.uk
- Owen Fenton**, Teagasc Environment Research Centre, Johnstown Castle, Co. Wexford, Ireland. owen.fenton@teagasc.ie
- Richard J. Godwin**, Harper Adams University, Newport, Shropshire, TF10 8NB, UK. dickjillgodwin@waitrose.com
- Rachel M. L. Guimarães**, Department of Agronomy, Federal University of Technology-Paraná, Via do Conhecimento, km 1 – 85503-390, Pato Branco, PR, Brasil. rachelguimaraes@utfpr.edu.br
- Nicholas M. Holden**, UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland. nick.holden@ucd.ie
- David C. McKenzie**, Soil Management Designs, Orange, New South Wales 2800, Australia. mckenzie@soilmgt.com.au
- Lars J. Munkholm**, Department of Agroecology, Aarhus University, Blichers Allé 20, P.O. Box 50, 8830 Tjele, Denmark. lars.munkholm@agro.au.dk
- Brian W. Murphy**, Office of Environment and Heritage, Cowra, New South Wales 2794, Australia. brian.murphy@environment.nsw.gov.au
- Mary Norton Scherbatskoy**, Blackland Centre, 5 Scotvein, Grimsay, North Uist, Western Isles, HS6 5JA, UK. mns@uistwool.co.uk
- Joséphine Peigné**, ISARA Lyon, 23 rue Jean Baldassini, 69364 Lyon cedex 07, France. jpeigne@isara.fr
- Mansonia A. Pulido Moncada**, Institute of Edaphology, Faculty of Agronomy, Universidad Central de Venezuela, Av. Universidad vía El Limón, Maracay, 2101, Aragua, Venezuela. mansoniapulido@gmail.com
- T. Graham Shepherd**, BioAgriNomics Ltd, 6 Parata Street, Palmerston North 4410, New Zealand. gshpherd@BioAgriNomics.com
- Gordon Spoor**, Model Farm, Maulden, Bedfordshire, MK45 2BQ, UK. g.spoor.t21@btinternet.com

Cássio A. Tormena, Department of Agronomy, State University of Maringá. Av. Colombo, 5790 - 87020-900, Maringá, PR, Brasil. catormena@uem.br

Anne Weill, Centre of Expertise and Technology Transfer in Organic Agriculture and Local Food Systems, 475, rue Notre-Dame Est, Victoriaville, Québec, G6P 4B3, Canada. weill.anne@cegepvicto.ca

Berwyn L. Williams, formerly Macaulay Land Use Research Institute (now James Hutton Institute), Aberdeen, AB21 9YA, UK. berwyn.williams@btinternet.com

Preface

This book describes the main methods for Visual Soil Evaluation (VSE) of soil structure and soil-related properties. It includes clear visual images of the variation of soil quality and how these relate to soil productivity and environmental sustainability. Such images raise awareness and provide a measure of the soil degradation that is a looming threat to the viability of world agriculture. Emphasis is given to recognizing, protecting and restoring soil quality as these are of vital importance for tackling problems of food insecurity, global change and environmental degradation. We show how these aims can be achieved with Visual Soil Evaluation by describing tools that can readily be used by land users and environmental authorities to assess crop performance, soil improvement and soil productivity. Visual Soil Evaluation is also placed in the context of future sustainable intensification of agriculture including factors of soil loss, resilience, climate change, scarcity of water and other resources, nutrient retention and increased risk of degradation. This book is relevant not only to students, lecturers, scientists and advisors working directly with soils but also to policy makers, food security experts, environmentalists and engineers who have an interest in soils and sustainable agricultural production. Last, but not least, we hope that these simple VSE techniques will be used extensively in years to come as a tool to link soil specialists and non-specialists together with the mutual aim of developing sustainable soil management to advance global food security and improve the environment.

This book developed mainly from the activities of members of the 'Visual Soil Examination and Evaluation' working group within the International Soil Tillage Research Organisation. The editors thank all the authors for their valued contributions, summarizing their extensive knowledge and experience. The editors are also grateful for the support from the publishers.

Bruce C. Ball
Lars J. Munkholm

Contents

List of Contributors	ix
Preface	xi
1 Describing Soil Structures, Rooting and Biological Activity and Recognizing Tillage Effects, Damage and Recovery in Clayey and Sandy Soils	1
<i>Anne Weill and Lars J. Munkholm</i>	
1.1 Evaluation of Soil Structure	2
1.1.1 Evaluation of the structure of clayey soils	2
1.1.2 Evaluation of the structure of sandy soils	4
1.1.3 Observation of the structure in the entire 0.6 or 1 m of the profile	7
1.1.4 Soils with natural structural limitation	9
1.2 Observation of Roots: Density, Deformation, Concentration in Cracks or Between Layers	10
1.2.1 Root development in clayey soils	10
1.2.2 Root development in sandy soils	11
1.3 Other Criteria for Recognizing Compaction	11
1.3.1 Evaluation of soil aeration using soil colour	11
1.3.2 Evaluation of biological activity	11
1.4 Conclusions	13
2 Assessing Structural Quality for Crop Performance and for Agronomy (VESS, VSA, SOILpak, Profil Cultural, SubVESS)	15
<i>Tom Batey, Rachel M.L. Guimarães, Joséphine Peigné and Hubert Boizard</i>	
2.1 Introduction	15
2.2 Visual Evaluation of Soil Structure (VESS) for Topsoil	16
2.3 Visual Soil Assessment (VSA) for Topsoil	17
2.4 SOILpak Method for Topsoil and Subsoil	19
2.4.1 Validation and future development	20
2.5 'Le Profil Cultural' or Agronomic Profile Method	20
2.5.1 Le profil cultural – evaluation and limitations	24

2.6	The Numeric Visual Evaluation of Subsoil Structure (SubVESS)	24
2.7	Recommendations	25
2.8	Conclusions	28
3	Reduction of Yield Gaps and Improvement of Ecological Function through Local-to-Global Applications of Visual Soil Assessment	31
	<i>David C. McKenzie, Mansonia A. Pulido Moncada and Bruce C. Ball</i>	
3.1	Introduction	31
3.2	Yield Gap Analysis	33
3.3	Soil Structure Assessment Using VSE	35
3.4	Soil Structure – Its Relationship with Soil Water Status and Hydrological Cycles	36
3.5	Land Management Frameworks Related to Soil Productivity, Yield Gap Assessment and Ecological Function	37
3.5.1	Frameworks for agricultural land management linked with VSE techniques at field scale	39
3.5.2	Packages for land management at the landscape scale with potential to be more effective if inter-linked with VSE techniques	41
3.5.3	A possible new and broad conceptual approach for yield gap reduction and ecological improvement based on VSE techniques	41
3.6	Relating Visually Assessed Soil Conditions to Crop Growth and Selection of Soil Management Inputs	44
3.7	Training of Practitioners	44
3.8	Conclusions	45
4	Visual Evaluation of Grassland and Arable Management Impacts on Soil Quality	49
	<i>Lars J. Munkholm and Nicholas M. Holden</i>	
4.1	Introduction	49
4.2	Evaluation of Arable Management Impact	49
4.2.1	Biological factors	51
4.2.2	Mechanical factors	52
4.3	Evaluation of Grassland Management Impact	54
4.3.1	Biological factors	56
4.3.2	Mechanical impacts	58
4.3.3	Drainage/water status	58
4.3.4	Management intensity	58
4.4	Aspects Requiring Further Development	59
4.4.1	Assessment of pores	59
4.4.2	Taking account of soil layering	59
4.4.3	Extraction and separation of soil blocks for assessment	60
4.4.4	Faunal activity	60
4.4.5	Need for specific methods or interpretations for grassland soils	61
4.5	Conclusions	62
5	Choosing and Evaluating Soil Improvements by Subsoiling and Compaction Control	66
	<i>Richard J. Godwin and Gordon Spoor</i>	
5.1	Introduction	66
5.2	Identification of Compaction Problems and Alleviation Requirements	68

5.3	Basic Action of Soil Loosening and Mole Drainage Equipment	69
5.3.1	Narrow tine disturbance and critical depth	69
5.3.2	Winged tine disturbance	69
5.3.3	Leg disturbance for subsoiling vs moling	72
5.4	Soil Disturbance with Multiple Tine Arrangements	73
5.5	Draught Forces and Power Requirements	74
5.6	Implement Selection, Adjustment and In-field Evaluation	76
5.6.1	Implement selection	76
5.6.2	Implement adjustment	77
5.6.3	In-field evaluation	78
5.7	Minimizing and Alleviating Recompaction	78
5.7.1	Reduced weight and inflation pressure	79
5.7.2	Controlled traffic farming	80
5.8	Conclusions	82
6	Valuing the Neglected: Lessons and Methods from an Organic, Anthropic Soil System in the Outer Hebrides	86
	<i>Mary Norton Scherbatskoy, Anthony C. Edwards and Berwyn L. Williams</i>	
6.1	Introduction	86
6.2	Background	88
6.2.1	Geology, slope and rainfall	88
6.2.2	Physical structure	88
6.2.3	Microbiological processes	90
6.2.4	Cultivation	90
6.2.5	Crofting: an agricultural and social system	90
6.2.6	Maintaining soil fertility within a mixed system	91
6.2.7	Current situation	91
6.3	Tools for Visual Evaluation	91
6.3.1	Methods	91
6.3.2	Blackland Index	95
6.3.3	Blackland Vegetation Scoring (BVS)	97
6.3.4	von Post Humification Scale	97
6.3.5	Evaluation	99
6.4	Return to Use	99
6.5	Conclusion	100
7	Evaluating Land Quality for Carbon Storage, Greenhouse Gas Emissions and Nutrient Leaching	103
	<i>Joanna M. Cloy, Bruce C. Ball and T. Graham Shepherd</i>	
7.1	Introduction	103
7.2	Soil Properties Regulating Carbon Storage, Greenhouse Gas Emissions and Nutrient Leaching and their Relationship with Soil Structure	103
7.2.1	Soil carbon storage and soil structure	104
7.2.2	Soil greenhouse gas exchange and soil structure	105
7.2.3	Soil nutrient leaching and soil structure	111
7.3	Estimation of Soil C Storage, GHG Emissions and Nutrient Leaching using Visual Techniques	112
7.3.1	Soil C storage	112
7.3.2	GHG emissions	114
7.3.3	Nutrient leaching	117
7.4	Future Directions	118
7.5	Conclusions	119

8	Soil Structure under Adverse Weather/Climate Conditions	122
	<i>Rachel M.L. Guimarães, Owen Fenton, Brian W. Murphy and Cássio A. Tormena</i>	
8.1	Introduction	122
8.2	Climate Change	123
8.3	Soil Structure under Intensive Rainfall	125
	8.3.1 Erosion and soil quality screening toolkit	126
8.4	Wet Weather Conditions and Soil Compaction	130
8.5	Periods of Droughts	133
8.6	Extreme Temperature	134
8.7	The Further Role of VSE	135
8.8	Conclusion	136
9	The Expanding Discipline and Role of Visual Soil Evaluation	142
	<i>Bruce C. Ball and Lars J. Munkholm</i>	
9.1	Introduction	142
9.2	The Scale and Scope of VSE and the Relationship with Crop Yield	142
9.3	Improving and Harmonizing VSE Methods	143
9.4	Expanding the Role of VSE	145
	9.4.1 Sustainability, environmental conservation and climate change	145
	9.4.2 Soil monitoring and resilience	146
	9.4.3 Improvement of arable and grassland soils	148
	9.4.4 Improvement of marginal and urban soils	149
	9.4.5 Soil science	151
9.5	Conclusions	152
	Index	155

1 Describing Soil Structures, Rooting and Biological Activity and Recognizing Tillage Effects, Damage and Recovery in Clayey and Sandy Soils

Anne Weill^{1*} and Lars J. Munkholm²

¹Center of Expertise and Technology Transfer in Organic Agriculture and Local Food Systems (Centre d'expertise et de transfert en agriculture biologique et de proximité – CETAB+), Cégep de Victoriaville, Québec, Canada; ²Department of Agroecology – Soil Physics and Hydropedology, Aarhus University, Tjele, Denmark

Soil compaction and erosion have emerged as major threats to global agriculture as they negatively affect plant production and have detrimental impacts on the environment. Soil compaction is responsible for decreased crop yield and quality, emissions of greenhouse gases and increased water runoff (Hamza and Anderson, 2005; Ball *et al.*, 2008). Unless severe, it is often unrecognized because plant growth can appear normal, especially when mineral fertilizers are used liberally. The major cropping factors affecting soil compaction are the weight of machinery, poor timing of field operations with respect to soil water content and intensification of crop production. Soil erosion is responsible for losses of soil particles, nutrients and agrochemicals resulting in decreased soil fertility as well as eutrophication of rivers and lakes (Rasouli *et al.*, 2014). Site characteristics (rainfall quantity and intensity, slope and soil texture) have strong effects on soil erosion; in addition, important cropping factors related to soil erosion are crop rotation, percentage soil cover and management practices affecting soil structure and compaction (Pimentel

et al., 1995; Morgan, 2005). Erosion deposits are mostly silt and fine sand with little structure and porosity and thus resemble soil damaged by compaction. Because compaction plays a central role in soil degradation and yield losses, it has to be properly diagnosed in the field. This can be done by observing soil structure, root development, aeration and evidence of biological activity.

This chapter will therefore focus on describing and illustrating important soil structural features associated with compaction and anaerobic conditions. It will cover the evaluation of soil structure and compaction status for both clayey and sandy soils. Since tillage is often responsible for the creation of a number of anthropic layers, each having a different structure, the identification of the different soil layers will be explained. The use of other indicators of soil compaction such as root development (density, deformation, concentration in cracks or between layers), aeration (soil colour) and biological activity (soil macroporosity of biological origin, rapidity of residue turnover, presence of earthworms) will also be covered.

*E-mail: weill.anne@cegepvicto.ca

A quick, preliminary evaluation of soil structure can be done using a spadeful of soil, allowing rapid verification of soil structure over the entire field. Since agricultural practices can often affect soil conditions to a depth of 30–50 cm, and sometimes more, soil condition may have to be investigated to such depths, depending on the situation.

Different tools can be used to assess soil structural quality, either using spade methods (e.g. the visual evaluation of soil structural quality, VESS, Ball *et al.*, 2007; Guimarães *et al.*, 2011), visual soil assessment (VSA, Shepherd *et al.*, 2008; Shepherd, 2009), or profile methods (e.g. Cultural Profile, Manichon, 1987; or the SoilPAK method, McKenzie, 2001). These tools are described by Batey *et al.*, Chapter 2, this volume.

Some helpful information for soil compaction diagnosis should also be collected by checking soil maps and interviewing farmers. The following information should be gathered:

- The origin and characteristic of the soil;
- The field situation; for example, surface and sub-surface drainage situation, crop rotation, yield variation in the field, size of the equipment for manure spreading and timing for spreading, harvesting strategy, tillage and number of passes, depth of tillage, etc.

For the purposes of this chapter a soil is considered to be in good condition if it has good structure, is well aerated and contains a sufficient amount of organic matter in the A horizon to be capable of supporting microbial activity and optimum plant growth.

1.1 Evaluation of Soil Structure

Soil structure is best evaluated considering soil texture because the criteria for assessing structure depend on the clay content. The pressure exerted on the soil by machinery forces aggregates to stick to each other and to form clods. Texture is important because the clods resulting from compacted clayey soil are often hard and difficult to break down, while clods resulting from compacted sandy soils are fairly easy to break. Although the relationship between soil characteristics and clay content lies on a continuous spectrum, the evaluation of soil structure will only be described here for two main, discrete

groups labelled as follows: clayey soils (more than 25–30% clay) and sandy soils (less than 25–30% clay). Soil having 20–30% clay content will sometimes behave more like a clayey soil and sometime more like a sandy soil, depending on clay type and the organic matter content.

1.1.1 Evaluation of the structure of clayey soils

The structure of clayey soils can mostly be evaluated by observing the shape of aggregates and clods. When describing structure, soil horizonation needs to be taken into account because organic matter content, root density, aeration and biological activity tend to be much higher in the A horizon and these foster aggregation. This section aims at describing typical good and typical poor structure for clayey soils for both topsoil (A horizon) and subsoil layers (B and C horizon). The structure of naturally recovered clay soil is also described.

1.1.1.1 Soil structure of clayey soils in good condition

TOPSOIL (A HORIZON). Aggregates of a well-structured clayey topsoil are small, in the 1–10 mm range, and well separated (Fig. 1.1a). They can be observed in some grasslands, some non-cultivated soils and in some areas that are not trafficked (permanent beds, controlled traffic systems). They are also common in intensively tilled top layers of recently cultivated soils.

If the compaction pressure is light enough, the clods that are formed have a rough surface because the aggregates that constitute them keep their individual shapes (Fig. 1.1b). They are porous because of the space between the aggregates (not always visible with the naked eye) and the biological activity which creates pores.

In a non-compacted soil it should be very easy to separate the aggregates in the clod by simply squeezing the clod in the fist. However, to do this the clod must be fairly moist. Clay becomes very hard when it dries, which can give a false impression of being highly compacted.

When examining a spadeful of healthy soil, it is often possible to see an excellent structure with aggregates well separated from each other

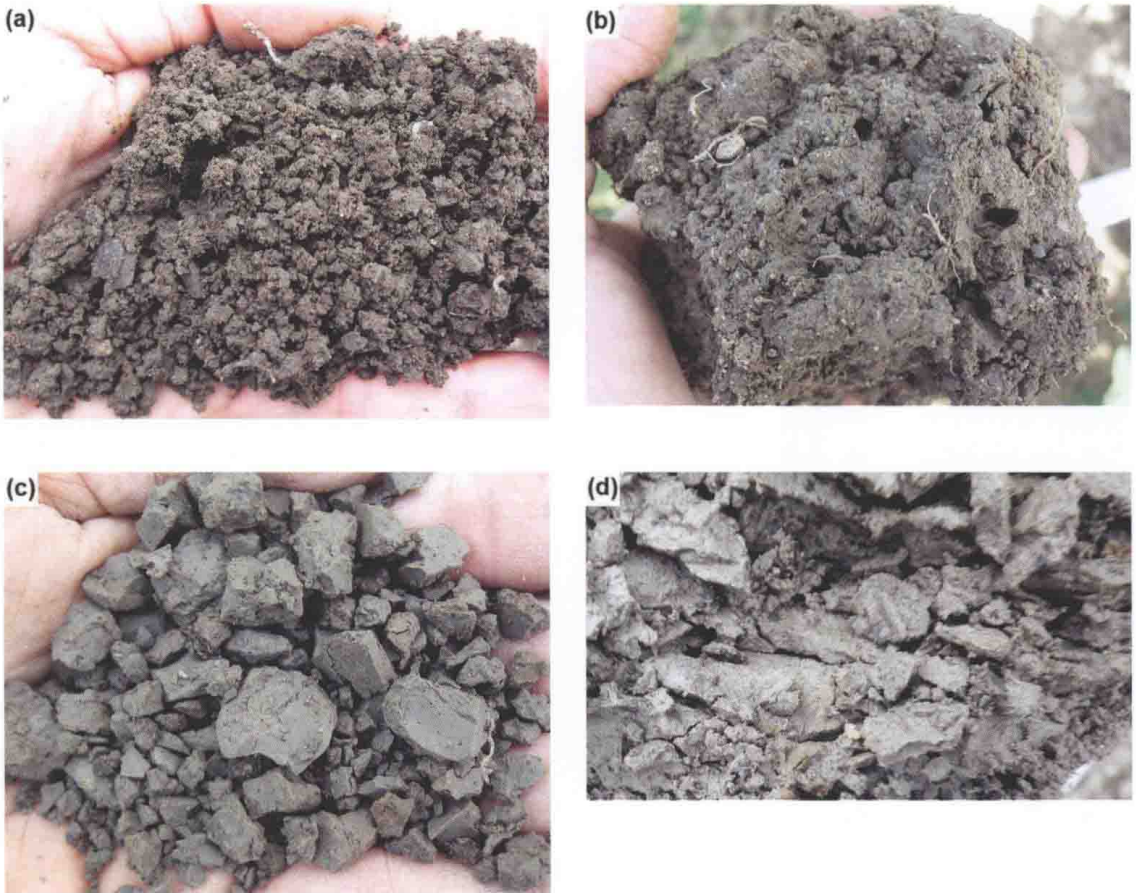


Fig. 1.1. Aggregates and clods in well-structured clayey soils. (a) Topsoil: small round aggregates, 1–5 mm in size, coming from a healthy A horizon. (b) Topsoil: very rough and porous clod coming from a very biologically active soil. The aggregates should detach from each other when the clod is squeezed. (c) Subsoil: small non-porous, angular, 2–10 mm aggregates. (d) Subsoil: lamellar structure, usually found in soil that contain less clay and more silt.

in the seedbed layer because of the effect of harrowing. Below the seedbed, the clods are rough and easy to break (Fig. 1.2).

SUBSOIL (B AND C HORIZONS). In a well-structured subsoil the aggregates are small (2–10 mm) and can either be rounded (Fig. 1.1a) or more angular in shape (Fig. 1.1c). They can be fairly massive and non-porous. Soils that are rich in silt sometimes have a lamellar structure (Fig. 1.1d). The thickness of the lamellae can be 2–10 mm.

1.1.1.2 Soil structure of compacted clayey soils

As the pressure exerted on the soil (topsoil or subsoil) by machinery increases, the aggregates

are more and more tightly pressed together and stick to each other more and more strongly. They form clods that are increasingly more difficult to break apart, more massive, less porous and smoother.

When examining a shovel full of compacted soil, the soil must be gently broken into pieces that can fit into a hand (Fig. 1.3a) (Ball *et al.*, 2007). When it is possible to break up the clods with pressure, the result will be a mixture of small and large aggregates (Fig. 1.3b). The more compact the soil, the smaller will be the proportion of small aggregates.

When compaction is severe the aggregates fuse to each other and lose their individual shape in the clod (massive structure) (Fig. 1.4a), which cannot be broken down in the hand.



Fig. 1.2. Healthy clay soil with mostly aggregates in the top part (seedbed) and rough and porous clods in the bottom part (below seedbed).

1.1.1.3 *Effect of texture on the identification of compaction of clayey soils*

When the soil is moist, but not waterlogged, the strength of clods of compacted soils increases with clay content (Barzegar *et al.*, 1994; Barzegar *et al.*, 1995); as a result soils with a low clay content can be broken down much more easily even when the soil is quite compact. As the clay content of a soil decreases, the situation will resemble more and more that of a sandy soil as described in the next section. Very wet, compacted clayey soils may have a plastic consistency, which results in clods being easily deformed by pressure.

1.1.1.4 *Natural recovery of clayey soils after compaction*

In clayey soils, the cycles of shrinking/swelling and freezing/thawing will fracture the soil by cracking. The clods (Fig. 1.4a) will crack into two pieces, then four and so on. Aggregates formed in this way often have flat sides

and angular edges. However, full recovery of structure in the A horizon such as that shown in Fig. 1.4b will only occur if roots and other biological activity develop in the soil.

1.1.2 *Evaluation of the structure of sandy soils*

The structure of sandy soils tends to be weaker than that of clayey soils because of their lower clay content and is more dependent on organic matter level and biological activity. In the topsoil it is also affected by tillage intensity. Visual assessment of sandy soil structure can be challenging and often needs to be complemented with observations of root development (see section below). This section aims at describing typical good and typical poor structure for sandy soils for both the topsoil and subsoil layers.

1.1.2.1 *Soil structure of sandy soils in good condition*

TOPSOIL (A HORIZON). As for the clayey soils, aggregates of well-structured sandy topsoils are small and rounded, in the 1–10 mm range (Fig. 1.5a). Such structure can be seen in soils that have a lot of organic matter, roots and biological activity. These are mostly grassland, non-cultivated soils and some cultivated soils with crops having a very dense rooting system and excellent biological activity. Small and rounded aggregates can also commonly be seen in recently tilled topsoil layers – particularly in seedbeds. They may be formed by the breaking up of larger aggregates during tillage and do not necessarily indicate a good stable structure. If the soil has been too intensively tilled the structure may easily collapse.

The lack of clay, unless organic matter content is high, causes aggregates of sandy soil to have a low resistance to compaction and they are easily crushed or compressed. After aggregate compression, the soil can appear massive whether it is very compact or not. The resulting clods have a smooth surface and are usually easy to break (Fig. 1.5b). When a clod is squeezed it usually crumbles easily into pieces that do not correspond to the