International Perspectives in Geography
AJG Library 9

Makiko Watanabe
Masayuki Kawahigashi *Editors*

Anthropogenic Soils in Japan

Springer

International Perspectives in Geography
AJG Library 9

Editor in Chief:
Yuji Murayama, Japan

Aims and Scope:

The AJG Library is published by Springer under the auspices of the Association of Japanese Geographers. This is a scholarly series of international standing. Given the multidisciplinary nature of geography, the objective of the series is to provide an invaluable source of information not only for geographers, but also for students, researchers, teachers, administrators, and professionals outside the discipline. Strong emphasis is placed on the theoretical and empirical understanding of the changing relationships between nature and human activities. The overall aim of the series is to provide readers throughout the world with stimulating and up-to-date scientific outcomes mainly by Japanese and other Asian geographers. Thus, an "Asian" flavor different from the Western way of thinking may be reflected in this series. The AJG Library will be available both in print and online via SpringerLink.

About the AJG

The Association of Japanese Geographers (AJG), founded in 1925, is one of the largest and leading organizations on geographical research in Asia and the Pacific Rim today, with around 3000 members. AJG is devoted to promoting research on various aspects of human and physical geography and contributing to academic development through exchanges of information and knowledge with relevant internal and external academic communities. Members are tackling contemporary issues such as global warming, air/water pollution, natural disasters, rapid urbanization, irregular land-use changes, and regional disparities through comprehensive investigation into the earth and its people. In addition, to make the next generation aware of these academic achievements, the members are engaged in teaching and outreach activities of spreading geographical awareness. With the recent developments and much improved international linkages, AJG launches the publication of the AJG Library series in 2012.

Series Editors:

More information about this series at http://www.springer.com/series/10223

Makiko Watanabe • Masayuki Kawahigashi
Editors

Anthropogenic Soils in Japan

Springer

Editors
Makiko Watanabe
Department of Geography, Graduate School
of Urban Environmental Sciences
Tokyo Metropolitan University
Hachioji, Tokyo, Japan

Masayuki Kawahigashi
Department of Geography, Graduate School
of Urban Environmental Sciences
Tokyo Metropolitan University
Hachioji, Tokyo, Japan

ISSN 2197-7798 ISSN 2197-7801 (electronic)
International Perspectives in Geography
ISBN 978-981-13-1752-1 ISBN 978-981-13-1753-8 (eBook)
https://doi.org/10.1007/978-981-13-1753-8

Library of Congress Control Number: 2018955286

© Springer Nature Singapore Pte Ltd. 2019
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

How can we efficiently contribute to the solution of problems associated with the management of sustainable cities? Efficient management ranks among the foremost global problems and concerns in expanding urban areas. Concentrations of transportation, services, and administrative networks in urban space increase their responsibility for proficient urban function year by year, in concert with an increase of coverage area by gray infrastructure made up of concrete and asphalt. In many countries of the world, the urban area has expanded with rapid population increase during the latter half of the twentieth century. Japan, having a small land area, is also characterized by a large infrastructure coverage per unit of population. In other words, the coverage rate of gray infrastructure in cities is increasing with population concentration, resulting in various environmental problems. Torrential rain events caused by uneven distribution of heat and moisture in the atmosphere and the heat island phenomenon are prime examples. Among measures to mitigate such problems, improvement of green infrastructure in urban areas is recommended in city planning for Japan, but these plans do not include soil information as the foundation.

Surface materials such as soil and uppermost sediments are porous media exhibiting dynamic interactive behavior with air, water, fine particles, and organic materials. Because of its specificity, soil not only becomes the foundation of green spaces but also performs various environmental functions through gas and heat exchange, underground water recharge, filtering, buffer action, carbon sink, etc. Soil is our life support system. Soil is not only important for rural areas but plays a primary role in improving urban resilience. Recognition of soil importance in urban areas has recently occurred on a global scale, and it is urgent to gather information on extremely diverse urban soils due to anthropogenic influences. As modern soil science is derived from the doctrine of the late-nineteenth-century Russian scholar V.V. Dokuchaev, it has become an issue in geography to establish a method to collect spatial information on artificially modified soils, the volume of which has recently increased due to human activities, and also to deepen our knowledge of their nature, function, and distribution.

"Urban soil" is a term first introduced by Bockheim in his talk entitled "Nature and properties of highly disturbed urban soils, Philadelphia, Pennsylvania," at the conference of the Soil Science Society of America, in Chicago, in 1974. Bockheim defined "urban soil" as a *soil material* having a non-agricultural, man-made surface layer more than 50 cm thick that has been produced by mixing, filling, or by contamination of the land surface in urban and suburban areas. On the basis of Bockheim's definition, large-scale maps of urban soils have been provided by the USDA/NRCS (https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/use/urban/). The Urban Soil Primer, also provided by the USDA, is an illustrated introduction to urban soils for homeowners and renters, local planning boards, property managers, students, and educators (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/use/urban/?cid=nrcs142p2_053993).

A new soil group name, "Technosols" (FAO/UNESCO/IUSS 2006, 2014), has given insight into distinguishing anthropogenic soils in non-cultivated areas from natural soils or farmland soils and is a milestone in academic discourse. The classification system of anthropogenic soils is an evolving topic for soil scientists worldwide. Recently, anthropogenic soil research has been steadily developed by activities of members of the Soils of Urban, Industrial, Traffic, Mining and Military Areas (SUITMA) alliance, a working group of the International Union of Soil Sciences (e.g., Soils within Cities 2017). Consultations with scientists and engineers are further required to support government and public understanding of the role of soils under urbanization, which is closely related to human health and resilience of the urban environment. For instance, evaluation of new soil processes in man-made soils, which may differ depending on geographical conditions, will provide beneficial insights into managing our land as a future resource, and creating a sustainable urban system.

People have continuously modified the soil for various reasons, including food production, establishing settlements, or to enhance transportation. More recently, the area of land that has undergone such artificial modifications has increased sharply, and to a significantly higher degree, resulting in the original soil and landscape being obscured. Considering the effective and sustainable use of the land for the future, it is important to archive characteristics of the initial, undisturbed land and the history of its modern modification. In addition, it is critically important to understand changes of soil after modification by considering topics such as the potential for industrial and municipal by-product contamination and the ecological impact on cities. This book, *Anthropogenic Soils in Japan*, was created as an unprecedented soil profile atlas that presents various modified soils with physicochemical properties data, in addition to soil profile photographs, with special attention to land history. Our aim is to visualize the feature of the soils beneath our feet.

Chapter 1 deals with soils that are usually difficult to see or access. We introduce how the soils exist under the asphalt and concrete pavement roads and what kind of properties they have. From Chaps. 2, 3, 4, 5, 6, 7, 8, and 9, soil profile descriptions and soil properties of anthropogenic soils in green spaces are introduced. Through examples from ski resorts, historical urban parks, and tsunami coastal forests, we aim to show that the foundations of green spaces are bound to various land histories and that soils are generated based on land modification. Chapters 10, 11, 12, and 13 deal with the dredged soil “Dorotsuke,” and soil of agricultural land using waste soil as examples of soils that have been altered to improve agricultural infrastructure. By targeting cities in Japan, where modifications are remarkable, we expect to provide material for predicting phenomena caused by wide-range urbanization in the future.

Hachioji, Tokyo, Japan
November 2017

Makiko Watanabe
Masayuki Kawahigashi

Contents

Chapter 1
Soils Sealed by Technic Hard Materials in Urban and Traffic Areas

Kimihiro Kida

Abstract Urban areas give rise to unique soil ecosystems, as they are drastically disturbed and modified by human activities. An example of such human activity is soil sealing. Soil sealing is identified as a threat to basement soil, and though enabling high trafficability, contributes to surface water discharge for flood control and the need for installation of facilities. Soil sealing is recognized as one of the most important anthropogenic pressures on soil biodiversity. The effects of soil sealing on major environmental components are concerned with the kinetics of chemical reactions that affect the proper functioning of the soil. Soil profiles beneath asphalt roads display unexpected soil layering, consisting of different materials from the top to the base of the soil profile. A boundary layer indicates that subbase materials mixed with surface soils through the paving process. Even 40 years after the road construction, the sealed soils have maintained properties of the original soil. Soils beneath asphalt pavement are classified as Ekranic Technosols according to the world reference base for soil resources (WRB; IUSS Working Group WRB, World reference base for soil resources 2014. International soil classification system for naming soils and creating legends for soil maps, World soil resources reports no. 106. FAO, Rome, 2014). A buried concrete or asphalt layer serves to stabilize the area beneath interlocking pavement blocks. Different soil materials were observed in the profile beneath the asphalt pavement due to disturbances of the original basement soil by mixing. The profile beneath interlocking pavement is classified as Ekranic Epitechnoleptic Technosol according to WRB, due to covering with interlocking pavement and buried continuous concrete debris. Mixed alkaline subbase materials exhibited an alkaline soil reaction especially in the upper layers, Higher electric conductivity in the profile beneath the building indicates continuous leaching of basic elements from foundation concrete. Thus, soil sealing material influences the soils beneath the sealing layer in different ways. High bulk density over 0.9 g cm^{-3} exceeds the criterion of Andosols despite observation of andic properties confirmed by a NaF soil reaction. Compaction with paving and mixing with

---

K. Kida (✉)
Department of Geography, Tokyo Metropolitan University, Tokyo, Japan
e-mail: k13_kida@tmu.ac.jp

M. Watanabe, M. Kawahigashi (eds.), *Anthropogenic Soils in Japan*,
International Perspectives in Geography 9,
https://doi.org/10.1007/978-981-13-1753-8_1

demolished construction material changes soil properties such that Andosols are converted into Technosols.

Keywords Soil sealing · Road construction · Asphalt · Concrete · Ekranic technosols

1.1 Introduction

Urban areas give rise to unique soil ecosystems, because urban soils are drastically disturbed and modified by human activities. An example of such human activity is soil sealing. Soil sealing refers to the permanent covering an area of land and soil using impermeable artificial material, such as asphalt or concrete, the components for building basements and roads (IUSS Working Group WRB 2015). Soil sealing is identified as a threat to basement soil (IUSS Working Group WRB 2015), even though it promotes high trafficability, as it contributes to surface water discharge to mitigate flooding and the need for installation of facilities. Soil sealing is recognized as the fourth most important anthropogenic pressure on soil biodiversity (Gardi et al. 2013). According to Scalenghe and Marsan (2009), the effects of soil sealing on major environmental components concern the kinetics of chemical reactions and the exchange of water, gas, particles, and energy between the soil and other environmental components, thereby affecting the proper functioning of the soil. Such soils covered with "technic hard materials" are classified as Ekranic Technosols in the international world reference base for soils (IUSS Working Group WRB 2014). Ekranic means that the soil surface is sealed by technic hard materials.

The total impermeable surface area (soil sealed area) of the world is estimated at 571,504 km^2 by calculations using satellite images (Schneider et al. 2009). Land area sealed by various forms of pavement and buildings is still expanding, prompted by urban development caused by population increases and concentration in the world. Road construction is generally the first step of urbanization or colonization (Laurance et al. 2014). Areas of urban land use, such as roads, settlements, and factories, are mainly adapted from pristine lands. For example, 90% of the road areas predicted to expand by 2050 in the world will exploit pristine lands of developing countries (Laurance et al. 2014). The urban land use area of Japan is about 32.7×10^3 km^2, equivalent to approximately 8.7% of Japanese land area. Of this, the area taken up by roads is about 13.7×10^3 km^2, equivalent to 3.6%, residential areas cover about 11.6×10^3 km^2 equivalent to 3.1%, industrial areas spread over 1.5×10^3 km^2 equivalent to 0.4%, with the remaining area (1.6%) for public use totaling about 5.9×10^3 km^2. In addition, urban land use is still expanding, due to encroachment on farmland (Ministry of Land, Infrastructure, Transport and Tourism of Japan (MLIT) 2014).

The paved road length of Japan is 81% of the total road length (MLIT 2015). Types of pavement are classified depending on the uppermost material layer, and include asphalt, concrete, or interlocking blocks. The structure of road pavement is roughly separated into two layers, a top layer and a subbase layer (Kinki Regional Development Bureau, MLIT 2012). The subbase layer is similar in composition irrespective of pavement type. Usually composed of large crushed gravel (below 40 mm diameter), this subbase material is occasionally mixed with quicklime (CaO) to enhance road stability, or repurposed concrete debris to decrease urban waste. On land with very weak basement soil or rocks, or a high groundwater level, sub slab concrete is recommended instead of crushed gravel as the subbase layer. In Japan, asphalt topped pavement is the predominant road pavement type (94% of the paved road length; MLIT 2015). The asphalt layer is a mixture of asphalt (as a binder), small crushed gravel (as aggregate with a range below 25 mm diameter) and powdered limestone (as filler) (Tada 2000). Concrete topped pavement is also used for roads in Japan (5% of the paved road length; MLIT 2015). The concrete layer is a mixture of cement (as binder) and crushed gravel (as aggregate) (Kobayashi and Takewaka 2015). Although concrete pavement has the advantages of longer life, higher durability, and self-sufficiency rate of materials compared to asphalt pavement, it takes longer to construct and has a higher maintenance cost for utility buried beneath it, including pipe systems for clean and waste water, gas supply, and electricity. Interlocking pavement using interlocking blocks for pavement tops is a special pavement for landscaping and is not recommended as a standard road pavement (Kinki Regional Development Bureau, MLIT 2012). Traffic volume is the key factor in designing thickness and the number of layers in any given pavement. Strong bearing capacity is also required for mineral soils covered with pavement. To keep road bearing capacity high, subgrade layers (total of 1 m thickness of mineral soil layers beneath pavement) are compressed by a combine roller and mixed with quick lime or demolished concrete debris, especially in weak bearing capacity areas.

Buildings also permanently cover the soil surface, resulting in absolute separation of the soil from other environments. Building foundations are now made of concrete in Japan, irrespective of building types that include wooden buildings, as authorized by the Enforcement Ordinance of Construction Standard Law. These concrete foundations are in direct contact with the soil surface, resulting in alkaline soil reactions beneath the man-made constructions. Moreover, such soils are also affected by cutting and banking followed by compaction in the building process before sealing. In this chapter, examples of such soil profiles beneath constructions will be introduced. Soils covered by construction have not been considered soils, but rather as ground materials. Chemical and biological processes under the ground have never been addressed from the pedogenic point of view. However, circulating water vapor in soils and rainwater seepage through cracks in building foundations can influence the subsoil beneath a construction. Those soils classified as Ekranic Technosols due to sealing with hard, impermeable materials yield no information relating to original soils prior to construction. Characterization of soils under buildings can be useful to identify original soils and evaluate the physical and chemical influences of sealant materials of constructions on subsoils.

1.2 Soils Sealed by Asphalt

1.2.1 Road Construction and History of Land Use Changes in Sanda-Town

Soil profiles beneath new and old asphalt pavement were investigated at a road construction site in 2012. This site is located in a suburban residential area of the Tokyo metropolis (Sanda-town, Hachioji-city, Tokyo, Japan; Fig. 1.1). From 1961 to 1964, this site was converted from an agricultural area to a residential area facilitated by construction of a road (Fig. 1.2). The color aerial photo (Fig. 1.2c), shows that soils in this site were sealed by asphalt pavement in 1974. New road construction across the old road, originally planned in 1961, was conducted from 2009 to 2013. Surface black soils, the presence of which were confirmed in Fig. 1.3a, were occasionally removed at this site during road construction to produce a gentle slope for comfortable driving.

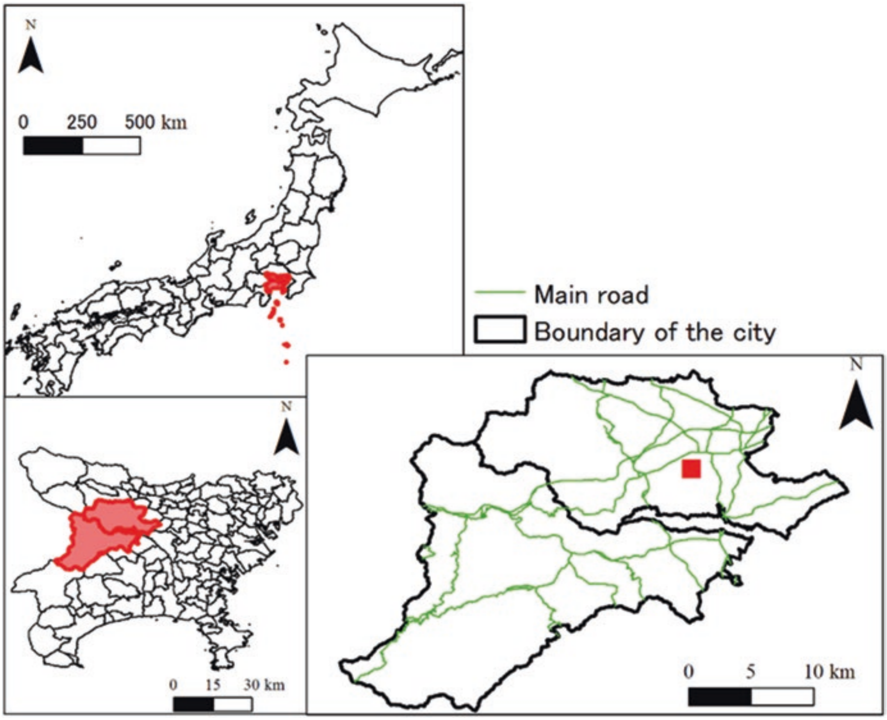

Fig. 1.1 Location of Sanda-town study site. The red square on the fully expanded map marks the position of the soil survey site (35°38′55.435″ N, 139°19′05.412″ E). Main roads are shown in green, and the city boundary is denoted by a thick line. These maps are constructed using Digital Map (Basic Geospatial Information) and Basic map data provided by the Geospatial Information Authority of Japan (GSI), and National municipality boundary data provided from the Environmental Systems Research Institute (ESRI) of Japan

Fig. 1.2 Aerial photo of the Sanda-town conversion from agricultural (a: 1961) to residential zoning (b: 1964). Photo (c) taken in 1974 shows the extent of asphalt pavement. The sealing condition has been continuous from the mid-1960s until now. Periodic road maintenance can disturb the subsoil beneath the site. The research site has been covered with asphalt since 1970. Photos from Geospatial In-formation Authority of Japan. (GSI: (**a**) MKT616-C2-8, (**b**) MKT646X-C1-5, (**c**) CKT7416-C3313)

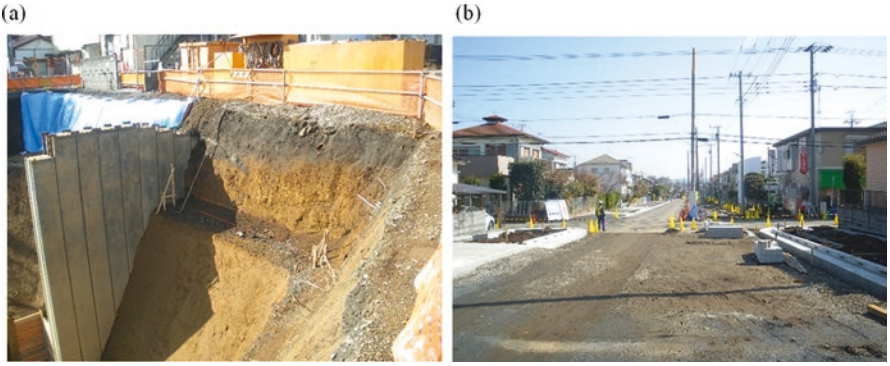

Fig. 1.3 Overview of the road construction site in Sanda-town, Hachioji-city, Tokyo, Japan. (**a**) a cliff before road construction, which will be leveled to connect the lowest point to the highest point within the construction zone, (**b**) subbase construction with crushed stones after compaction using a heavy roller

1.2.2 Soil Profile Characteristics at the Sanda-Town Road Construction Site

The soil profiles shown in Fig. 1.4a (beneath the new road) and 4b (over 38 years after initial road construction) clearly indicate different materials between the upper and basal sections of the mineral soil layer. The thickness of pavements on profiles shown in Fig. 1.4a, b are 16 cm (6 cm asphalt layer and 10 cm subbase layer) and 17 cm (5 cm asphalt layer and 12 cm subbase layer), respectively. The clear boundary observed around 10 cm from bottom of subbase horizon (Profile a: 30 cm depth, Profile b: 25 cm depth) denotes the depth of subbase material mixing by compaction for pavement construction (Table. 1.1). Soil materials in both deeper horizons showed andic soil properties confirmed by increases in soil pH after treatment with a NaF solution. The values of pH(H_2O) in the subbase and at the top of the mineral soil of the profile beneath the old pavement were lower than that beneath the new pavement, suggesting the leaching of alkaline materials from subbase gravels to deeper mineral soils. This leaching process was discussed in Kida and Kawahigashi (2015). Both profiles were classified as Ekranic Technosols due to sealing by asphalt according to the international world reference base for soil resources (IUSS Working Group WRB 2014).

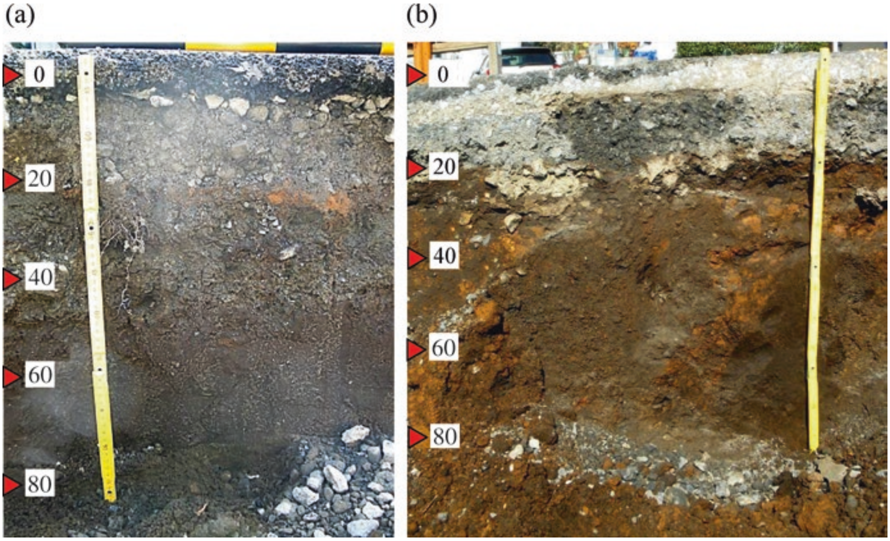

Fig. 1.4 Profiles beneath asphalt pavement: (**a**) newly constructed asphalt road in 2012, (**b**) old asphalt road, constructed 38 years ago. Numbers on white squares with red closed triangles indicate the soil depth in cm. The top of the asphalt was set as zero. The asphalt layer has 5 cm thickness and the subbase layer reached to 20 cm depth in both of profiles. Subbase layers consisted mainly of crushed stones over 40 mm width and were mixed with on-site soil materials and materials from other sites to reach the ground level. Profile (**a**) is filled with external soil materials with a sandy soil texture. Original soil materials fill the entire soil profile in (**b**)

Table 1.1 Properties of soil profiles in Sanda-town

	Depth (cm)	EC (mS/m)	pH (H_2O)	Gravel content (wt%)	TC (g/kg)	TN (g/kg)
Profile a	Subbase: 6–16	57.0	10.8	80.2	34.3	0.5
	Cu: 16–30	21.6	8.3	48.6	24.1	1.5
	C: 30–57+	17.1	5.9	0.2	74.7	6.0
Profile b	Subbase: 5–17	16.4	6.9	62.7	13.4	0.6
	Cu: 17–25	50.9	6.6	26.1	47.4	3.8
	C: 25–65+	41.6	6.6	6.0	51.8	4.1

Data from Kida and Kawahigashi (2015)

1.2.3 Maintenance History of Sewer Lines, Ishikawa-Town

In 2012, the soil profile beneath an old asphalt pavement was examined at a construction site during sewer pipe maintenance. This site is located in a suburban residential area of the Tokyo metropolis (Ishikawa-town, Hachioji-city, Tokyo, Japan; (Figs. 1.5 and 1.6). Ideally, maintenance of sewer lines or the road pavement itself with removal of pavement, renewal of the subbase structure, and repaving is required every 20–30 years. Confirmation of the age of the pavement is difficult, but land use as roads started at least 55 years ago, and at least 38 years have passed from first use of the asphalt pavement in this area (Fig. 1.7).

1.2.4 Soil Profile Characteristics Under the Ishikawa-Town Asphalt Road

The overview and soil profile of this site are shown in Figs. 1.6 and 1.8, respectively. The total thickness of the pavement was 20 cm, with an asphalt layer of 5 cm, and subbase layer of 15 cm thickness. This profile shows a clear distinction between materials at the top and base of the subbase layer, suggesting that subbase materials were mixed with surface soils through the compaction process for paving. The matrix soil materials were andic, based on a positive reaction with a NaF solution. Highly compacted mineral soils in the profile were confirmed by results of compactness greater than 25 mm using a Yamanaka cone penetrometer, suggesting limitations on root growth. Although soil beneath the pavement has been well compacted for pavement construction, the bulk densities of soils in the deeper part of this profile were lower than the upper limit of the criterion of andic properties (IUSS Working Group WRB 2014) (Table 1.2). At this site, even soils that were sealed for approximately 40 years seem to retain their original properties. Both upper and lower sections of the profile classify as Ekranic Technosol due to asphalt paving according to the classification of the WRB (IUSS Working Group WRB 2014).

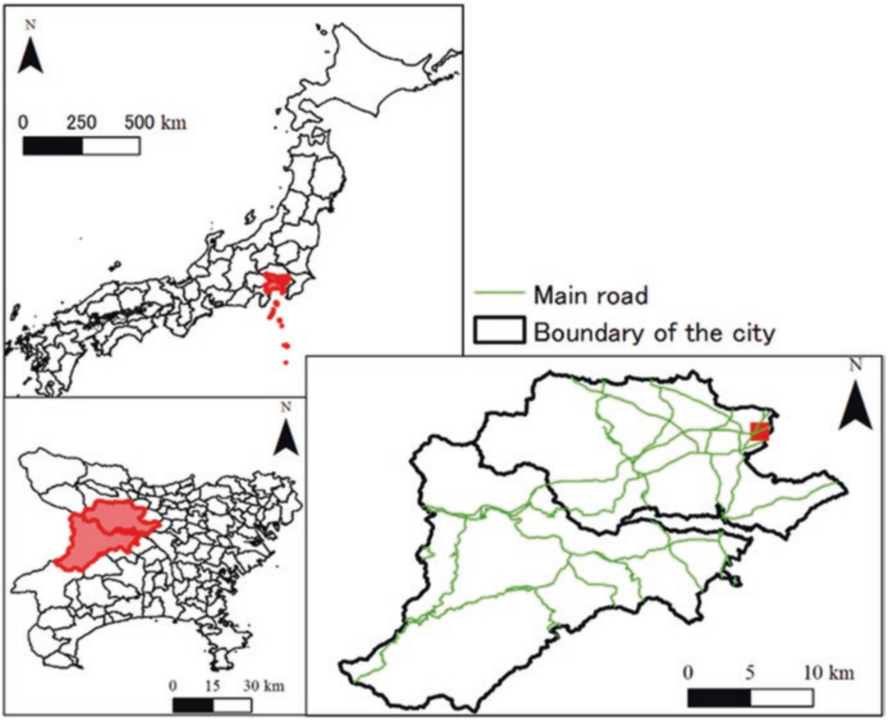

Fig. 1.5 Location of the Ishikawa-town site: The red square point on the fully expanded map marks the position of the soil survey site (35°40′32.808″ N, 139°22′04.713″ E). Main roads are shown in green, and the city boundary is denoted by a thick line. These maps are constructed using Digital Map (Basic Geospatial Information) and Basic map data provided by the Geospatial Information Authority of Japan (GSI), and National municipality boundary data provided from the Environmental Systems Research Institute (ESRI) of Japan

Fig. 1.6 Overview of Ishikawa-town site. (**a**) subgrade digging using a backhoe after opening the asphalt layer, (**b**) materials of soil and crushed stones to fill the road construction

Fig. 1.7 Aerial photos of the Ishikawa-town site. In (**a**), a photo taken in 1957 shows previous agricultural land use. The photo in (**b**) taken in 1961 shows the construction of a road. The asphalt pavement in photo (**c**) is proof of the continuing existence of asphalt pavement in 1974. Red arrows indicate the constructed road at the research site. The original agricultural field changed into a factory space covered with asphalt and concrete. The road appeared in 1974, indicating that 40 years passed since the construction. Photos are from Geospatial Information Authority of Japan. (GSI: (**a**) KT573YZ-C1-174, (**b**) MKT615-C29B-7, (**c**) CKT7416-C31-18)

1.2.5 Construction Site of a Highway Interchange in Ogura-Town

A soil profile beneath old asphalt pavement at the construction site for a highway interchange on-ramp was examined in 2013. The location of this site is Ogura-town, Midori-ward, Sagamihara-city, Kanagawa prefecture (Fig. 1.9). This roadway has been in existence for well over 100 years, as confirmed by a map published in 1892 from the Land Surveying Department, Empire of Japan (GSI 2017). Establishment of asphalt pavement occurred at least 38 years ago (Fig. 1.10).

Fig. 1.8 Soil profile beneath the asphalt pavement for car traffic taken at Ishikawa-town during sewer pipe repair by Hachioji City. Numbers on white squares indicate the soil depth in cm. Profile photo (**a**) is approximately 80 cm depth from the surface of asphalt layer. Profile photo (**b**) shows a depth to 140 cm, with a steel board and bar required for safety and to prevent pit collapse

Table 1.2 Properties of the soil profile in Ishikawa-town site

Depth (cm)	EC (mS/m)	pH (H_2O)	Gravel content (wt%)	TC (g/kg)	TN (g/kg)	Bulk density (Mg/m^3)
Asphalt: 0–5	28.2	9.2		77.8	0.90	
Subbase:5–20	64.3	8.8	71.4	21.6	0.60	
Cu: 20–35	33.2	7.4	79.2	11.2	1.10	
C1: 35–55	29.3	6.8	4.6	19.5	1.80	
C2: 55–83	19.4	6.7	0.0	14.1	1.47	0.80
C3: 83–128	15.1	6.8	0.0	13.8	1.37	0.69
C4: 128–143+	15.6	6.7	0.4	23.3	2.30	0.73

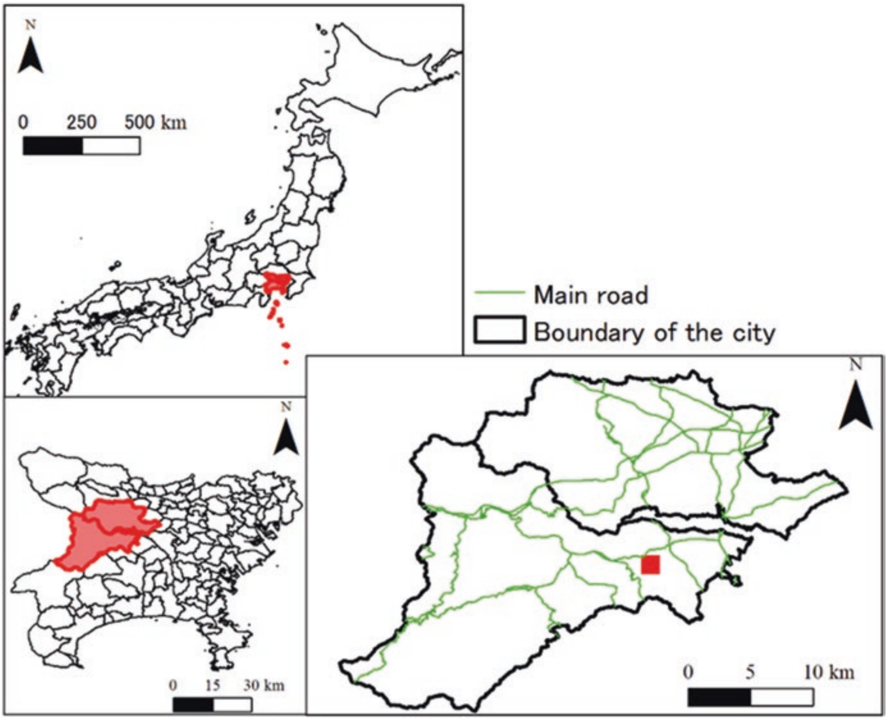

Fig. 1.9 Location of the construction site in Ogura-town. The red square on the fully expanded map denotes the soil survey site (35°34′47.7″ N, 139°17′21.1″ E). Main roads are shown in green, and the city boundary is denoted by a thick line. These maps are constructed using Digital Map (Basic Geospatial Information) and Basic map data provided by the Geospatial Information Authority of Japan (GSI), and National municipality boundary data provided from the Environmental Systems Research Institute (ESRI) of Japan

1.2.6 Soil Description and Profile Characteristics Beneath Thick Subbase Gravel, Ogura-Town

1.2.6.1 Soil Description of Profile (Ekranic Technosol: WRB)

Asphalt: 0 to 20 cm,
Subbase1: 20 to 30 cm, grayish yellow brown (10YR 4/2), dominant angular gravels (ϕ 2–4 cm), no NaF soil reaction,
Subbase2: 30 to 48 cm, brownish black matrix (10YR 3/1) and gray crust (5Y 6/1), dominant angular gravels (ϕ 2–10 cm), no NaF soil reaction,
Subbase3: 48 to 65 cm, black (10YR 2/1) and gray crust (5Y 6/1), dominant angular gravels (ϕ 2–10 cm), no NaF soil reaction,
Cu: 65 to 80 cm, reddish brown (5YR 4/6) and bright yellowish-brown crust (2.5Y 7/6), abundant weathered angular gravels (ϕ 1–2 cm) and few slightly weathered angular gravels (ϕ5–10 cm), positive NaF soil reaction,

Fig. 1.10 Aerial photo of the Ogura-town highway construction site taken in 1975. Red arrow indicates the position of the research site. The road has already been paved. Photos from Geospatial Information Authority of Japan. (GSI: CKT7416-C39-10)

C1: 80 to 95 cm, dark reddish brown (5YR 3/6) and yellowish-brown crust (2.5Y 5/6), abundant weathered angular gravels (ϕ 1–2 cm), positive NaF soil reaction,

C2: 95 to 105 cm, dark reddish brown (5YR 3/6), few weathered angular gravels (ϕ 1–2 cm), positive NaF soil reaction,

C3: 105 to 165+ cm, brown (7.5YR 4/6), no gravels, positive NaF soil reaction

1.2.6.2 Profile Characteristics

The overview and soil profile of this site is shown in Fig. 1.11. The total thickness of the pavement was 65 cm, of which the asphalt layer was 20 cm and the subbase layer, divisible into three layers by color, totaled 45 cm. Roads pressured by heavy

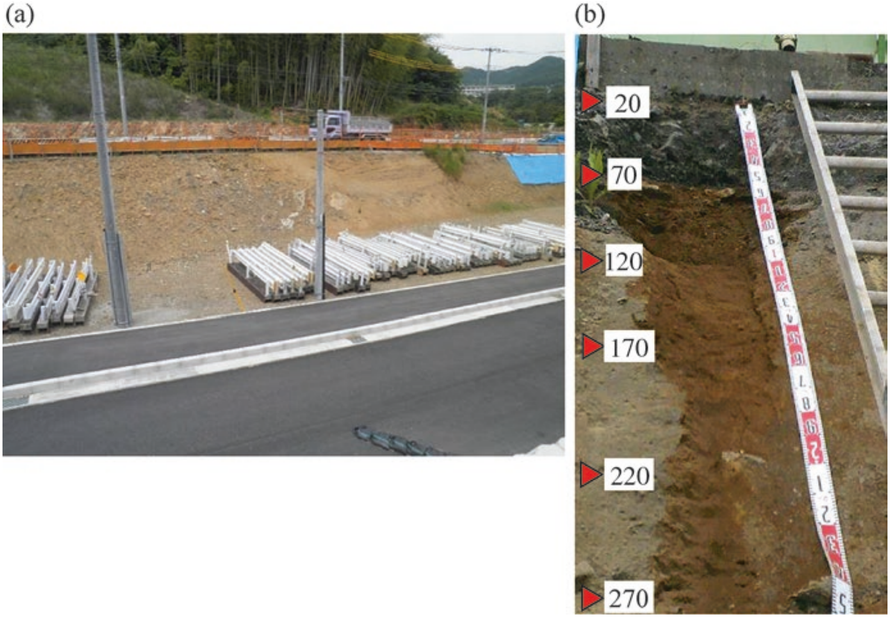

Fig. 1.11 Field photos of the Ogura-town construction site. Photo (**a**) is an overview of the construction site. The subgrade underneath the original road constructed in 1974 was exposed during construction. The lower part of this photograph shows a newly constructed and paved road. Photo (**b**) is the soil profile beneath the original road construction. The soil profile was newly exposed by removal of the slope surface Numbers on white squares indicate the soil depth in cm. The upper number from 0 with a plus sign is the thickness of covered materials

traffic volume require such thick pavement. This profile indicates clearly different material exists between the top and base of the mineral soil layer. The boundary (at 15 cm depth) of materials denotes the area of subbase material mixed by compaction for paving. The matrix soil materials showed andic properties through positive reactions with NaF solutions. A 5 mm crust on the surface of the profile was observed. This crust formed by accumulation of salts of basic cations leached from the subbase material. The crust showed higher electrical conductivity (EC) and pH(H_2O) values relative to the depth of soil horizons in corresponding soil profiles (Table 1.3). Under sealed conditions, leaching of basic cations with no drain route is not expected to result in the formation of a salt crust. These profiles can be classified as Ekranic Technosol due to asphalt paving according to WRB classification (IUSS Working Group WRB 2014).

Table 1.3 Properties of the soil profile in Ogura-town site

	Depth (cm)	EC (mS/m)	pH (H_2O)	Gravel content (wt%)	TC (g/kg)	TN (g/kg)
Profile	Asphalt: 0–20	33.2	9.1		33.0	0.40
	Subbase 1: 20–30	23.0	9.6	78.4	23.1	0.60
	Subbase 2: 30–48	18.7	8.9	64.5	8.6	0.44
	Subbase 3: 48–65	8.5	9.1	81.1	7.6	0.50
	Cu: 65–80	8.4	7.7	40.5	3.5	0.45
	C: 80–95	7.5	7.2	17.0	8.2	0.90
	C2: 95–105	7.2	6.6	11.0	8.3	0.77
	C3: 105–165+	5.3	6.7	3.3	7.2	0.76
Crust	Crust 1: 20–65	16.9	8.8	72.6	5.8	0.44
	Crust 2: 65–105	25.5	8.0	25.7	24.1	0.43
	Crust 3: 105–165+	33.1	7.1	2.7	10.7	0.57

1.3 Soil Sealed by Interlocking

1.3.1 Use of Interlocking and Asphalt Pavements and History of Land Use Change in Minamiosawa

Soil profiles beneath asphalt and interlocking pavement were studied on the campus of Tokyo Metropolitan University, Minamiosawa campus, located in Minamiosawa, Hachioji-city, Tokyo, Japan (Fig. 1.12). Pre-construction land development in the early to late 1980s included clearing of forest vegetation, followed by land cutting up to 10 m in depth and land filling in order to create a level surface (Fig. 1.13a). Construction at the university building site started at the end of 1980s (Fig. 1.13b). The study sites where profiles were investigated are located in land cutting areas.

1.3.2 Description and Characteristics of a Soil Profile with Buried Concrete

Soil profiles, location overview, and properties of soil and paving materials are shown in Figs. 1.14 and 1.15 and Table 1.4, respectively. Soil sealing, which occurred in 1988, was renewed using interlocking pavement in 2014 (Fig. 1.14a). The asphalt pavement, which had been constructed in 1988, also was renewed in 2010 (Fig. 1.14b). Buried concrete pavement was observed in the profile beneath the interlocking pavement. Such buried concrete or asphalt layers are commonly used to stabilize the area beneath the interlocking pavement. Different soil materials were observed in the profile beneath the asphalt pavement due to disturbances of the

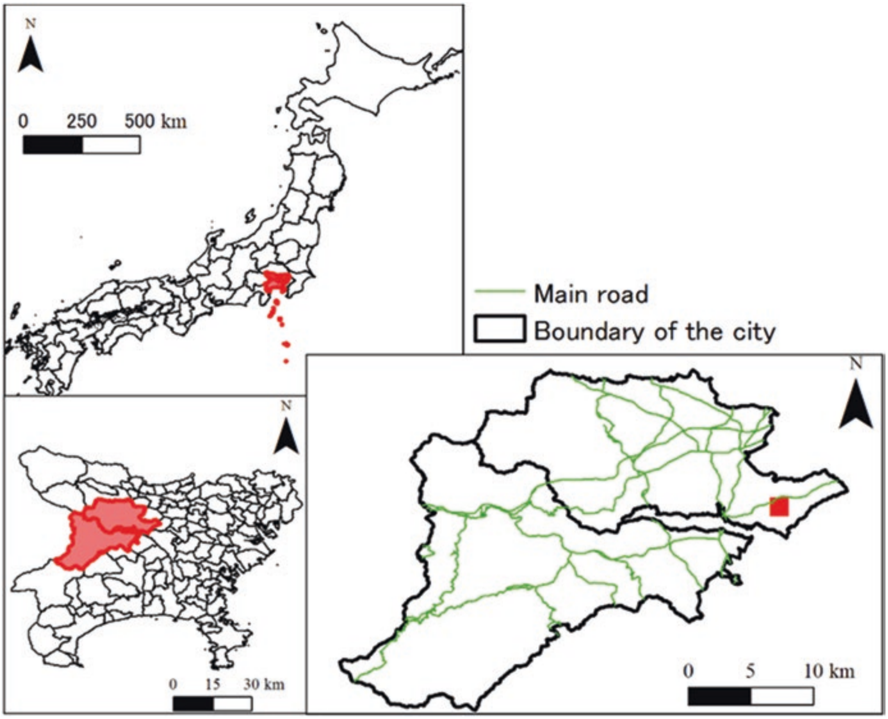

Fig. 1.12 Location of observation site of on the Minamiosawa campus, Tokyo Metropolitan University (35°37′14.930″ N, 139°22′53.594″ E). The red square on the fully expanded map marks the study site. Main roads in the area are shown in green, and the city boundary is denoted by a thick line. These maps are constructed using Digital Map (Basic Geospatial Information) and Basic map data provided by the Geospatial Information Authority of Japan (GSI), and National municipality boundary data provided from the Environmental Systems Research Institute (ESRI) of Japan

original basement soil followed by mixing with demolition wastes to bank the excavated layer during the construction process. Because of deep soil removal during land development, no soil materials in either profile showed andic properties using the NaF reaction test. The profile beneath the interlocking pavement could be classified as Ekranic Epitechnoleptic Technosol according to WRB (IUSS Working Group WRB 2014), due to covering with interlocking pavement and buried continuous concrete debris (Fig. 1.15a). The profile beneath the asphalt pavement was classified as an Ekranic Technosol (Fig. 1.15b).

1.3.2.1 Soil Description of Profile a (Ekranic Epitechnoleptic Technosol: WRB)

Interlocking block: 0 to 5 cm,

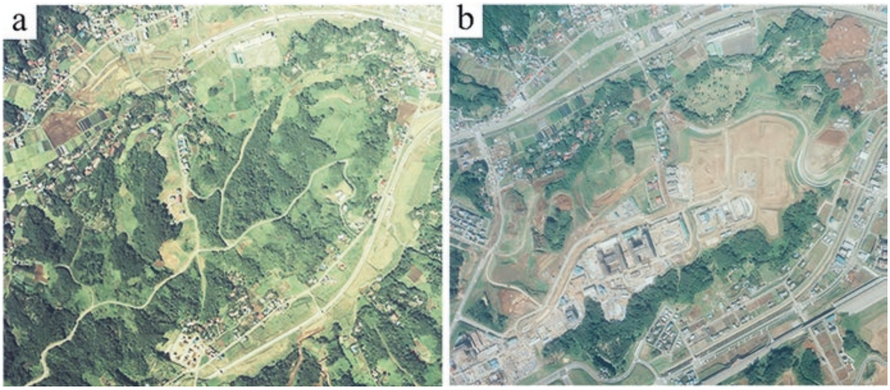

Fig. 1.13 Aerial photos of land use change at Minamiosawa from (**a**) 1979 to (**b**) 1989. The hill top has been removed to flatten the area for construction of buildings. Cut and banking also took place for land leveling. Soils have been disturbed through the process of construction. Photos from Geospatial Information Authority of Japan. (GSI: a; CKT841-C28-18, b; CKT841-C28-18)

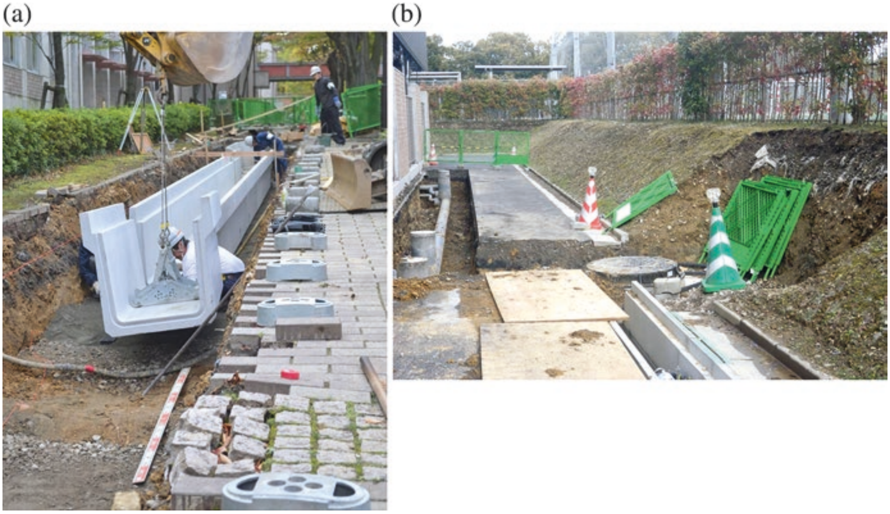

Fig. 1.14 Photo (**a**) shows the installation of sewer pipe systems. Soil excavated to 1 m depth to install the U-type pipe was surveyed. Top of soil was sealed with interlocking pavement. Photo (**b**) shows the installation work of a sewer pipe system sealed by asphalt pavement

^Cu: 5 to 10 cm, olive black (10Y 3/1), compactness unavailable, no gravels, no NaF soil reaction,

Subbase: 10 to 30 cm, olive black (10YR 3/1), compactness 17–25, dominant subangular gravels (ϕ 0.2–4 cm), no NaF soil reaction,

M (Buried concrete): 30 to 50 cm,

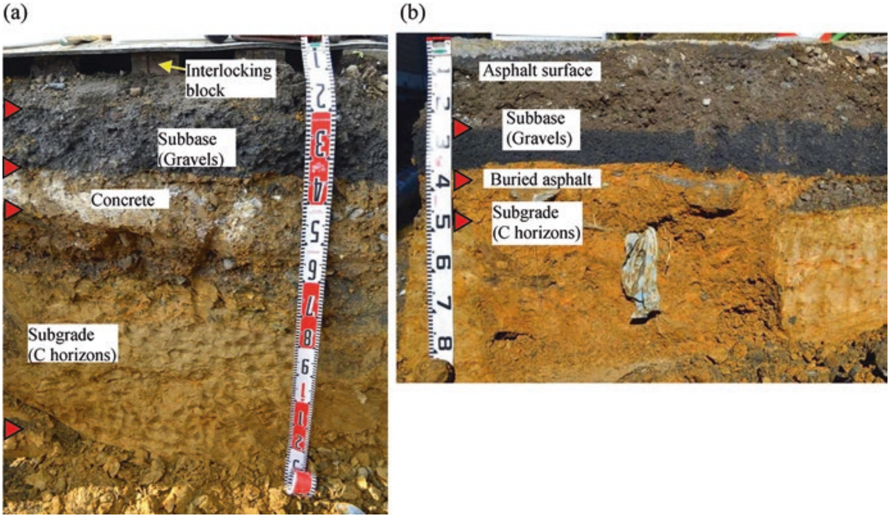

Fig. 1.15 Photo (**a**) shows the soil profile beneath the interlocking pavement. Photo (**b**) shows an artificially piled soil profile beneath asphalt pavement. Interlayers consisting of concrete and asphalt were observed to enhance the bearing capacity to traffic load. Red closed triangles on the profiles indicate the border between layers in the soil profiles

Table 1.4 Properties of soil profiles in Minamiosawa campus of TMU

Profile name	Depth (cm)	EC (mS/m)	pH (H_2O)	Gravel content (wt%)	TC (g/kg)	TN (g/kg)	Bulk density (Mg/m^3)
Profile a	^Cu:5–10	6.2	8.9	4.2	4.88	0.33	
	subbase: 10–30	17.8	9.2	65.8	19.87	0.44	
	M(concrete): 30–50	90.8	11.2		11.86	0.34	
	2Cu: 50–60	68.2	9.7	63.0	13.74	0.46	
	3C1: 60–70	7.1	7.2	7.1	1.61	0.52	1.51
	3C2: 70–90	3.5	6.9	0.2	0.49	0.27	1.50
	3C3: 90–110	3.5	6.9	0.0	0.58	0.29	
	4C4: 110–120+	4.3	7.0	0.1	0.67	0.50	
Profile b	asphalt: 0–8	3.4	9.3		36.75	0.64	
	subbase1:8–24	39.7	10.2	77.1	23.25	0.29	1.27
	subbase2: 24–35	6.9	9.6	39.8	9.54	0.39	1.86
	Cu: 35–55	9.4	8.9	6.9	1.06	0.28	1.39
	C:55–85+	7.2	8.6	4.3	0.82	0.50	1.31
	2^C (right): 50–85+	1.7	7.7	0.2	0.41	0.28	1.36

2Cu: 50 to 60 cm, olive brown (2.5Y 4/4), compactness 17 or 26, frequent sub-angular gravels (ϕ 5–10 cm), no NaF soil reaction,
3C1: 60 to 70 cm, yellowish brown (2.5Y 5/4), compactness 25, frequent fine sub-angular gravels (ϕ 1–2 cm), no NaF soil reaction,
3C2: 70 to 90 cm, yellowish brown (2.5Y 5/4), compactness 25, no gravels, no NaF soil reaction,
3C3: 90 to 110 cm, yellowish brown (2.5Y 5/6), compactness 28, no gravels, no NaF soil reaction,
4C4: 110 to 120+ cm, yellowish brown (10YR 5/8), compactness 27, no gravels, no NaF soil reaction

1.3.2.2 Soil Description of Profile b (Ekranic Technosols: WRB)

Asphalt: 0 to 8 cm,
Subbase1: 8 to 24 cm, dark grayish yellow (2.5Y 4/2), compactness 29, dominant sub-angular gravels (ϕ 0.2–4 cm), no NaF soil reaction,
Subbase2: 24 to 35 cm, black (N 1.5/0), compactness 27, dominant sub-angular gravels (ϕ 0.2–4 cm), no NaF soil reaction,
Cu: 35 to 55 cm, yellowish brown (2.5Y 5/6), silty loam, compactness 20, common sub-angular gravels, no NaF soil reaction,
C (left): 55 to 85+ cm, yellowish brown (2.5Y 4/6), loam, compactness 16, no gravels, no NaF soil reaction,
2^C (right): 50 to 85+ cm, yellowish brown (2.5Y 6/6), silty loam, compactness 26, no gravel, no NaF soil reaction

1.4 Soils Sealed by Concrete

1.4.1 Land Use and Overview of the Kameino Site

Soil profiles beneath asphalt pavement and a recently demolished building were examined at the Shonan campus of Nihon University, located in Kameino, Fujisawa-city, Kanagawa-prefecture, Japan (Figs. 1.16, 1.17, and 1.18). This campus was established in 1943. Prior to the founding of the campus, the area was used as an agricultural field. The buildings and asphalt pavement covering the profiles were removed for reconstruction before the soil survey in 2014.

Fig. 1.16 Photo (**a**) shows the construction area where Andosols have been located in the research area. Sealants consisting of asphalt, concrete, and interlocking blocks were removed prior to the start of construction. Photo (**b**) shows the ground surface being prepared for new buildings. This site provided a valuable case to have a survey between demolition and reconstruction of buildings

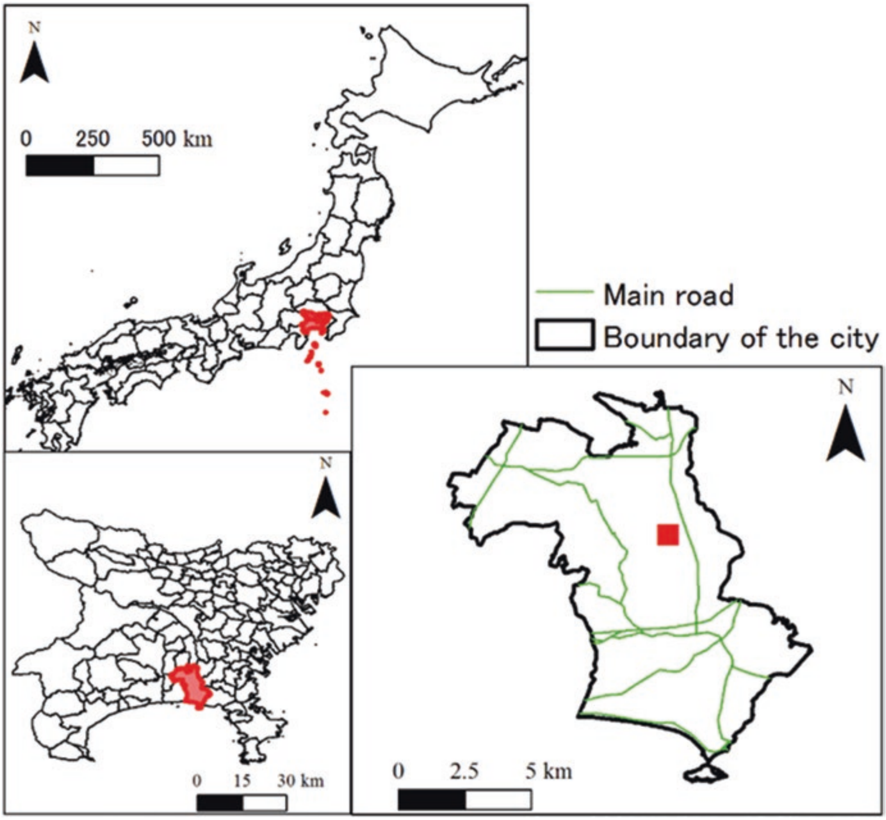

Fig. 1.17 Location of Nihon University, Shonan campus. The red square on the fully expanded map denotes the soil survey site (35°22′50.955″ N, 139°28′06.736″ E). Main roads are shown in green, and the city boundary is denoted by a thick line. These maps are constructed using Digital Map (Basic Geospatial Information) and Basic map data provided by the Geospatial Information Authority of Japan (GSI), and National municipality boundary data provided from the Environmental Systems Research Institute (ESRI) of Japan

Fig. 1.18 Aerial photo taken before the demolition of buildings on the Shonan campus of Nihon University in 2007. Red arrow indicates the research site at which the building demolished and rebuilt. Photos from Geospatial Information Authority of Japan (GSI; CKT20074-C3-26)

1.4.2 Soil Description and Profile Characteristics Under a Demolished Building and Associated Asphalt Road

Soil profiles and their properties are shown in Fig. 1.19 and Table 1.5. The pavement and building materials on top of the soil profiles were completely removed prior to the survey. The profile shown in Fig. 1.19a was covered with asphalt pavement and another profile shown in Fig. 1.19b was covered with a concrete foundation from the previous building. Different soil materials were observed in the soil profile beneath the asphalt pavement due to excavation and banking throughout the construction processes. The soil materials in both profiles have andic properties, confirmed by a positive NaF reaction. Both profiles can be classified as Urbic Technosols (IUSS Working Group WRB 2014), mainly due to the high content of artifacts and removal of any impermeable surface cover. Higher soil reaction in the upper soil layer and lower EC were shown in the profile beneath the asphalt pavement as

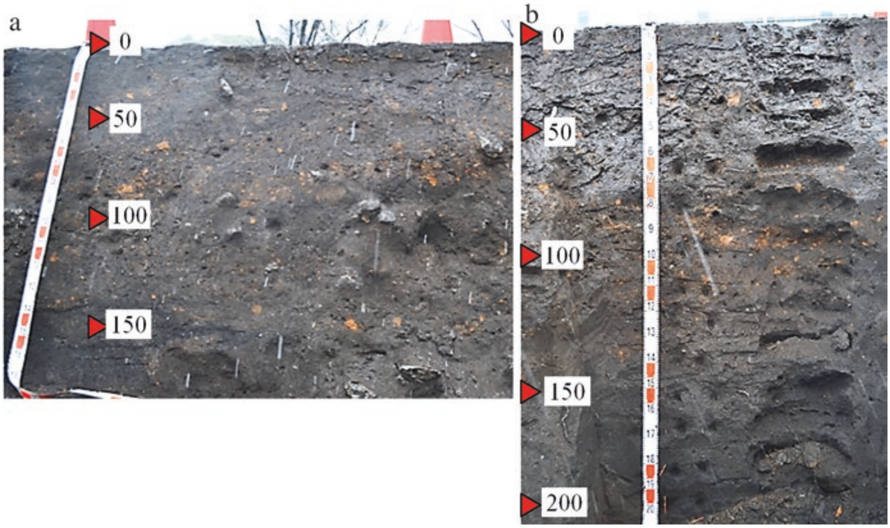

Fig. 1.19 Soil profiles at the Shonan campus of Nihon University. In (**a**), the soil profile covered with asphalt pavement is shown, and in (**b**) that beneath a demolished building is presented. Numbers on white squares indicate the soil depth in cm. Original soil was Umbric Andosol Profundihumic (IUSS Working Group WRB 2014) or Pachic Melanudand (Soil Taxonomy 2014, United States Department of Agriculture)

Table 1.5 Properties of soil profiles in Shonan campus of Nihon University

	Depth (cm)	EC (mS/m)	pH (H_2O)	Gravel content (wt%)	TC (g/kg)	TN (g/kg)	Bulk density (Mg/m^3)
Profile a	Subbase: 0–15	33.8	7.5	36.1	59.8	3.63	1.04
	Cu1: 15–30	17.9	7.0	3.2	50.7	3.45	0.83
	Cu2: 30–40	12.1	6.9	2.8	39.6	2.72	1.12
	Cu3: 40–150	15.7	6.6	2.1	33.6	2.39	0.99
	Cu4: 150–180+	28.8	5.8	0.0	97.6	5.59	0.54
Profile b	Subbase: 0–15	46.6	6.6	7.9	64.8	4.56	0.78
	Cu1: 15–30	63.6	6.4	8.4	65.3	4.34	0.77
	Cu2: 30–45	54.2	6.4	7.3	59.4	4.14	0.75
	Cu3: 45–75	72.9	6.0	5.7	69.7	4.76	0.67
	Cu4: 75–170	59.3	6.0	8.4	65.8	4.41	0.61
	C: 170–180+	40.2	5.8	0.9	81.7	5.16	0.61

compared to the profile beneath the building. These differences were probably caused by construction protocols. Beneath the asphalt pavement, the top mineral soil section showed a higher degree of mixing of gravel with filling materials through the compaction process of the subbase and asphalt layer. The mixed alkaline subbase materials produce alkaline soil reactions, especially in the upper layers. Higher EC in the profile beneath the building indicates continuous leaching of basic elements from the foundation concrete. The higher solubility forms of basic elements, as chloride salts, exhibit weaker alkaline soil reactions than oxides and hydroxides. Thus, soil sealing material and type have a variable influence on the soils beneath the sealing soil layer of both soil profiles. High bulk density over 0.9 g cm^{-3} exceeds the criterion of Andosols despite identification of andic properties confirmed by the NaF soil reaction. Compaction associated with paving processes and mixing with demolished material changes the properties of Andosol into Technosol.

1.5 Conclusion

Urbanization typically requires a level landscape, often achieved first through civil engineering processes of cut and bank, and then by complete sealing with impermeable materials such as asphalt and concrete. Compression of cut or bank soil by construction machinery is performed to increase the bearing capacity of the construction site. Soils beneath road and building construction sites are classified as Ekranic Technosols, which are covered with technic hard materials. Those soils are chemically and physically altered during the construction processes. Alkaline soil reaction is usually confirmed mainly due to the addition of lime for stabilization of paving materials. Relatively high electric conductivity is also a common feature of the soils beneath construction areas. The surface layer of a potential Andosol profile beneath a construction site had a high bulk density over 0.9 g cm^{-3}, indicating that the soil cannot be classified as a criteria of Andosols. It was considered that basement soils have may never been affected by sealing materials because of prevention of water seepage into subsoil. However vertical leaching of alkaline components was confirmed from the changes in soil chemical properties, indicating that vertical water movement through cracks on the surface or vapor-phase water circulation with changes in soil temperature can promote soil modifications beneath construction sites. It will be necessary to evaluate the soil processes for Ekranic Technosols for identifying recognition of soil characteristics and their potential for reuse after removal of constructions. General properties of original soils should be taken into account for soil classification as well as recognition of the soil processes.

References

Gardi C, Jeffery S, Saltelli A (2013) An estimate of potential threats levels to soil biodiversity in EU. Glob Chang Biol 19:1538–1548

GSI (Geospatial Information Authority of Japan) website (2017) Library service for maps and aerial photos. http://mapps.gsi.go.jp/Latest. Citation in Feb. 2017 (in Japanese)

IUSS Working Group WRB (2014) World reference base for soil resources 2014. International soil classification system for naming soils and creating legends for soil maps, World soil resources reports no. 106. FAO, Rome

IUSS Working Group WRB (2015) World reference base for soil resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps, World soil resources reports no. 106. FAO, Rome

Kida K, Kawahigashi M (2015) Influence of asphalt pavement construction processes on urban soil formation in Tokyo. Soil Sci Plant Nutr 61:135–146. https://doi.org/10.1080/00380768.2015.1048182

Kinki MLIT (Kinki Regional Development Bureau, Ministry of Land, Infrastructure and Transport) (2012) Design manual -road part-. Kinki MLIT, Osaka, p 638 (in Japanese)

Kobayashi K, Takewaka K (2015) Latest concrete technology, 6th edn. Morikita Publishing Co., Ltd, Tokyo (in Japanese)

Laurance WF, Clements GR, Sloan S, O'Connell CS, Mueller ND, Goosem M, Venter O, Edwards DP, Phalan B, Balmford A, Van Der Ree R, Arrea IB (2014) A global strategy for road building. Nature 513(7517):229–232. https://doi.org/10.1038/nature13717

MLIT (Ministry of Land, Infrastructure, Transport and Tourism of Japan) (2014) White paper on land 2014. MLIT, Tokyo (in Japanese)

MLIT (Ministry of Land, Infrastructure, Transport and Tourism of Japan) (2015) Road statistics annual report 2015. MLIT, Tokyo (in Japanese)

Scalenghe R, Marsan FA (2009) The anthropogenic sealing of soils in urban areas. Landsc Urban Plan 90(1–2):1–10. https://doi.org/10.1016/j.landurbplan.2008.10.011

Schneider A, Friedl MA, Potere D (2009) A new map of global urban extent from MODIS satellite data. Environ Res Lett 4(4):44003. https://doi.org/10.1088/1748-9326/4/4/044003

Tada H (2000) Pass down the paving technology. Kashima publishing, Tokyo, p 130 (in Japanese)

Chapter 2
Soils on Ski Slopes

Masayuki Kawahigashi

Abstract Vegetation in abandoned ski areas has gradually been replaced by various tree species, indicating that vegetation succession has progressed after termination of mowing work in these areas. Vegetation changes become a major cause of concern for soil erosion and/or landslides due to changes or removal of grass cover. Soils on abandoned ski slopes were surveyed in the Gifu prefecture. Under managed ski runs, high degrees of compaction are conducive to development of high bulk density in soils arising from volcanic precursors (products of Norikura volcano). Low content of organic carbon (C) in the soil indicates removal of top soil during land forming for ski run construction. Weak development of soil structure under conditions of high soil compaction suggests processes of land modification on the skiing grounds. Many large boulders were commonly observed on the soil profiles, indicating that ski runs were constructed to achieve high bearing capacity. Periodic management to maintain the ski slope is essential to keep high trafficability for skiers as well as machines. However, abandoned ski slopes cannot be managed by land forming processes, resulting in loose soil structure caused by random root system development on the compacted subsurface soil layer. Differences in the physical conditions between surface and subsurface soil horizons could induce a landslide.

Keywords Vegetation succession · Green infrastructure · Mowing · Soil erosion

2.1 Introduction

Outdoor recreation surged in popularity in the 1960s and 1970s due to economic growth. Large-scale development of recreation areas for skiing and golf thrived in that period, and also in the early 1990s (Kureha 2014). Opening ski resorts requires large-scale engineering works using heavy machines for cutting trees, clearing

---

M. Kawahigashi (✉)
Department of Geography, Graduate School of Urban Environmental Sciences,
Tokyo Metropolitan University, Hachioji, Tokyo, Japan
e-mail: kawahigashi-masayuki@tmu.ac.jp

M. Watanabe, M. Kawahigashi (eds.), *Anthropogenic Soils in Japan*,
International Perspectives in Geography 9,
https://doi.org/10.1007/978-981-13-1753-8_2

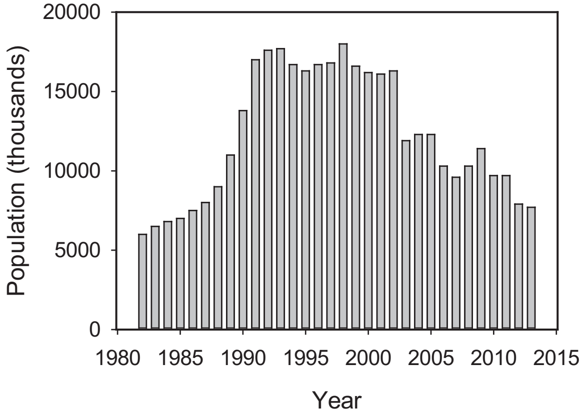

Fig. 2.1 Change in population of active skiers between 1982 and 2013 (JTA MLIT 2015)

stumps, and removal of boulders, resulting in the movement of large quantities of soil, and the removal of habitats including seed banks for the next generation of vegetation. Spaced gentle and steep slopes and other relief features were also artificially landscaped using heavy machinery at ski areas in response to demand from the skiing community. However, creation of artificial land forms without suitable management of cover vegetation leads to severe soil erosion (Yamane 1976). Exotic plants were introduced as cover vegetation but sometimes failed to grow properly, resulting in the exposure of the land surface followed by soil erosion. Artificial snow used on ski pistes (groomed runs) affects the soil temperature regime, resulting in vegetation changes and soil erosion (Rixen et al. 2003).

The number of abandoned ski areas increased following the collapse of the prosperous economic conditions of the late 1990s, due to a decrease in the number of skiers (Fig. 2.1). Small-scale ski resorts with few lifts have closed (Kureha 2014). Vegetation in abandoned ski areas has shown a gradual increase in occupation by various tree species, indicating that vegetation succession has progressed after the termination of mowing work in these areas (Koyama and Koyama 2002). Vegetation changes are probably a major cause of concern for soil erosion and/or landslides due to changes or removal of grass cover. Physical and chemical properties of soils can also change along with vegetation succession. This chapter discusses soil profiles and properties on ski courses with and without management of grass vegetation for grazing.

2.2 Ski Hills in Gifu Prefecture

2.2.1 Management of Ski Hills

In Japan, grasses and weeds grow well under conditions of high precipitation and solar radiation in the summer, especially in open forests and on ski runs. Most ski resorts in Japan have not been used for rangeland despite the high productivity of

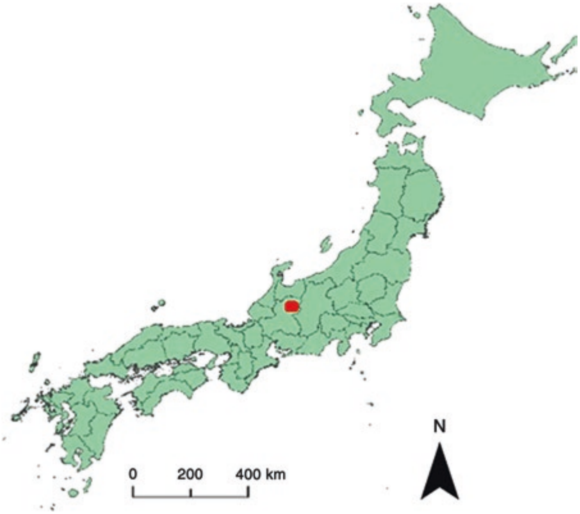

Fig. 2.2 Location of ski areas in Gifu prefecture. (35°36′20.42″ N, 139°48′32.12″ E)

grasses, which differs from the situation in Europe. Ski runs at resorts in Europe are usually managed as pasturelands in the summer. Grasses are periodically machine-mowed or grazed by livestock, whereas grasses on Japanese ski runs are left to grow as is. Periodical mowing is required in the-off season because tall grasses easily fall to the ground. Damaged grasses whither on the ground, resulting in soil erosion.

Soil profiles on ski slopes were surveyed in the city of Takayama, Gifu Prefecture (Fig. 2.2). The Kariyasu ski hill, managed by the city of Takayama, has a northeast facing slope (Fig. 2.3a). Mowing is conducted once a year, and cattle are grazed during daylight hours in summer. To build the ski runs, large-scale land forming was conducted using heavy machinery in the 1960s. In contrast, the Hida-Takayama ski hill has never opened for cattle grazing, despite hosting a variety of grass species. Mowing is conducted several times in the summer season. The north-west facing slope was developed for skiing (Fig. 2.3b), and land forming to manage the area has been performed several times.

2.2.2 Soil Description and Physico-chemical Properties at Different Ski Hills

2.2.2.1 Soil Description of Kariyasu Ski Hill

Photographs of vegetation and a soil profile from the Kariyasu ski hill are shown in Figs. 2.4a and 2.5a, respectively.

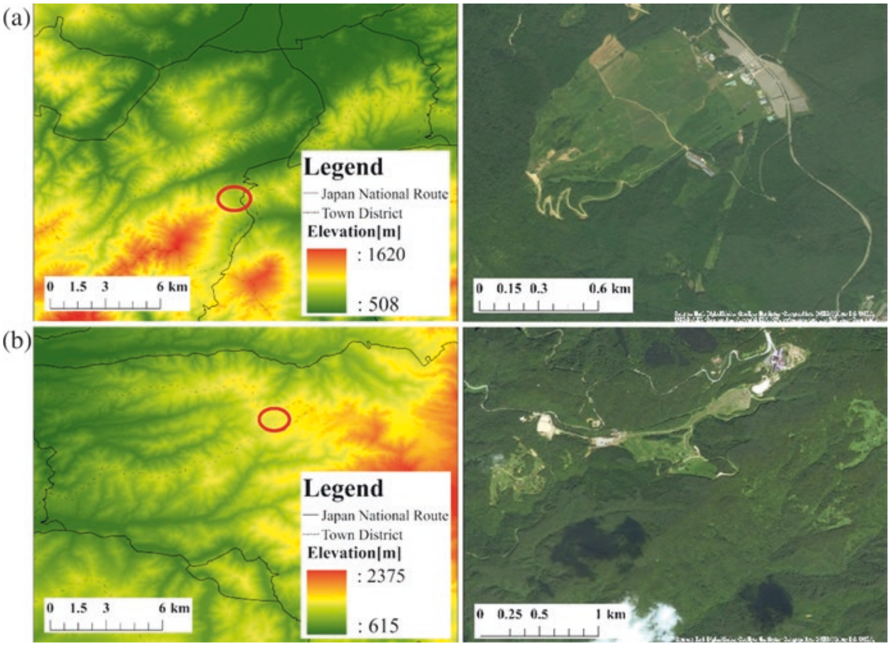

Fig. 2.3 Topography (left) and aerial photos (right) of (**a**) Kariyasu ski hill, (**b**) Hida-Takayama ski hill

Fig. 2.4 Vegetation on the ski slopes (**a**) used for pastureland with periodical management of grasses at Kariyasu ski hill (Timothy, Orchard grass, Reed Canary grass, Red top), (**b**) growth without management by grazing of the pastureland at Hida-Takayama ski hill. Many grass species were observed

A: 0 to 4 cm, dull yellowish brown (10YR 4/3), silty clay loam, weak crumb structure, dry, compactness 13, no gravels, medium organic matter, many fine roots, no NaF soil reaction, clear abrupt boundary,

BC: 4 to 24 cm, dark olive brown (2.5Y 3/3), sandy loam, weak subangular blocky structure, dry, compactness 23, many fine gravels and/or frequent angular abundant gravels (ϕ 5–20 cm), medium organic matter, no NaF soil reaction, diffuse irregular boundary,

R: 24 to 40+ cm, yellowish brown (10YR 4/3)

2.2.2.2 Soil Description of Hida Takayama Ski Hill

Vegetation cover and a soil profile from the Hida Takayama ski hill are shown in Figs. 2.4b and 2.5b, respectively.

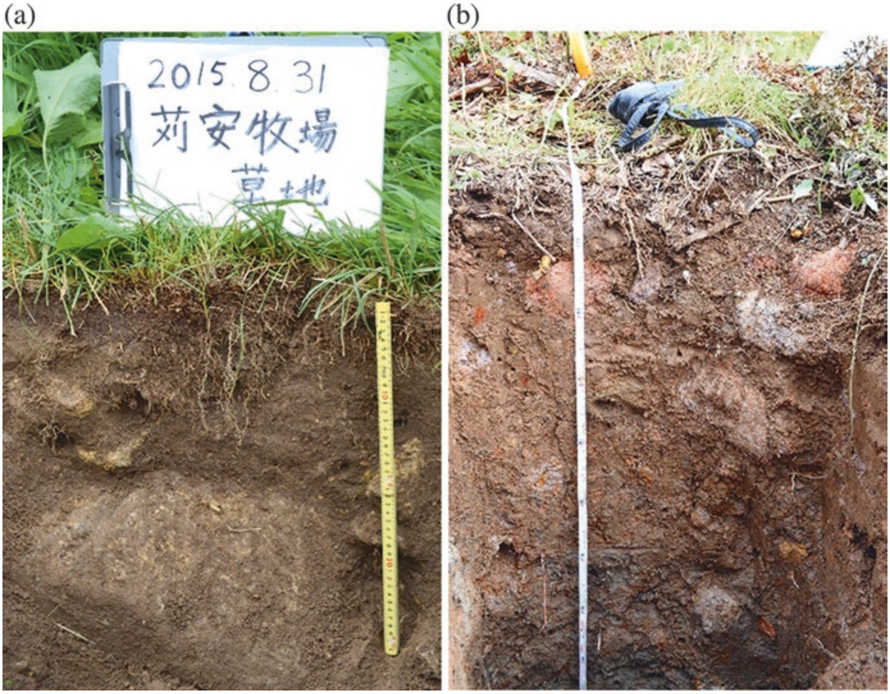

Fig. 2.5 Soil profiles at (**a**) Kariyasu ski hill, and (**b**) Hida-Takayama ski hill

A: 0 to 5 cm, brownish black (7.5YR 3/2), loam, weak crumb structure, dry, compactness 6, few fine gravels, high organic matter, few fine roots, positive NaF soil reaction, clear abrupt boundary,

BA: 5 to 60 cm, brownish black (10YR 4/3), loam, weak granular and/or medium subangular blocky structure, dry, compactness 17, few fine and/or frequent large gravels (ϕ 10–20 cm), medium organic matter, no roots, slightly positive NaF soil reaction, irregular gradual boundary,

BC: 60 to 75 cm, brown (7.5Y 4/6) and/or brownish gray (7.5YR 1/6), sandy loam, weak granular structure, dry, compactness 17, few fine gravels (ϕ 1–2 cm) and/or few large gravels, low organic matter, very few fine roots, positive NaF soil reaction, smooth gradual boundary,

C: 75+ cm, grayish yellow (2.5Y 6/2), sandy, weak granular structure, dry, compactness 12, many rocks, low organic matter, no roots, positive NaF soil reaction

2.2.2.3 Physico-chemical Properties of the Kariyasu and Hida Takayama Ski Hills

General physico-chemical properties are shown in Tables 2.1 and 2.2. Although the ski hills are closely located to one another, the soil parent materials were different at the two sites. Properties of volcanic ash are observed in soils of the Hida Takayama ski hill, which differs from Kariyasu. High compaction of soils is conducive to high bulk density of the Hida Takayama soil despite its volcanic origins (products of Norikura volcano). Low organic carbon (C) in the Hida Takayama soil indicates disturbance of the top soil during land forming process for ski hill construction.

Table 2.1 Physico-chemical properties of soils on the Kariyasu ski hill

Depth (cm)	EC (mS/m)	pH (H_2O)	pH (KCl)	Gas (%)	Liquid (%)	Solid (%)	Bulk density	TC (g/kg)	TN (g/kg)	C/N
A(0–4)	26.8	4.45	3.96	17.6	49.8	32.6	0.81	78.9	6.95	11.4
BC(4–24)	2.0	5.47	4.41	13.2	36.8	50.0	1.32	21.6	1.41	15.3
R(24–40+)	–	–	–	–	–	–	–	–	–	–

Table 2.2 Physico-chemical properties of soils on the Hida-Takayama ski hill

Depth (cm)	EC (mS/m)	pH (H_2O)	pH (KCl)	Gas (%)	Liquid (%)	Solid (%)	Bulk density	TC (g/kg)	TN (g/kg)	C/N
A(0–5)	2.09	5.22	4.15	14.4	49.6	36.0	0.95	26.31	1.88	14.0
BA(5–60)	2.92	5.24	4.33	11.1	50.9	38.0	1.01	13.69	0.94	14.6
BC(60–75)	17.93	5.46	4.25	–	–	–	–	7.7	0.54	14.3
C(75+)	1.33	5.51	4.31	–	–	–	–	7.1	0.48	14.8

However, management of the grazing field at the Kariyasu farm ensures large amount of organic matter in the surface horizon. Management of grass vegetation at the Hida Takayama ski hill has not affected the accumulation of organic matter in the soil significantly, probably due to frequent soil disturbances from land forming process. Land surface erosion is also a possible cause of the prevention of soil C accumulation at the surface. Many boulders in the soil profile at both sites consisted not of concrete or asphalt debris but rock fragments, indicating that the land forming process had moved soil and rocks at the site. Acidic soil properties also indicate no contamination by artifacts such as concrete or asphalt affecting the soil reaction.

2.3 Conclusion

Periodic mowing and land forming are necessary to manage ski grounds. These management processes result in the subsoil being too hard to extend plant root growth. Large bulk density of soil profiles accompanied by a high percentage of solid phases prevents vertical water permeation. Lateral transmission of seepage water causes shifting of layers at the border between the surface horizon with root growth and highly compacted subsoil. Large bulk density of soil profiles at the research site requires a change in soil name using supplementary qualifiers like as densic or skeletic due to exceeding this one essential criterion of Andosols. An increase in the number of closed ski runs after the beginning of the twenty-first century should be addressed from the viewpoint of vegetation succession, because vegetation change affects soil structure and root systems in surface horizons. Land management after the closure of ski runs is also necessary to recover adapted forest vegetation.

References

JTA MLIT (Japan Tourism Agency Ministry of Land, Infrastructure, Traffic and Tourism) (2015) Report of various surveys and examples. JTA MLIT, Tokyo (in Japanese)

Koyama Y, Koyama K (2002) Vegetation change over a 20-year period at abandoned ski slopes in northern Nagano Prefecture, central Japan. Bull Inst Nat Educ Shiga Height, Shinshu University, 39: 1–6 (in Japanese with English summary)

Kureha M (2014) Regional patterns of use of closed ski courses in Japan. J Ski Sci 11(1):27–42 (in Japanese with English summary)

Rixen C, Stoeckli V, Ammann W (2003) Does artificial snow production affect soil and vegetation of ski pistes? A review. Persp Plant Ecol Evol Syst 5:219–230

Yamane I (1976) Issues regarding soil in fields used for recreation. In: Kiyoshi O (ed) Study on the influence of field recreation management on the ecosystem. Ministry of Environment, Tokyo, pp 40–56 (in Japanese)

Chapter 3
Soils on River Embankments

Mizuki Morishita and Kenta Yamada

Abstract Embankments or levees are constructed along river banks to prevent flooding. Vegetation on a levee is expected to prevent soil erosion and provide suitable conditions to support an active biotope. River banks fostering these fragile ecosystems have been artificially constructed using anthropic soils mixed with various types of artifacts. A research site was located along the Rokkaku-gawa River in the Saga prefecture that flows into Ariake Bay. The constructed levee reaches three meters in height and functions to prevent seawater intrusion into agricultural fields and to provide protection from floods brought on by heavy rain along the course of the meander of the river. Soils for the embankment were transported from the surrounding mountains. The top of the levee is sealed with asphalt pavement to provide a traffic route for levee management. Artifacts in the soil profile were common in a higher section of the levee, resulting in higher pH. Mixing of different soil materials to establish the levee stable was also observed especially at the central section. Soil disturbance was not detected in the soil profile at the bottom of the levee, and soils here had relatively low pH values. Cogon grass (*Imperata cylindrica*), a native plant species, covers the slopes of embankments under natural conditions. However, goldenrod (*Solidago canadensis*), an invasive foreign species, was growing well at the study site. High values of pH on the upper sections of the levee provide suitable growing conditions for goldenrod. The relationship between the growth rate of invasive foreign species and soil pH is an excellent example of the effect of artificial soils on vegetation communities.

Keywords River banks · Embankment · Foreign vegetation · Soil erosion

---

M. Morishita (✉) · K. Yamada
Department of Geography, Tokyo Metropolitan University, Tokyo, Japan
e-mail: morishita-mizuki@ed.tmu.ac.jp; yamada-kenta@ed.tmu.ac.jp

M. Watanabe, M. Kawahigashi (eds.), *Anthropogenic Soils in Japan*,
International Perspectives in Geography 9,
https://doi.org/10.1007/978-981-13-1753-8_3

3.1 Introduction

Embankments are an infrastructure, commonly constructed in populated areas along rivers to prevent flooding and to manage agricultural production for daily life. Roads with asphalt pavement have often been constructed on river levees as a means to manage vegetation and water flow, and to facilitate dredging of river bottom sediments. Thus, the soils on the river banks, especially on constructed levees, should be affected by anthropogenic management.

On the other hand, the richness of biological activity in urban areas is another characteristic of the river bank. Even if the river bank is located near urbanized areas, fauna such as waterfowl, waterside organisms, insects, and plants inhabit this ecotope. In particular, the vegetation cover on the levee has a significant role in protecting it from soil erosion and provides a living space for various organisms mentioned above (Nanakusa Embankment Working Group 2015). However, many river embankments fostering precious ecosystems have been artificially constructed using anthropic soils mixed with various types of artifacts. Therefore, discussions on the effect of artificial soil management on the river bank ecosystems are necessary to ensure biological diversity. Here, we introduce examples of artificial soils on a river levee that affect the riverside ecosystem.

3.2 The Embankment Along the Rokkaku-Gawa River

3.2.1 Construction of the Levee Along the Rokkaku-Gawa River

The Rokkaku-gawa River, located in Saga prefecture, flows into Ariake Bay and runs a full 57.2 km (Fig. 3.1). Here, the embankment is approximately 3 m higher than surrounding agricultural areas in the back-swamp areas (Fig. 3.2). The embankments have had to be artificially reinforced against floods because of the vigorous meandering of the river. Rivers with complex meanders are common and prone to flooding in Japan, due to the steep slope of their drainage systems which promotes rapid water flow. The Rokkaku-gawa River is also characterized by the tidal effect. Seawater intrusion into the upper-stream reaches upwards of 29 km from the river mouth. Thus, the constructed levee functions as high-tide protection as well. For the embankment, necessary volumes of soil were transported from the surrounding mountains. In addition, the top of the levee is sealed with asphalt pavement to provide a traffic route for the management of the levee (Fig. 3.3). Such anthropogenic measures in support of levee construction affect the riverbank ecosystems due to addition of non-native soil to the biotope.

Fig. 3.1 Location of the Rokkaku-gawa River and the study site. Blue shading indicates the water surface, the red dot marks the study area. This map was constructed from Digital map (Basic Geospatial Information) data provided by the Geospatial Information Authority of Japan

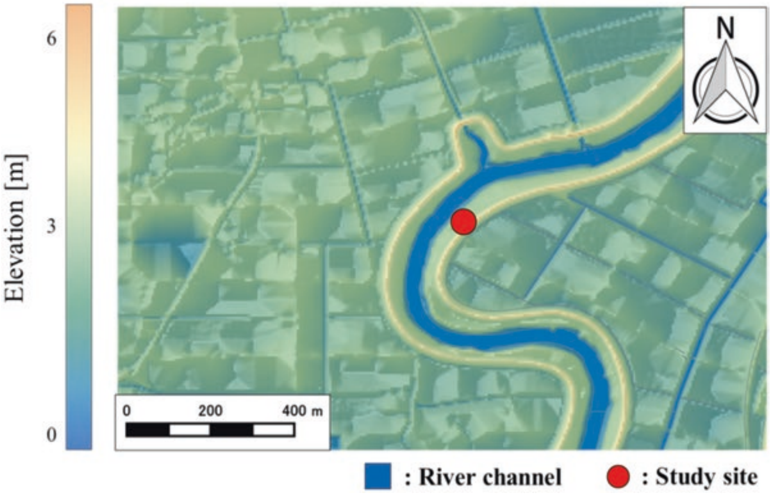

Fig. 3.2 Topographic map around the study sites. The river channel is shown in dark blue, with the study site marked by a red dot. This map was made from a 5 m–mesh of Digital Elevation Map (Basic Geospatial Information) data provided by the Geospatial Information Authority of Japan

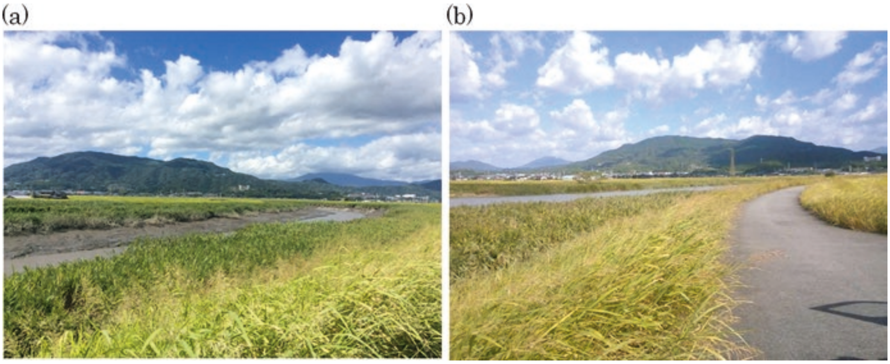

Fig. 3.3 Photos (**a**) and (**b**): Landscape of the river levee along the Rokkaku-gawa River

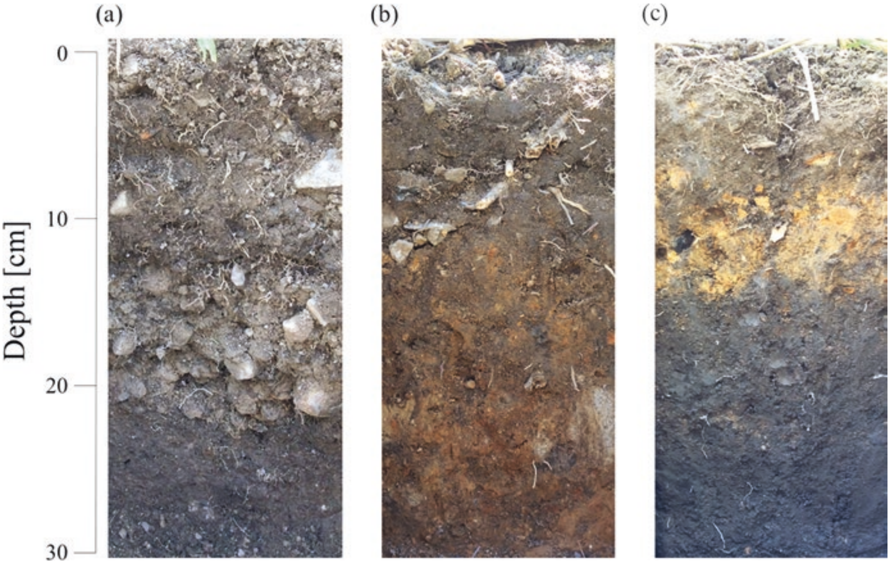

Fig. 3.4 Soil profiles located on the different position on the embankment of the Rokkaku-gawa River. (**a**) Upper side of the slope, (**b**) Middle of the slope, (**c**) Downside of the slope

3.2.2 Soil Descriptions and Profiles

Our site location is shown in Fig. 3.2, and the surrounding landscape with vegetation cover is shown in Fig. 3.3. Three soil profiles located at different positions on the slope of the Rokkaku-gawa River embankment are shown in Fig. 3.4. Soil in the upper section (Fig. 3.4a) is characterized by a large amount of foreign rock in the subsurface horizon (13–20 cm). These rocks serve as the subbase for the asphalt pavement. Dark grey horizons without rock appear below a depth of 20 cm. In the

Table 3.1 Soil pH and electric conductivity at each profile depth shown in Fig. 3.4

Position	Depth (cm)	pH (H_2O) Av.	±SD	pH (KCl) Av.	±SD	EC (mS/cm) Av.	±SD
Upper slope	0–13	8.57	0.04	7.36	0.01	0.15	0.02
	13–20	9.00	0.02	7.58	0.02	0.11	0.01
	20–30	9.01	0.04	7.64	0.02	0.16	0.01
Middle of slope	0–10	8.20	0.02	7.17	0.00	0.29	0.01
	10–20	8.81	0.01	7.40	0.00	0.15	0.01
	20–30	8.29	0.01	6.62	0.01	0.08	0.00
Bottom of slope	0–8	7.13	0.01	5.95	0.00	0.09	0.00
	8–15	7.33	0.04	5.62	0.01	0.07	0.00
	15–30	8.12	0.05	6.66	0.01	0.17	0.01

Av average, SD standard deviation

middle of the slope (deeper than 10 cm), a subsurface horizon was identified and consists of artificially mixed soils including brown soils with loamy texture, dark grey soils with sandy texture, and light grey clayey materials (Fig. 3.4b). The surface (0–10 cm) of the mid-level profile contained a small amount of rock originated from the subbase layer. The profile at the bottom of the slope (Fig. 3.4c) was located at the edge of levee. The dark grey horizon (15–30 cm) was considered to be the original surface layer before embankment construction. This horizon was wetter than the others, because it is nearer to the ground water table. In addition, the clayey yellow horizon visible from 10 to 15 cm was unique to this profile.

The measured values of soil pH and electric conductivity (EC) at each observed horizon are shown in Table 3.1. Soil pH at the upper section of the slope, where a large amount of foreign rock was found, was high. This is in accordance with Kida and Kawahigashi (2015), who reported that subbases under asphalt layers can be a source of basic cations. Conversely, the measured values of soil pH at the bottom of the slope were relatively low due to the absence of artificial rock. In particular, the three profiles are obviously different, despite their location on the same vertical slope of the river bank. This reflects the fact that soils from various and diverse origins were brought in for the embankment construction.

3.2.3 Growth of Invasive Grass Species on the Levee

In this study area, cogon grass (*Imperata cylindrica*) is a native plant species that generally covers the slopes of embankments under natural conditions. This species is good for slope greening because its deep root system stabilizes surface soils (Nanakusa Embankment Working Group 2015). However, goldenrod (*Solidago canadensis*), an invasive foreign species, was observed at the study site. Owing to their shallow root systems, the invasion of golden rod into the embankment may lead to surface soil erosion. On the basis of an on-site survey, the average height of golden rod at 2 m^2 intervals was recorded as follows; 68.6 cm (± 10.25) on the upper side of the slope, 35.3 cm (± 5.81) on the middle of slope, and 116.9 cm (± 9.51) at the bottom of slope. In this area, grasses rooting from the upper to middle parts of the slope are regularly mowed to keep the landscape open, which resulted in the highest recorded height of goldenrod at the bottom of the slope. Curiously, the height of golden rod on the upper slope was higher than in the middle even though the growth term was probably almost the same. Hiradate et al. (2009) reported that the invasion of foreign plants in Japan tends to be aggressive on high pH soils. In agreement with this trend, goldenrod was growing well on the upper side of the slope because of high pH induced by interbedded artifacts. The measured values of EC on the surface also support a difference in growth rate between goldenrod of different positions. On the middle of the slope where goldenrod height was low, EC was higher than the others. This can be considered as a result of salt accumulation due to leaching from the upper asphalt and subbase layers.

The above relationship between the growth rate of foreign species and soil pH is an excellent example of the effect of artificial soils on vegetation structure. Eventually, this may become an indirect trigger of the collapse of present ecosystems in river banks. As such, it is important to understand the migration of artificial materials that cause a reduction in the quality of the soil and subsequent environmental changes.

3.3 Conclusion

Soils of constructed levees in Japan tend to contain substantial amounts of construction debris mixed with soil material excavated from nearby mountainous areas. The percentage of artifacts at the study site differed depending on vertical location in the levee along the Rokkaku-gawa River. Soils of the upper section of the profile had an alkaline soil reaction, indicating that transported soil matter added to the top of the levee was mixed with artifacts. Soils closer to base position of the levee showed a natural soil profile and soil properties. Herbaceous layers on the levee coincided with the differences of soil properties, which differed by position on the levee. Vegetation with different root systems may influence soil physical conditions leading to soil erosion on the levee.

References

Hiradate S, Kusumoto Y, Morita S (2009) Soil pH and available phosphoric acid related to the invasion of alien species. The research report of the National Institute for Agro-Environmental Science 25: 30–31 (in Japanese)

Kida K, Kawahigashi M (2015) Influence of asphalt pavement construction processes on urban soil formation in Tokyo. Soil Sci Plant Nutr 61:135–146

Nanakusa Embankment Working Group (2015) An instruction for creating the biodiversity in embankment vegetation. Tonegawa-Karyu River Office, p 51 (in Japanese)

Chapter 4
Soils in Historical Urban Parks

Tomoyoshi Murata, Kawai Nobuo, Natsuko Uoi, and Makiko Watanabe

Abstract Urban parks are one of the large infrastructures that enhance quality of life in a metropolis. It is therefore important to maintain a record of soil history, including the development and alteration of land in urban areas. Three historical urban parks were surveyed to obtain information of the land use history. The Institute for Nature Study, designated as a national monument and historical landmark in 1949, is a particularly important site for the study of pedogenesis in urban green spaces. As compared to a reference site, "the Meiji Shrine", past construction activities, production of artifacts, and land cutting and banking resulted in a disruption of natural soil horizons. Horizon sequences were relatively similar among sites on earthworks but not on terrace surfaces, reflecting the high frequency of change in land use on these areas. Accumulation of total organic carbon decreased with increasing soil depth probably due to forest regeneration. Non-crystalline components increased with increasing soil depth mainly as a result of leaching of non-crystalline components by complexation with soil organic matter under forest vegetation. δ^{13}C values of soil increased with increasing soil depth reflecting vegetation succession. The δ^{13}C values of soil were significantly negatively correlated with a color index of extracted organic matter, indicating that C4 plants have contributed to accumulated carbon, mainly after episodes of fire. Shinjuku-Gyoen site

---

T. Murata (✉)
Center for Regional Environmental Research, National Institute for Environmental Studies, Ibaraki, Japan
e-mail: tmurata@nies.go.jp

K. Nobuo
Createrra Inc., Tokyo, Japan
e-mail: k-nov@createrra.co.jp

N. Uoi
Mitsui Consultants Co., Ltd., Tokyo, Japan
e-mail: uoi-natsuko@mccnet.co.jp

M. Watanabe
Department of Geography, Graduate School of Urban Environmental Sciences, Tokyo Metropolitan University, Hachioji, Tokyo, Japan
e-mail: m.wata@tmu.ac.jp

M. Watanabe, M. Kawahigashi (eds.), *Anthropogenic Soils in Japan*,
International Perspectives in Geography 9,
https://doi.org/10.1007/978-981-13-1753-8_4

has experienced changes in its land use history during the past four centuries. There were several drastic differences in general soil properties with depth. These soil characteristics reveal signatures of anthropogenic impact such as banking and cutting in the soil profiles. Short and frequent complex anthropogenic alterations were observed in the historical park. High variability of soil properties in the Shinjuku Gyoen site indicates high frequency of land use changes within its history. In the Kitanomaru Garden connected to the East Gardens of the Imperial Palace, three large-scale constructions were performed from the Edo era (1603–1868) to the present. Soils in Kitanomaru Garden are classified as Urbic Technosols, and feature artifacts such as bricks, tiles, concrete, or potteries originating from buildings from the past 400 years. Soils in Kitanomaru Park had a higher soil pH, lower total carbon content and relatively high cation exchange capacity (CEC) compared with natural volcanic ash soils. Moreover, the vertical distribution of soil compactness was characterized by disorders of the compaction layers or having a consolidated layer within 1 m deep. The spatial distribution of the soils having non-intrusive and densely-compacted layers correspondences with the restoration position of a building and land-grading works.

Keywords Urban parks · Land use history · Land creation history · Urbic technosols

4.1 Introduction

Urban areas and green spaces created within cities are gradually expanding in Japan. The area of urban green space in Japan is 121,446 ha or 10.14 m^2/person as of March 2015 (Ministry of the Environment Government of Japan 2017a), which is about 0.4% of the Japanese land area.

Expansion of urban areas causes specific environmental problems in a metropolis, such as “urban heat islands” and “urban floods”. In order to provide healthy ecosystem services, the soil in urban ecosystems must be conserved, as soil is an essential natural resource for maintaining life. Urban soils develop under circumstances associated with intensive stress of human activities, and their properties may further change by various processes of human activities. Nevertheless, soils in urban area may have miscellaneous functions that create sustainable urban environments such as mitigation of heated atmosphere, recovery of infiltration capacity, biodiversity, and storage of carbon.

Tokyo is recognized as a large city, but in fact, many green spaces within the city have existed quite some time. An urban park is one of the large infrastructures to support a comfortable life in a metropolis. In this chapter, three historical parks in the Tokyo Metropolis, including the Institute for Nature Study park, the Shinjuku-Gyoen park, and the Kitanomaru park, are introduced to understand basic characteristics of soil development of urban park soils in consideration with land use history, land creation methods, current land coverage, and management.

4.2 The Institute for Nature Study, Shiroganedai, Tokyo

4.2.1 History of Land Use at the Institute for Nature Study

The Institute for Nature Study, managed by the National Museum of Nature and Science of Japan, is located on the site of the former imperial estate Shirogane-Goryouchi, and covers an area of approximately 20 ha in Shiroganedai, Minato-ku, Tokyo (35°38′7.6–29.0″ N, 139°43′1.7–21.3″ E; Figs. 4.1 and 4.2). This area is on

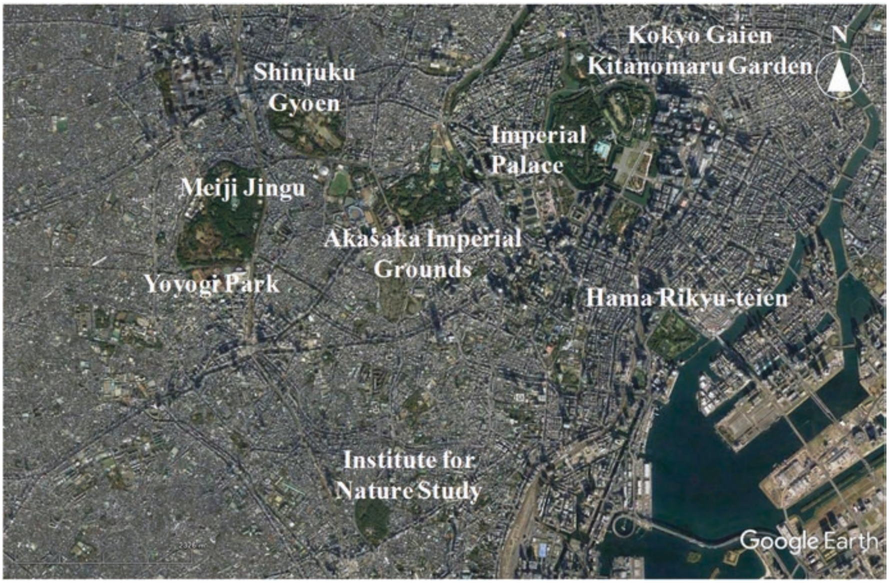

Fig. 4.1 Urban green spaces in Tokyo. Base photo map is taken from Google Earth

Fig. 4.2 Overview of the Institute for Nature Study in Tokyo. (**a**) Aerial panorama photograph, (**b**) promenade, and (**c**) earthwork site No. 5 (Fig. 4.4), (**d**) valleys and wetland

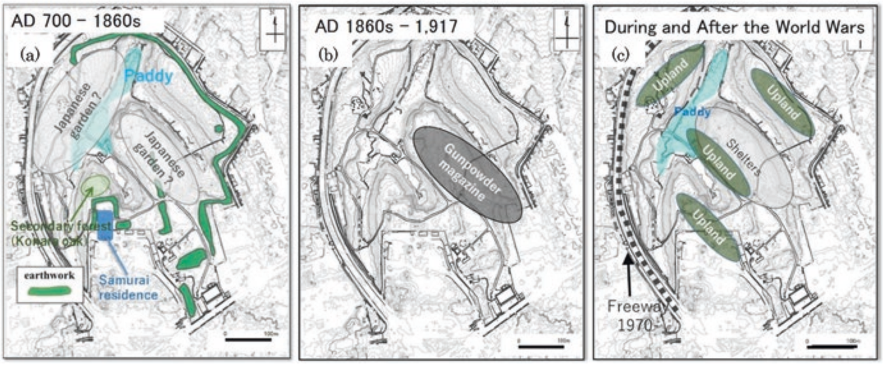

Fig. 4.3 Land use history of the Institute for Nature Study in Tokyo

the Yodobashi-dai of the Shimosueyoshi surface, and forms flat valley bottoms in the hills eroded by three effusive springs (Tokyo Metropolitan Government 1997). Extensive land disturbance has been prohibited since 1949 when the area was designated as a National Treasure and Historical Site. This is a particularly important site for the study of pedogenesis in urban green spaces, since there are many historical records on land use and vegetation cover available for this area.

Although it is not known when the first humans settled this area, pottery and shell mounds from the mid-Jōmon period (about 2500 years ago) were found here, suggesting that the region was already settled at that time. From 700 to 1860, this area was under the control of powerful clans and samurais. Archeological evidence suggests that they constructed earthworks and residences, produced some artifacts, and may also have developed Japanese gardens, a secondary forest, and paddy fields for food production (Fig. 4.3a). During the Meiji period (1868–1912), the site was used as a gunpowder magazine, under the control of the Army Ministry. It was taken over by the Imperial Household Ministry in 1917 and renamed the Shirokane Imperial Estate (Fig. 4.3b). The area seems to have considerably degraded during the World Wars because of disorganized land use. However, after World War II, its management was taken over by the Ministry of Education, and designated as a special natural treasure in 1949. Since then, the area has been recovering, including regeneration of natural environments (Fig. 4.3c). Presently, most of the area is covered with forest and grass. The park has been opened to the public and has become an oasis. Whereas terrace surfaces have had several land uses, earthworks have not changed much for the past 500 years. Therefore, a comparative study of earthworks and terraces would be useful to understand how man-made alterations influence the pedogenesis of an urban area.

4.2.2 Soil Description and Soil Properties Including $\delta^{13}C$ Values

Soil surveys and sampling sites are shown in Fig. 4.4. Soils in this area are mostly covered with Silandic Andosols according to the world reference base for soil resources (WRB; IUSS Working Group WRB 2014). Here, the Andosols are derived from volcanic ejecta, and primary volcanic ash, pumice, and scoria from eruptions of Mt. Fuji.

Soil profiles are shown in Fig. 4.5. As a reference site, the soil profile of the Meiji Shrine soil is also shown (Kaneko et al. 1991). The Meiji Shrine is located on the same geomorphic surface (the Shimosueyoshi terrace) and is located ~4.5 km north-northwest from the Institute for Nature Study (Fig. 4.1). The horizon sequence of the Meiji Shrine soil has been essentially maintained as an undisturbed sequence, and is composed of four chronological black soil horizons, dated at ~300 to 10,000 years of age, and the Kanto-Loam that was formed in the Pleistocene following the eruption of tephra from Mt. Fuji. Black soil infers that horizons A1–4 are rich in humus. The color of the black soil horizon has the value ≤3, chroma ≤3, except 3/3. A dark brown horizon refers to horizon AB, which has the soil color “3/3” – “3/4.”

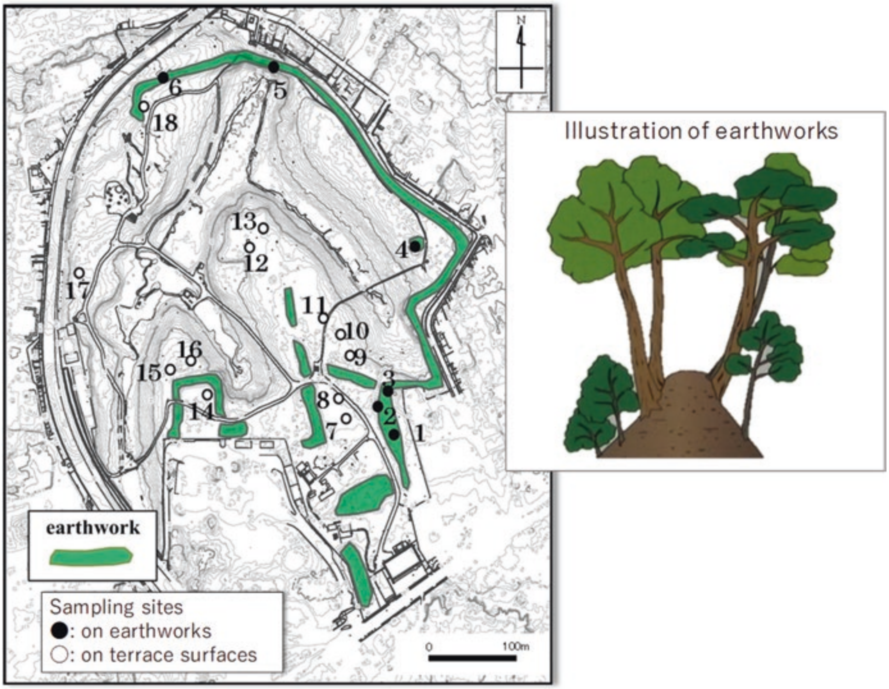

Fig. 4.4 Sampling sites shown on a topographic map at the Institute of Nature Study and with illustration of earthworks indicated by green shading

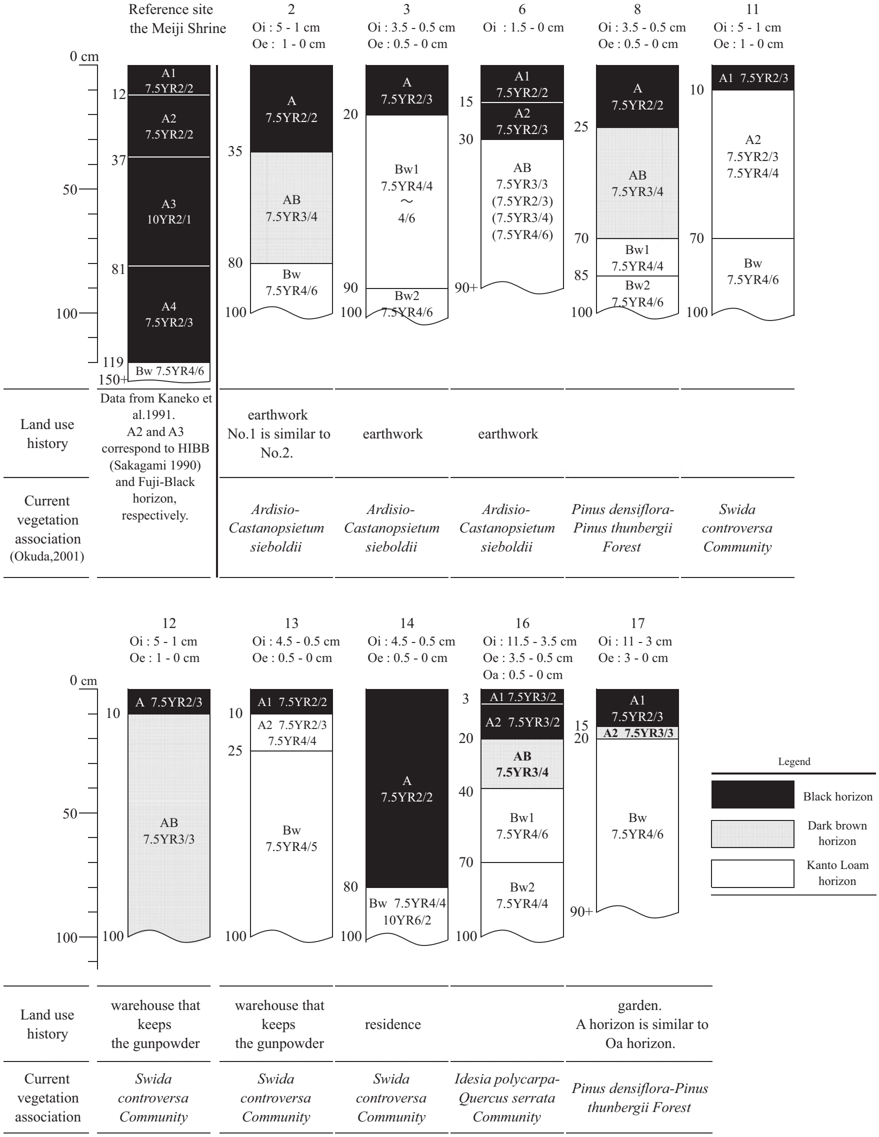

Fig. 4.5 Descriptions of soil profiles at the Institute for Nature Study. Site numbers over profiles indicate the profile location on the topographic map of Fig. 4.4

Results show that past construction activities, production of artifacts, and land cutting and banking resulted in a disruption of natural soil horizons at the Institute for Nature Study. In fact, undisturbed horizon sequences were not found in any of the sampled sites, meaning all sites were, at some point, more or less affected by man-made alterations. Still, the relative thickness of individual horizon sequences was relatively similar among sites on earthworks, but not on terrace surfaces, reflecting the high frequency of change in land use on these areas.

4.2.2.1 Soil Properties

Soil chemical properties at the sites on the grounds of the Institute for Nature Study are shown in Table 4.1. Accumulation of total organic carbon decreased with increasing soil depth. This might be due to forest regeneration, which allowed a high quantity of fresh organic matter to be returned to the soil surface by the existing vegetation.

The amounts of oxalate-extractable Al and Fe, such as non-crystalline components, met the requirements for Andosols in all sites and in all horizons. In both earthworks and terraces these amounts increased with increasing soil depth. This trend, particularly in the earthworks, might have resulted from the leaching of

Table 4.1 Soil chemical properties at the sites on the grounds of the Institute for Nature Study

Site no.	Horizon	Depth (cm)	pH (H_2O)	T-C (g kg^{-1})	Alo + 1/2FeO (%)	$\delta^{13}C$ (‰)	Melanic index
Earthwork							
2	A	0–35	5.1	186	5.4	−26.1	1.88
	AB	35–80	4.8	39	9.8	−20.9	1.64
	Bw	80–100+	5.6	20	11.8	−22.2	2.23
5	A	0–15	4.7	83	8.9	−24.7	1.99
	AB	15–25	4.7	68	9.3	−24.7	1.94
	Bw1	25–60	5.1	41	10.5	−24.0	1.92
	Bw2	60–100+	5.4	35	12.0	−23.1	1.78
Terrace surface							
8	A	0–25	4.6	200	6.5	−26.3	1.81
	AB	25–70	5.2	24	12.5	−22.6	1.67
	Bw1	70–85	5.7	20	12.2	−23.3	1.84
	Bw2	85–100+	5.8	19	7.1	−24.2	–
9	A	0–25	5.2	236	5.6	−27.7	1.97
	Bw1	25–70	5.2	17	13.5	−21.9	1.95
	Bw2	70–100+	5.8	16	12.6	−22.1	1.92
16	A1	0–3	4.5	282	3.9	−28.0	2.20
	A2	3–20	4.3	110	7.3	−26.5	2.01
	AB	20–40	4.6	67	8.5	−25.0	1.79
	Bw1	40–70	5.2	19	12.1	−23.7	2.11
	Bw2	70–100+	5.6	15	12.9	−22.5	–
18	A1	0–15	5.3	167	7.8	−26.9	2.08
	A2	15–35	4.8	54	9.5	−23.7	1.77
	AB	35–55	–	–	–	–	–
	Bw	55–90+	6.2	23	13.0	−22.6	1.95

non-crystalline components by complexation with soil organic matter, which is present in large amounts in the soil profiles.

$\delta^{13}C$ values of soil increased with increasing soil depth at most sites in this study. It is likely that grass vegetation of C4 plants (approximately −27‰ on average) such as *M. sinensis* had widely occupied this area and that soil organic matter (SOM) that was derived from present-day C3 plants (approximately −13‰ on average) (O'Leary 1995; Yoneyama et al. 2001) is now mixed into SOM derived from C4 plants that had grown at these sites in the past. Furthermore, the $\delta^{13}C$ values of soil had a significant negative correlation with the Melanic Index (the abundance of highly humified organic matter). Therefore, highly humified SOM as expressed by the Melanic Index was assumed to derive from C4 plants that had continuously been burned off. This study was detailed in Kawai et al. (2015).

4.3 Shinjuku Gyoen Park

4.3.1 History of Land Use at Shinjuku Gyoen Park

Shinjuku Gyoen Park (35°40′52.7″–41′19.0″ N, 139°42′15.1–56.0″ E), is located on the Yodobashi upland of the Shimosueyoshi surface that formed 125 thousand years ago (Figs. 4.1 and 4.6). Within the park there is a water channel, running from the northwestern end toward the southeast, that is an abandoned channel of the Shibuya River, and also three ponds (Upper, Middle, and Lower ponds) that have been created by damming. Small plateaus exist on the northern and southern ends across the water channel. Other micro-topographical features have been altered to create a rolling landscape. Related history is provided on the website of Ministry of the Environment, Government of Japan, as follows (Ministry of the Environment Goverment of Japan 2017b). Shinjuku Gyoen Park was constructed on the site of a private mansion belonging to Lord Naito (Early 17 c.), a 'daimyo' or feudal lord of the Edo era, and has been one of the most important gardens since the Meiji era (1868–1912). The Naito Shinjuku Research Institute was founded in this park in

Fig. 4.6 Aerial photographs of (**a**) Shinjuku Gyoen Park, (**b**) landscapes of the French Formal Garden, and (**c**) the English Landscape Garden

1872, as a result of public aspiration to promote modern agriculture. In 1906, the Gyoen was completed as an imperial garden. During the Second World War, the Gyoen was used as a field. In 1945, the Great Tokyo Air Raids resulted in burning of buildings in Shinjuku Gyoen. After the Second World War, Shinjuku Gyoen was re-designated as a National Garden and opened to the public in 1949. Currently, three formal gardens, the French Formal Garden (Fig. 4.6b), the English Landscape Garden (Fig. 4.6c), and the Japanese Traditional Garden, are arranged within the 58.3 ha area.

4.3.2 *Soil Compactness and Physico-chemical Properties*

Soil surveys were conducted at three sites within the lawn areas of the park (Fig. 4.7) (Uoi 2014; Uoi et al. 2013). OP-A was a site in the French Formal Garden developed ca. 1908. The area where OP-B and -C are located was developed in a former forest or Japanese garden ca. 1908. OP-C was close to OP-B and subject to redevelopment by raising of the ground level for construction of a central rest house in 1998.

Vertical profiles of soil compactness were obtained by measuring softness (cm drop^{-1}) using a cone penetrometer at a maximum depth of 1 m (Fig. 4.8; H-100; Daitou Techno Green Inc. Tokyo, Japan). The measurement was conducted by dropping a 2 kg weight from a height of 50 cm to penetrate a ϕ 20 mm cone with an angle of 60°. Softness was defined as the depth penetrated in (cm) per drop,

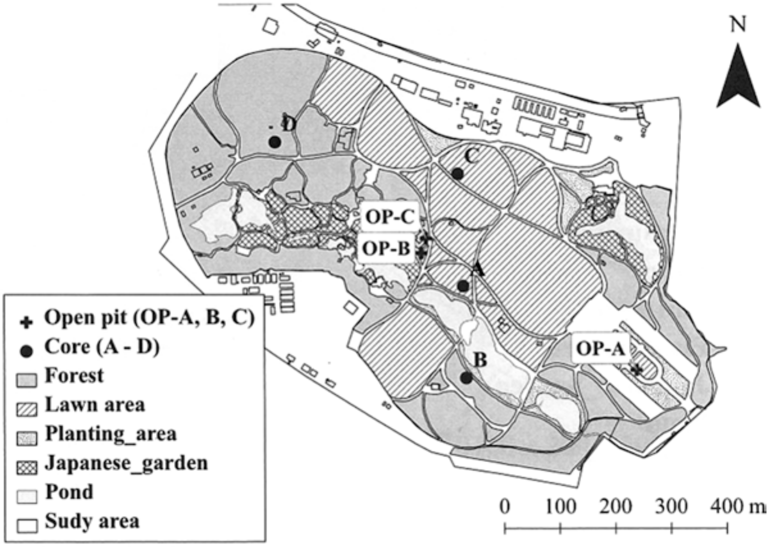

Fig. 4.7 Location map of the study area and survey sites in the Shinjuku Gyoen park

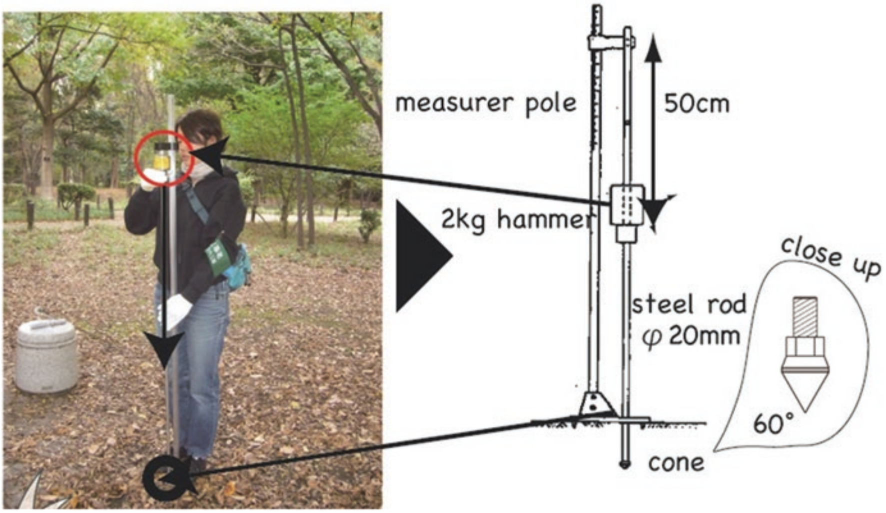

Fig. 4.8 Methodology of measuring soil compactness (soil softness) using the Hasegawa-type corn penetrometer

which has practical applications in planting techniques to evaluate the physical condition and properties of the soil. The critical values for tree and root growth, as suggested by the Research Committee of Japanese Institute of Landscape Architecture (2000), are:

Softness ≤1.0: interference for tree root extension
Softness ≥4.0: strength deficiency and water shortage for trees

4.3.2.1 Soil Properties

There were several drastic differences in soil properties across a horizon (layer) boundary at a depth of 20 cm in the soil profile of OP-A (Fig. 4.9 and Table 4.2). Soil color changed drastically, from 10YR2/3 to 10YR4/6. Field soil texture became more clayey with increasing soil depth (CL → LiC). In addition, the compactness, measured by the Yamanaka method using a pushing corn, was 8–9 mm at 0–20 cm depth compared with 23 mm at 20–80 cm depth. A dramatic increase in the soil liquid phase ratio and a decrease in gas phase ratio were observed with increasing soil depth. In contrast with the soil compactness, soil softness decreased with increasing soil depth and a drastic shift was observed around the horizon boundary. These soil characteristics indicate signatures of anthropogenic impact such as banking and cutting in soil profiles.

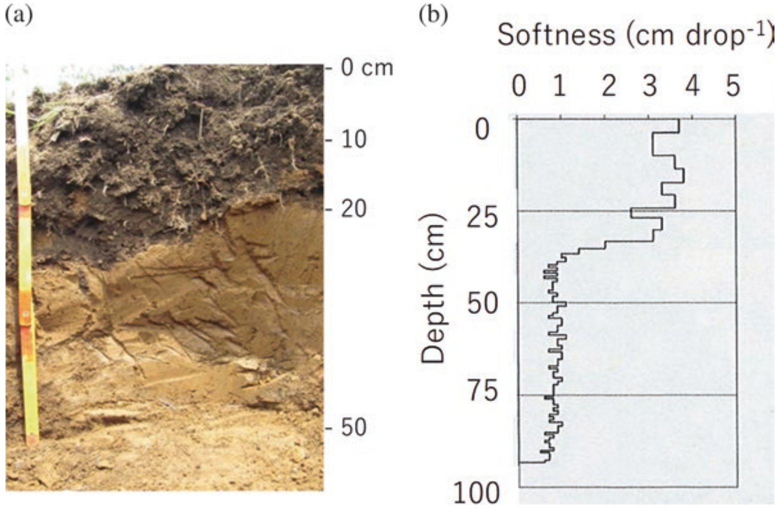

Fig. 4.9 (**a**) Soil profile and (**b**) vertical distribution of soil softness (cm/drop) of profile OP-A

Table 4.2 Soil properties at OP-A

Depth (cm)	Horizon	Soil color (moist)	Texture	Compactness (mm)	Three phases of soil (%) Solid	Liquid	Gas	pH (H_2O)	TC (g kg^{-1})	TN
0–10	A1	10YR2/3	CL	8 ± 2	19.7	41.1	39.2	5.5	77.8	6.3
10–20	A2	10YR2/3	CL	9 ± 1	32.0	54.7	13.3	5.3	57.2	4.7
20–80+	Bw	10YR4/6	LiC	23 ± 2	20.8	68.5	10.7	5.6	13.6	1.1

In contrast to OP-A, there was little vertical variation in soil softness at OP-B, where the values ranged from ~1–2.5 cm drop^{-1} (Fig. 4.10). Compaction was accomplished in a complicated manner, and the vertical profile showed signs of discontinuity, which could be a result of short and frequent anthropogenic alteration (Table 4.3).

Although OP-C was located very close to OP-B, the soil profile characteristics were definitely different. This profile contained a greater amount of anthropogenic debris such as asphalt in every layer (Fig. 4.11, Table 4.4). Therefore, various soil properties changed at the depth of every 3–10 cm. Anthropogenic compaction might reduce gas phase ratios in the whole soil profile and the values at OP-C were much lower than those at OP-A and OP-B. Furthermore, anthropogenic inputs such as debris of asphalt and concrete might induce an increase in soil pH values. Horizon names in these soil profiles are still provisional.

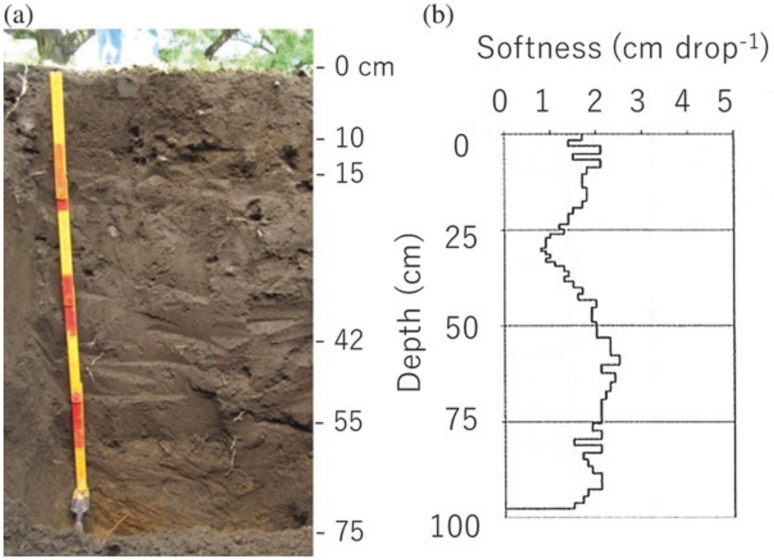

Fig. 4.10 (**a**) Soil profile and (**b**) vertical distribution of soil softness (cm/drop) of profile OP-B

Table 4.3 Soil properties at OP-B

Depth (cm)	Horizon	Soil color (moist)	Texture	Compactness (mm)	Three phases of soil (%)			pH (H_2O)	TC	TN
					Solid	Liquid	Gas		($g\ kg^{-1}$)	
0–15	A1	10YR3/2	SiCL	19 ± 1	28.9	49.9	21.2	5.3	42.2	3.2
15–42	A2	10YR3/3	CL	25 ± 4	25.3	46.5	28.2	6.2	40.8	3.1
42–55	A3	10YR3/3	CL	15 ± 1	18.8	54.4	26.8	6.3	40.2	3.0
55–75	A/B	10YR3/3	CL	16 ± 2	37.2	50.0	12.8	6.3	39.7	2.9
75–110+	Bw	10YR4/4	LiC	–	21.4	47.0	31.5	6.1	14.4	1.3

4.4 Kitanomaru Garden

4.4.1 History of Land Use at Kitanomaru Garden

Kitanomaru Garden, with an area of approximately 19.3 ha, is connected to the East Gardens of the Imperial Palace (Fig. 4.12). The park was opened to the public as a National Garden in 1949. Prior to this date, this area was a part of the Imperial Palace grounds and the Kitanomaru district was occupied by the Konoe Military Regiment (Special Imperial Guard) or Government Buildings from 1874 until early 1945. Prior to this time period, this vast area was densely populated by relatives of the Tokugawa Shogun (Fig. 4.13).

When the Shogun Tokugawa Ieyasu entered Edo (currently Tokyo), several private houses, a forest, and a shrine were situated in the area. In 1607 (Edo era), a castle tower base, mound, and moat were created. Since this area was constructed as

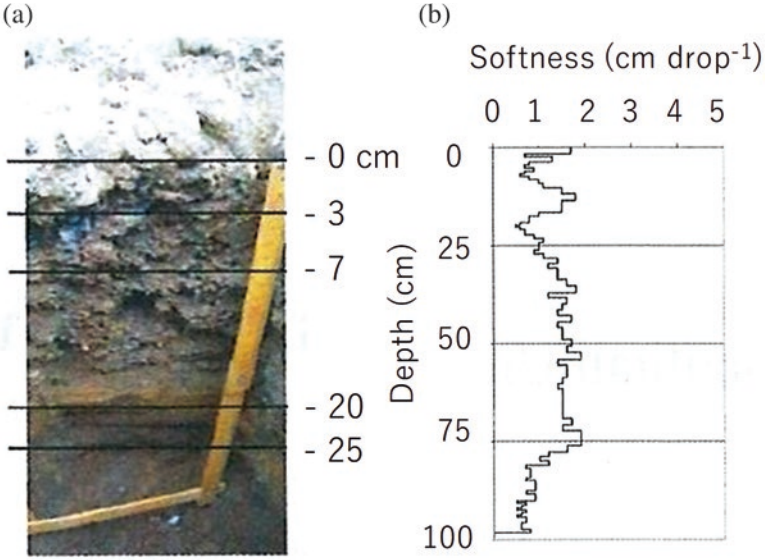

Fig. 4.11 (**a**) Soil profile and (**b**) vertical distribution of soil softness (cm/drop) of profile OP-C

Table 4.4 Soil properties at OP-C

Depth (cm)	Horizon	Soil color (moist)	Texture	Compactness (mm)	Three phases of soil (%)			pH (H_2O)	TC	TN
					Solid	Liquid	Gas		(g kg^{-1})	
0–3	A(C)	10YR3/2	LiC	15	38.1	43.9	18.0	7.2	12.0	0.7
3–7	AB(C)	10YR3/1	SL	20	–	–	–	7.0	31.9	2.3
7–20	AC2	10YR3/2	LiC	17	35.2	58.3	6.5	7.0	32.2	2.3
20–25	Bw	10YR4/6	CL	18	25.9	72.3	1.8	6.9	17.5	1.4
25–40	2A	10YR2/3	LiC	19	30.0	61.9	8.1	6.4	48.5	3.8
40–90+	2Bw	10YR4/6	–	–	–	–	–	6.2	25.4	2.1

a part of the Shogun castle, the mansions of Tokugawa Shogunate hereditary daimyo, and the Tayasu and Shimizu families occupied the land until the Household Division was created in 1874.

After World War II, the remains of the Household Division became a national asset, and a student dormitory and government agency buildings were constructed. These two to three story (24,133 m^2) buildings were composed of brick architecture, reinforced concrete (18,426 m^2), wooden mortar (10,620 m^2), and wood (19,046 m^2). There was vacant land for training and a hippodrome in the center of the garden when the Household Division was based there. The park construction project was approved in 1946, and launched in 1961. Construction was completed in 1969, and the park was opened to the public.

About 400 years from the Edo era to the present, three large-scale landscaping projects were performed in the Garden, as documented in existing records. The last

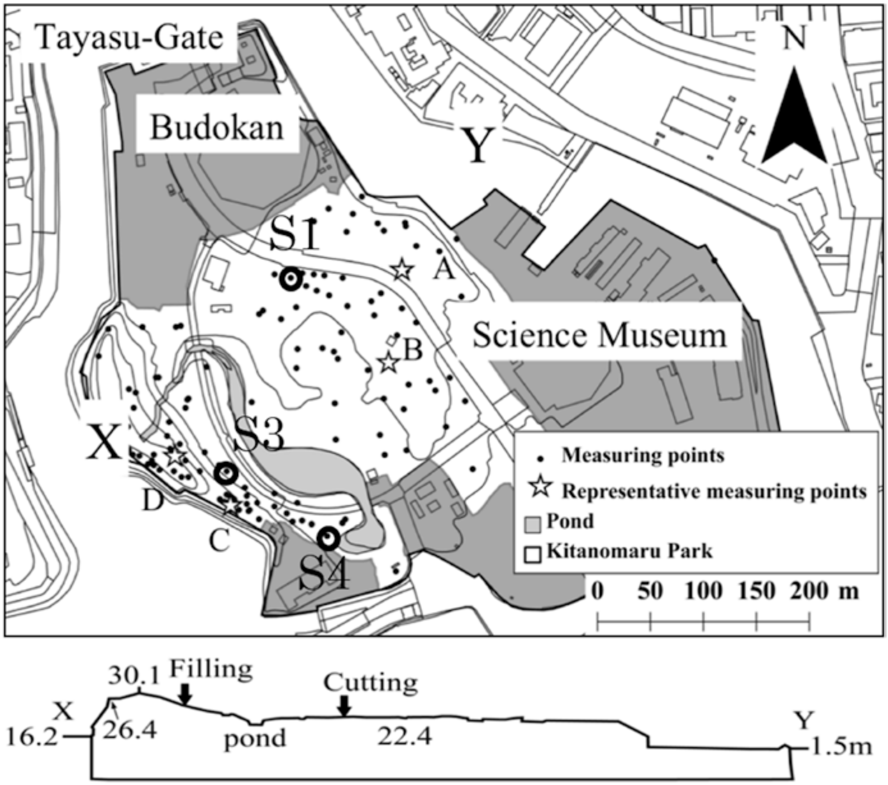

Fig. 4.12 Location map of the measuring points and topographical cross section X–Y in the Kitanomaru Garden

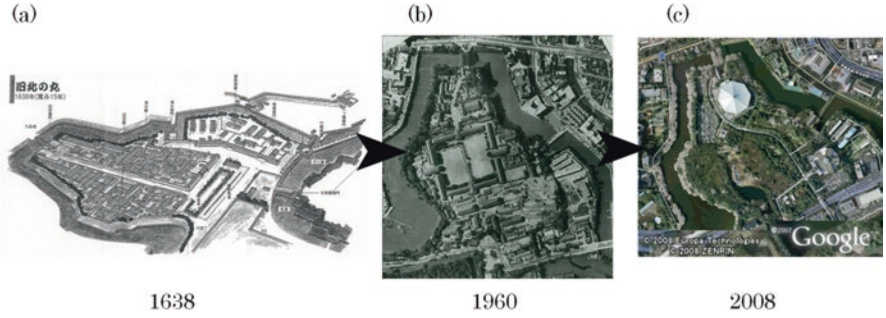

Fig. 4.13 Land use history of Kitanomaru Garden. (**a**) Edo era (1603) through the Meiji period (1868), showing the mansion area for the Tokugawa Shogunate hereditary daimyo, (**b**) Early Meiji period through mid-Showa period (1961), used for housing during World War II, and later became government buildings, private facilities, and houses after the war, (**c**) Mid-Showa period (1969) to Present, opened to public as a National Garden

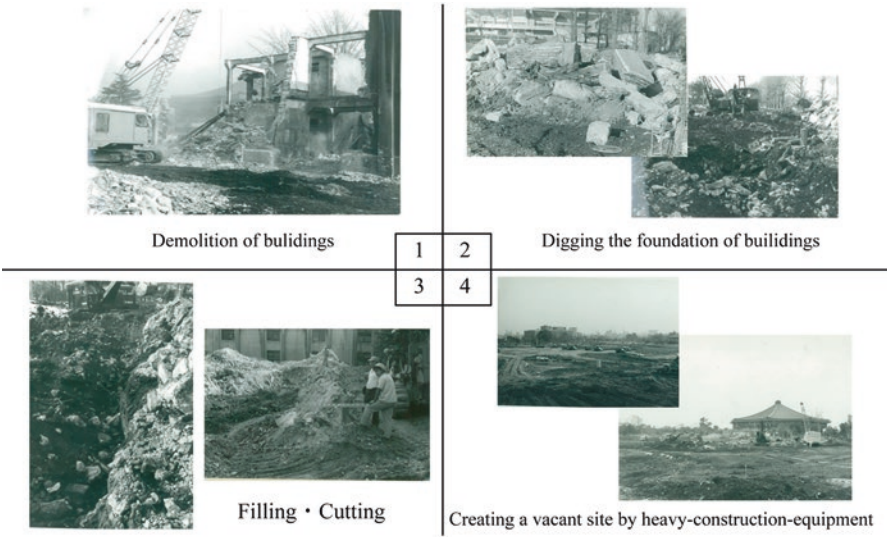

Fig. 4.14 Procedure of land modification, 1961–1969. Land modifications were performed using the following procedure (*1*) demolition of buildings, (*2*) building foundation excavation, (*3*) filling and cutting, (*4*) ground smoothing by heavy construction equipment

landscape project was performed in parts for several years as it took a great deal of time to be executed. Landscaping from 1961 to 1969 was conducted on a large scale using heavy machinery (Fig. 4.14). First, all buildings were removed. Second, cutting and filling were carried out in the newly vacant area. These places were ground leveled, and homogenized. After this step, the roads, garden paths, ponds, and planting zones were constructed. Bricks of the former building and reinforced concrete with deep foundation were dug up to 30 cm and removed. The ground was smoothed to mimic a natural gradient. Concrete debris, pieces of rock, and rebar exposed at the surface were removed. Before filling, the surface was plowed more than 10 cm depth and consolidated. After such works, soil was filled up to 30 cm depth. Fifteen-ton tire rollers and ten-ton bulldozers were used to compact the fill (Ministry of the Environment Government of Japan 2017c; Uoi et al. 2014).

4.4.2 Soil Classification and General Properties

The features of three representative soil profiles (S1, S3, S4) are shown in Fig. 4.15 (Uoi 2014). The constructed soils in Kitanomaru Garden were classified as Urbic Technosols, according to the WRB (IUSS Working Group WRB 2014), that is soils having 20% or more (by volume, by weighted average) artifacts in the upper 100 cm

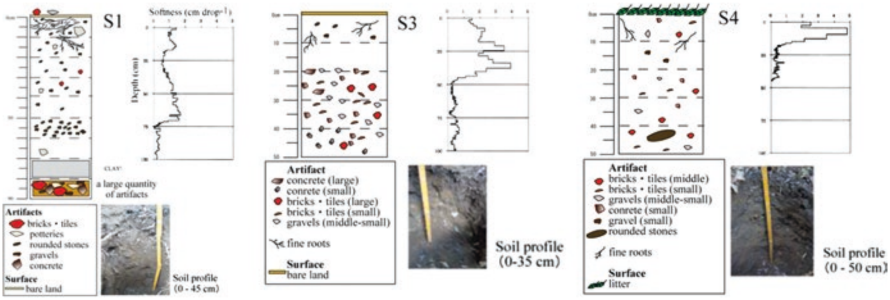

Fig. 4.15 Soil profile descriptions and vertical chart of soil compactness (Softness cm/drop) of survey sites S1, S3, and S4 at Kitanomaru Garden

from the soil surface or to a continuous rock, cemented, or indurated layer, whichever is shallower, and having a layer >20 cm thick within 100 cm of the soil surface, with >20% artifacts containing >35% (by volume) rubble and refuse of human settlements. The studied soils in Kitanomaru Garden had artifacts >20 wt% in the profile within a depth of 50 cm, including bricks, tiles, concrete, or potteries originating from pre-existing buildings during the past 400 years. Moreover, the vertical distribution of soil compactness was characterized by disorders of compaction layers or having a consolidated layer beneath 10 cm depth.

4.4.2.1 Soil Chemical Properties

Samples of S1, S3, and S4 were obtained at 10 cm intervals, up to depths of 30–90 cm depth, depending on the site. Chemical analyses from Uoi et al. (2014) and Uoi (2014) are shown in Table 4.5. Soil pH (H_2O), total carbon content (TC) and cation exchange capacity (CEC) ranged from 6.0–7.8, 9.6–56.9 g kg^{-1}, and 22.8–40.5 cmol$_c$ kg^{-1}, respectively. Overall, the constructed soils in Kitanomaru Park were characterized by higher soil pH, lower TC content, and relatively high CEC compared with natural volcanic ash soils. S1 is located in a forest area where the soil surface was bare because of regular removal of litter. However, the pH (H_2O) value was alkaline in the deeper layers. TC content was highest for layers at 0–10 cm and 60–70 cm. CEC decreased in the 10–20 cm and 40–50 cm layers. S3, also in the forest area, had a bare soil surface because of regular removal of litter. The pH (H_2O) values (6.9–7.3) ranged from weakly acidic to weakly alkaline. TC content decreased towards the lower layers, but showed an inversion at the depth of 40–50 cm.

Table 4.5 Soil properties at Sites S1, S3, and S4. S1 and S3 correspond to Point A and B, respectively, in Fig. 4.12

Site (point)	Depth (cm)	Soil color (moist)	Texture	pH (H_2O)	TC ($g\ kg^{-1}$)	TN ($g\ kg^{-1}$)	CEC ($cmol_c kg^{-1}$)
S1	0–10	7.5YR3/2	SL	6.0	36.0	2.7	26.2
(A)	10–20	7.5YR3/2	SL	6.5	19.3	1.6	24.3
	20–30	7.5YR3/4	SL	7.0	19.0	1.5	25.5
	30–40	7.5YR4/6	SiL	7.1	19.9	1.4	26.8
	40–50	7.5YR5/6	SiL	7.0	18.2	1.3	22.8
	50–60	7.5YR4/4	SL	7.0	20.1	1.5	26.8
	60–70	7.5YR3/1	L	7.8	24.9	1.7	24.6
	70–80	7.5YR4/2	SiL	7.8	11.2	0.7	25.3
	80–90	7.5YR5/6	CL	7.6	9.6	0.7	24.4
S3	0–10	10YR2/2	SL	6.9	48.4	3.5	39.4
(B)	10–20	7.5YR2/3	SL	6.8	41.0	2.8	33.0
	20–30	7.5YR3/3	SiL	7.1	20.6	1.4	26.2
	30–40	7.5YR3/2	SiL	7.5	18.0	1.1	28.3
	40–50	7.5YR2/2	SiL	7.3	35.2	1.7	27.7
S4	0–10	7.5YR3/2	SL	6.2	56.9	4.2	40.5
	10–20	7.5YR3/3	L	6.7	25.5	1.9	26.2
	20–30	7.5YR4/4	L	7.3	14.9	1.1	25.9
	30–40	7.5YR3/4	L	7.5	13.2	1.0	28.2
	40–50	7.5YR4/6	SL	7.7	14.2	1.0	29.3

4.4.2.2 Soil Physical Properties

Vertical soil hardness was measured at 134 points in the Kitanomaru Garden using a cone penetrometer. Then, spatial analysis was carried out using GIS software to analyze the correspondence of the soil physical characteristics with anthropogenic land use, such as history of previous buildings, reclamation methods, and current park management. A non-intrusive layer, defined as one with a penetration depth of less than 50 cm, was counted up to 34 times (25%) among the entire 134 points. The dense-compacted layer was observed at 115 (85.8%) points out of 134. It is not clear whether there is a relationship between compactness by building and the non-intrusive layer or the dense-compacted layer. The total thickness of the dense-compacted layer was thicker at 25–50 cm. At the points of cutting and lawn areas, the total thickness of the dense-compacted layer was particularly thicker, more than 50 cm. In the study area, the dense-compacted layer formed from 0–25 cm depth, and appeared 1–2 times in a soil profile. In addition, the total thickness of the dense-compacted layer became 25–50 cm, and occupied more than half entire soil profile. Furthermore, the frequency of appearance of dense-compacted layers was less than two at points in the vacant land surrounded by buildings in the past. The formation of non-intrusive layer versus dense-compacted layer of soils revealed a spatial correlation with land use history and land grading (Fig. 4.16).

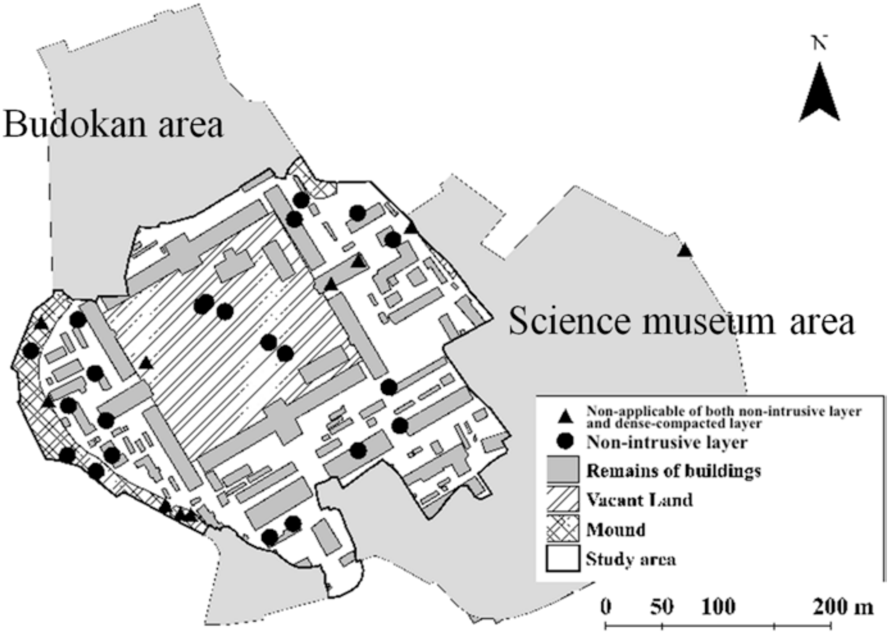

Fig. 4.16 Spatial correspondence of the physical properties of the Kitanomaru Garden soils with past land use before 1961, including locations of building remains, vacant land, and a mound. Solid circle (●) and solid triangle(▲)represent the location of the non-intrusive layer counted up to 34 times (25%) among the entire 134 points surveyed, and the location of the absence of non-intrusive layer or dense-compacted layer, respectively. (Revised from Uoi et al. 2014)

4.5 Conclusion

Soil properties obtained by soil surveys and chemical and physical analyses provide records of vegetation succession and land use history in urban parks. Vertical distribution of organic carbon stable isotope ratios document a vegetation change from C4 to C3 plants by forest regeneration. Amorphous Al and Fe also reflect vertical leaching with dissolved organic matter from the forest floor. These processes have been occurring since the construction of earthworks five centuries ago. Discoloration of black soil was also confirmed to accompany forest regeneration. The process of construction of urban parks can be identified by frequent changes in physical properties such as soil softness and distribution of artifacts. Anthropogenic impacts are recognized in drastic changes between soil layers as a sign of artificial cut and banking, and irregular distribution of organic carbon and related soil properties. Relatively high pH is considered to be an effect of artifacts buried in subsoils. A precise survey of spatial distribution of soil compaction, known as one of the representative characteristics of anthropogenic soils in an urban area, revealed a significant correspondence of the appearances of non-intrusive and dense-compacted layers with land use history and land grading.

References

IUSS Working Group WRB (2014) World reference base for soil resources 2014. International soil classification system for naming soils and creating legends for soil maps, World soil resources reports no. 106. FAO, Rome

Kaneko S, Tanaka N, Takahashi M (1991) The natural soils of the Meiji shrine forest in Tokyo. Jpn J For Environ 33:92–98 (in Japanese with English summary)

Kawai N, Murata T, Watanabe M, Tanaka H (2015) Influence of historical manmade alterations on soil-forming processes in a former imperial estate (Shirogane-goryouchi), the institute for nature study: development of a soil evaluation technique and importance of inventory construction for urban green areas. Soil Sci Plant Nutr 61:55–69

Ministry of the Environment Government of Japan (2017a) Annual report on environmental statistics. http://www.env.go.jp/en/statistics/index.html

Ministry of the Environment Government of Japan (2017b) Shinjuku Gyoen National Garden, Ministry of the Environment. http://www.env.go.jp/garden/shinjukugyoen/english/index.html

Ministry of the Environment Government of Japan (2017c) Kokyo Gaien National Garden, Ministry of the Environment. https://www.env.go.jp/garden/kokyogaien/english/index.html

O'Leary MH (1995) Environmental effects on carbon isotope fractionation in terrestrial plants. In: Wada E, Yoneyama T, Minagawa M, Ando T, Fry BD (eds) Stable isotopes in the biosphere. Kyoto University Press, Tokyo, pp 78–91

Okuda S (2001) Vegetation map of the institute for nature study. Rept Inst Nat Stud 33:71–79 (in Japanese)

Research Committee of the Japanese Institute of Landscape Architecture (2000) Ground maintenance manual in landscape planting. J Jpn Inst Landscape Architec 63:224–241 (in Japanese)

Sakagami K (1990) Kurobokudo. In: Asami S (ed) Soil geography. Kokon-shoin, Tokyo, pp 186–194 (in Japanese)

Tokyo Metropolitan Government (1997) Fundamental land classification survey "West-South part of Tokyo" scale 1:50,000 map. Tokyo Metropolis, Tokyo (in Japanese)

Uoi N (2014) A study on soil classification and evaluation based on vertical soil compaction for urban green spaces. Doctoral dissertation of Tokyo Metropolitan University

Uoi N, Kawahigashi M, Ono M, Murata T, Watanabe M (2013) Estimation of soil carbon storage in Shinjyuku Gyoen national garden based on land use history and soil compactness profiles. Geogr Rep Tokyo Metrop Univ 48:13–24

Uoi N, Watanabe M, Murata T (2014) Relation between vertical soil compaction and land use history in urban green space. – a case study in Kitanomaru Garden, Kokyo Gaien national garden. J Jpn Soc Reveget Tech 39:412–421 (in Japanese with English abstract)

Yoneyama T, Nakanishi Y, Morita A, Liyanage BC (2001) δ13C values of organic carbon in cropland and forest soils in Japan. Soil Sci Plant Nutr 47:17–26. https://doi.org/10.1080/00380768.2001.10408364

Chapter 5
Soils on Newly-Constructed Coastal Berms for Reforestation of Coastal Forests Damaged by the 2011 Mega-Tsunami

Kenji Ono and Akihiro Imaya

Abstract The mega-tsunami following the Great Eastern Japan Earthquake of March 2011 greatly damaged coastal forests along the Pacific Ocean coastline from the Aomori to Chiba Prefectures. According to reports on tsunami-damaged forests, groundwater levels in areas where trees were uprooted were less than ca. 1 m below the surface, which implies that the vertical root depths of most uprooted trees were too shallow to resist the tsunami. Increase of effective soil depths is required for planting trees on berms to allow the development of deeper root systems when reconstructing the coastal forests. To prevent further damage in the affected area, it is necessary to deepen our understanding in regard to which physical characteristics of soils are affected by constructing berms. Soils in the surveyed berms located along the Pacific coast in the Miyagi Prefecture have characteristics of high density and low water permeability, due to the use of heavy machines to construct the berms. These soils can be classified as Linic Spolic Technosol according to the world reference base for soil resources 2014 (WRB 2014; IUSS Working Group WRB. World Reference Base for Soil Resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps. World soil resources reports no. 106. FAO, Rome (2015)) mainly due to both the existence of quite low permeability horizons and the high content of artefacts. Soils consisting of relatively high permeability horizons can be classified as Spolic Technosol (IUSS Working Group WRB, World reference base for soil resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps, World soil resources reports no. 106. FAO, Rome, 2015) due to the high content of artefacts. Tillage after berm construction can effectively eliminate the compacted soil layer and can induce high water permeability in berms. Most of soils have no structure containing gravels and boulders in some soil profiles. Soils with

---

K. Ono (✉)
Tohoku Research Center, Forestry and Forest Products Research Institute, Morioka, Japan
e-mail: don@ffpri.affrc.go.jp

A. Imaya
Japan International Research Center for Agricultural Sciences, Tsukuba, Japan
e-mail: imaya@affrc.go.jp

M. Watanabe, M. Kawahigashi (eds.), *Anthropogenic Soils in Japan*,
International Perspectives in Geography 9,
https://doi.org/10.1007/978-981-13-1753-8_5

weak sub-angular blocky structure have been observed only at surface horizons. Tillage after the berm construction is the only way to enhance water permeability and vertical root extension.

Keywords Berm · Black pine · Soil compaction · Water permeability · Ground water level

5.1 Introduction

The mega-tsunami following the Great East Japan Earthquake of March 2011 greatly damaged coastal forests along the Pacific Ocean coastline from the Aomori to Chiba Prefectures (Forestry Agency of Japan (FAJ) 2013). The total extent of tsunami-hit forests covered ca. 140 km of coastal areas (FAJ 2013). Destruction of conservation facilities such as seawalls and breakwaters, and subsidence and washout of coastal forest lands occurred across the tsunami-hit areas. Many trees were also heavily damaged. Observations in damaged coastal forests found that some trees were wholly or partially uprooted while others sustained damage such as stem breakage (Sakamoto 2012; Nakamura et al. 2012; Hoshino 2012). According to the results of reports on tsunami-damaged forests, groundwater levels in the areas where trees were uprooted were less than ca. 1 m below the surface, which implies that the vertical root depths of most uprooted trees were too shallow to resist the tsunami (Tamura 2012; Watanabe et al. 2014). It has been found that coastal forests helped to reduce the damage from the tsunami to some extent by mitigating the tsunami energy, preventing the inflow of drifting materials and delaying its arrival (Noguchi et al. 2012; Sakamoto 2012). The Ad Hoc Committee on Regeneration of Coastal Disaster Prevention Forests related to the Great East Japan Earthquake, which was established by the FAJ in 2011, suggested the necessity of planting trees in berms to increase effective soil depths and allow the development of deeper root systems when reconstructing the coastal forests (Committee on Regeneration of Coastal Disaster Prevention Forests related to the Great East Japan Earthquake 2012). In accordance with this suggestion, the FAJ has been building berms along the coast in the damaged areas since 2012 (FAJ 2015). These berms use sandy soil materials brought from adjacent hills as a growth medium for the seedlings of domestic tree species. However, soil surfaces in these growth mediums are often compacted by bulldozing and other heavy machinery, leaving the soil susceptible to submersion (Ito 2015; Ohta 2015; The Asahi Shinbun Company 2015). The submersion of soils in water may interfere with the restoration of coastal forests (Ito 2015). It is necessary to develop a deeper understanding of which physical characteristics of soils are affected by building berms because of the important role that will be played by restored coastal forests in future disaster prevention in the tsunami-damaged areas. A summary of the soil profiles and general observations in the restored coastal forests along the north-east Pacific coastline are shown below.

5.2 Matsu-Bayashi National Forest District (Arahama Area)

5.2.1 Geological Information on Constructed Soil Materials

Matsu-Bayashi National Forest District (Arahama area), located in the northern area of Sendai Bay, is one of the tsunami-hit forests along the northeast Pacific coastline (Figs. 5.1 and 5.2). Here, berms have been created from sandy soil and/or loamy sand brought from adjacent hills to the north of Sendai City, and seedlings of domestic tree species have been planted onto these. The geological origin of the berm soil materials is unconsolidated sediment from the Miocene and Pliocene Epochs (Economic Planning Agency 1972a). Some berms have made partial use of recycled materials from disaster debris in their foundation layers. The recovery works in the damaged coastal disaster-prevention forests started in 2011, with a ten-year completion target (FAJ 2016). The berm, completed in March 2013, has a soil fill layer at least 2.4 m above groundwater level to ensure an effective soil layer in which planted trees could develop deep vertical roots. The soil surface was covered with wood chips made from dead black pine (*Pinus thunbergii*) timber damaged by the tsunami to stabilize the sandy soil and prevent wind erosion. Planting of Japanese black pine in the present site was completed in May 2013.

5.2.2 Soil Description and Physico-chemical Properties

Berm material: Marine and non-marine sandy soils of Pliocene to Miocene age, brought from adjacent hills to the north of Sendai City. These were used as a man-made growth medium for all C horizons, which were mainly composed of unweathered or very weakly weathered parent materials, except for 2C horizons

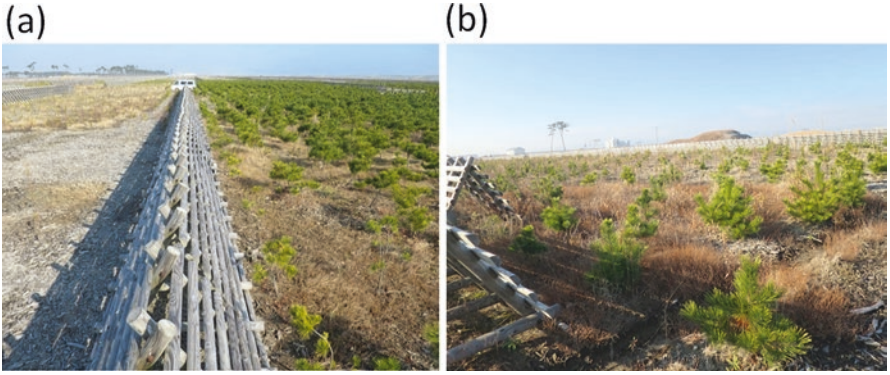

Fig. 5.1 Overview of the Matsu-Bayashi National Forest District, photographed in December 2016. Photograph (**a**) faces north and (**b**) faces south

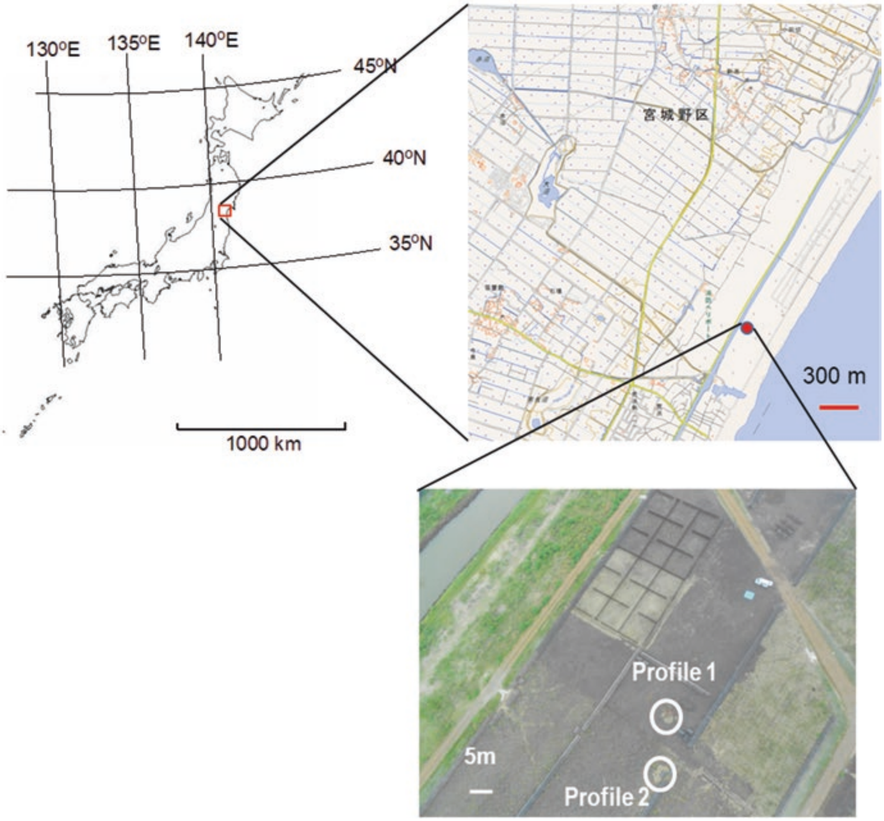

Fig. 5.2 Location of the survey points (white open circles) in Matsu-Bayashi National Forest District, Sendai City, Miyagi Prefecture. The terrain map was obtained from the GSI website. (Geospatial Information Authority of Japan 2017)

Location: Arahama, Wakabasyashi, Sendai City, Miyagi Prefecture (38°13′29″ N, 140°59′16″ E)
Elevation: T.P. 4 m above sea level (ASL)
Topography: Top of the berm built on the back shore at ca. 250 m from shoreline
Soil classification: Immature Soil (Forest Soil Division 1976), Linic Spolic Technosol according to the WRB 2014 (IUSS Working Group WRB 2015) Vegetation: recently planted black pine (*Pinus thunbergii*) seedlings

5.2.2.1 Description of Soil Profile 1 (Survey Date: April 28, 2014): Fig. 5.3

L horizon: 10 to 20 cm thickness of wood chips
C1: 0 to 8 cm, dull yellowish brown (10YR 4/3), loamy sand, moist, few medium rounded weathered gravel, moderate platy structure, very friable, compactness of

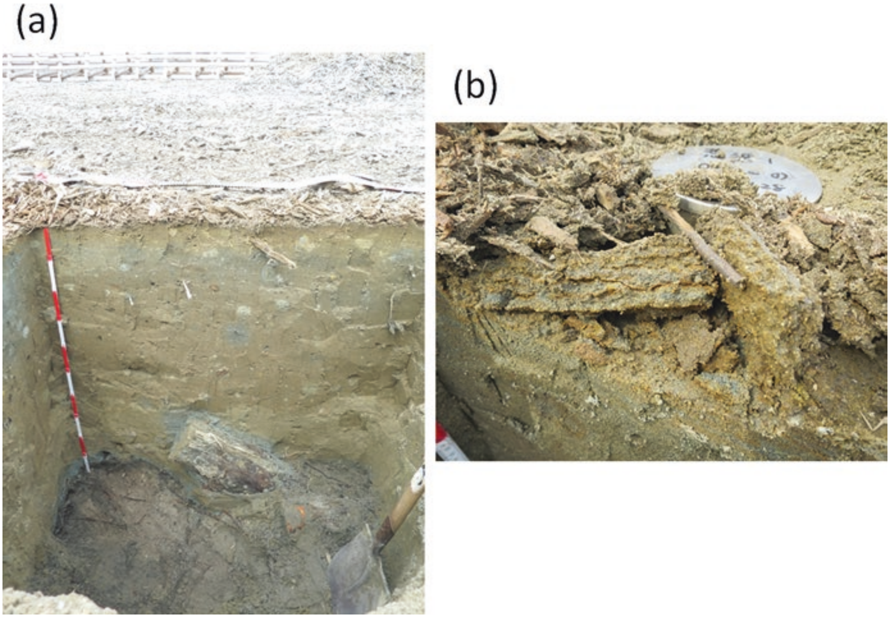

Fig. 5.3 (**a**) Photograph of soil profile 1 from newly constructed berm for planting black pine seedlings in April 2013 to restore the coastal disaster prevention forest, and (**b**) Photograph of iron cementation of topsoil on the surface of the cracks between platy structures created by machinery compaction. Profile depth is 120 cm

15.4*, interstitial voids, broken platy weakly cemented iron, none living roots, gradual irregular boundary,

C2: 8 to 25 cm, dark olive gray (2.5GY 4/1), partly strong gleying and partly weak gleying (See Fig. 5.3a), loamy sand, moist, common medium rounded weathered gravel, massive structure, friable, compactness of 23.8*, none voids, none living roots, gradual irregular boundary,

C3: 25 to 60 cm, brown (10YR 4/4), loamy sand, moist, very few medium rounded weathered gravel, massive structure, friable, compactness of 17.5*, interstitial voids, none living roots, gradual irregular boundary,

C4: 60 to 93 cm, olive brown (2.5Y 4/4), loamy sand, moist, none gravel, massive structure, friable, compactness of 20.2*, interstitial voids, none living roots, abrupt irregular boundary,

C5: 93 to 98 cm, dark olive gray (5GY 4/1), loamy sand, moist, none gravel, no structure, friable, compactness of 16.2*, interstitial voids, none living roots, few buried dead woody timbers, roots, or stumps damaged by huge tsunamis, abrupt irregular boundary,

2A: 98 to 100 cm, black (7.5YR 1.7/1), loam, moist, none gravel, no structure, friable, compactness of 15.2*, interstitial voids, none living roots, few buried dead woody timbers, roots, or stumps damaged by huge tsunamis, abrupt irregular boundary, 2C: 100 to 120+ cm, dark grayish yellow (2.5Y 5/2), sand, moist-dry, none gravel, no structure, loose, compactness of 7.4*, interstitial voids, none living roots, few buried dead woody roots or stumps damaged by huge tsunamis.

*: Compactness (Unit: mm) means the averages of five measured values of Yamanaka's soil compactness tester.

5.2.2.2 Description of Soil Profile 2 (Survey Date: May 8, 2014): Fig. 5.4

No wood chip layer (No L horizon)

C1: 0 to 4 cm, dull brown (7.5YR 5/4), loamy sand, dry, none gravel, massive structure, very friable, compactness of 5.0*, interstitial voids, none roots, abrupt smooth boundary,

C2: 4 to 10 cm, dull reddish brown (5YR 5/4), loamy sand, dry, none gravel, massive structure, very friable, compactness of 16.9*, interstitial voids, none roots, diffuse smooth boundary,

C3: 10 to 40 cm, brown (10YR 4/4), loamy sand, dry-moist, few coarse rounded strongly weathered gravel, massive structure, very friable, compactness of 26.2*, interstitial voids, none living roots, diffuse smooth boundary,

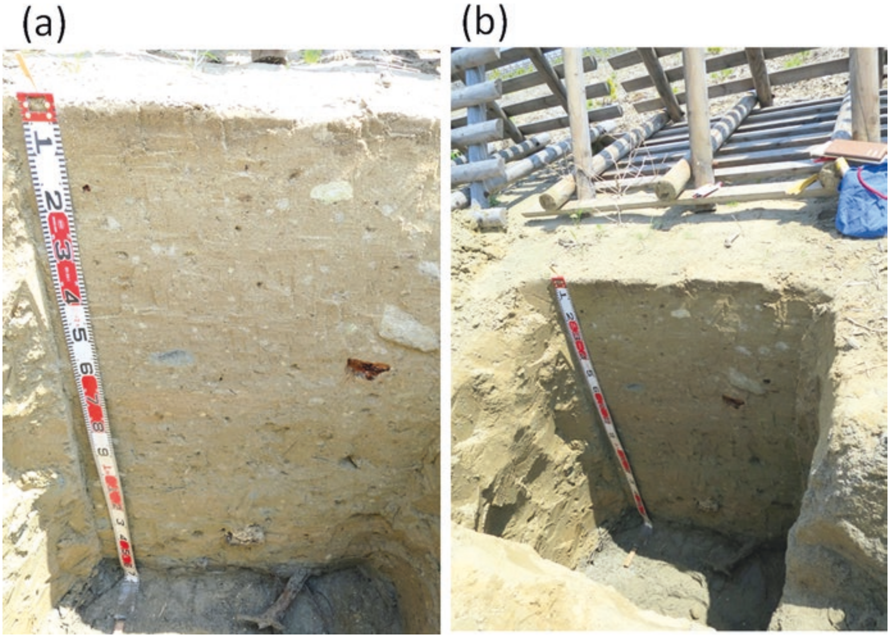

Fig. 5.4 Photographs (**a** and **b**) of soil profile 2 from newly constructed berm planted with black pine seedling on May 2013 to restore the coastal disaster prevention forest. No wood chips were spread around the hedgerow. Profile depth is 175 cm

C4: 40 to 60 cm, brown (10YR 4/4), few mottling of gley (dark olive gray 2.5GY4/1), loamy sand, dry-moist, few coarse rounded strongly weathered gravel and few rounded strongly weathered stones, and very, few sub-rounded weathered gravel, massive structure, very friable, compactness of 26.2*, interstitial voids, none living roots, diffuse smooth boundary,

C5: 60 to 80 cm, brown (10YR 4/4), few mottling of gley (dark olive gray 2.5GY4/1), loamy sand, dry-moist, few coarse rounded strongly weathered gravel and few rounded strongly weathered stones, and very few sub-rounded weathered gravel, no structure, very friable, compactness of 22.4*, interstitial voids, none living roots, diffuse smooth boundary,

C6: 80 to 100 cm, olive (5Y 5/4), few mottling of gley (gray 10Y4/1), loamy sand, moist, very few coarse rounded weathered gravel, no structure, very friable, compactness of 18.2*, interstitial voids, none living roots, gradual smooth boundary,

C7: 100 to 130 cm, yellowish brown (2.5Y 5/4), few mottling of gley (gray 10Y4/1), loamy sand, moist, no gravel, no structure, very friable, compactness of 18.0*, interstitial voids, none living roots, gradual smooth boundary,

C8: 130 to 158 cm, dark olive (5Y 4/4), loamy sand, moist, very few rounded weathered stones, no structure, very friable, compactness of 13.8*, interstitial voids, none living roots, abrupt smooth boundary,

2C: 158 to 175+ cm, grayish yellow (2.5Y 6/2), sand, moist, none gravel, no structure, loose, compactness of 10.4*, interstitial voids, none living roots, few buried dead woody roots and stumps damaged by tsunamis.

*: Compactness (Unit: mm) means the average of five measured values of Yamanaka's soil compactness tester.

5.2.2.3 Soil Physico-chemical Properties

General physical properties of soil profiles 1 and 2 are shown in Table 5.1. Soils in berms in the reforestation area in Arahama are generally hard with high density and low water permeability, especially at the C2 and C3 horizons in both profiles 1 and 2, due to compaction of soils by heavy machinery used to build up the berms. There is no structure or massive structure in either soil profile. Profile 1 has a gley layer directly under the topsoil, which is caused by a reduction of Fe^{3+} with mineralization of dissolved organic matter originating from wood chips under anaerobic conditions. Both soil profiles are classified as Immature Soil according to the Classification of Forest Soils in Japan (Forest Soil Division 1976). Also these soils can be classified as Linic Spolic Technosol, according to the WRB 2014 (IUSS Working Group WRB 2015), mainly due to both the existence of the quite low permeability horizons, especially, C2-C3 or C3 horizons in the respective profiles 1 and 2, and the high content of artefacts (i.e., usage of a different source of land-filling soil material obtained from adjacent hills with the natural soils in 2A and 2C horizons of the original coastal forest for constructing C horizons of the berms except for 2C horizons) in both profiles. Soils in both profiles are mostly composed of sand

Table 5.1 Physical characteristics of the berm soils in Matsu-Bayashi National Forest District (Arahama area)

Sample ID	Depth (cm)	Permeability[a] 5 min (ml/min)	15 min	Average	Hydraulic conductivity (mm/h)	Bulk density (Mg/m³)	Soil pore composition[b] Total (vol%)	Fine (vol%)	Coarse (vol%)	Three phase distribution Solid (vol%)	Liquid (vol%)	Gas (vol%)	Maximum water holding capacity (vol%)	Minimum air capacity[c] (vol%)
Profile 1														
C1	0–8	24.6	22.5	23.5	113.0	1.62	37.9	30.5	7.4	62.1	32.3	5.6	39.4	–1.5
C2 (weak gleying)[d]	8–25	36.7	32.8	34.7	166.6	1.60	40.1	30.3	9.8	59.9	32.6	7.5	40.5	–0.3
C2 (strong gleying)[d]	8–25	3.4	3.0	3.2	15.2	1.62	39.9	31.2	8.7	60.1	31.5	8.4	40.8	–0.9
C3 upper[e]	25–40	5.0	4.6	4.8	23.0	1.50	44.3	27.1	17.2	55.7	32.0	12.3	38.7	5.6
C3 lower[e]	40–60	35.4	30.8	33.1	158.9	1.49	44.4	28.2	16.2	55.6	32.8	11.6	47.2	–2.8
C4	60–93	51.8	46.9	49.4	237.1	1.37	49.0	28.4	20.6	51.0	30.2	18.8	49.3	–0.3
C5	93–98	n.d.[f]	n.d.[f]	n.d.[f]	n.d.[f]	1.36	49.5	n.d.[f]	n.d.[f]	50.5	7.5	41.9	n.d.[f]	n.d.[f]
2C	100–120+	n.d.[f]	n.d.[f]	n.d.[f]	n.d.[f]	1.37	48.5	n.d.[f]	n.d.[f]	51.5	9.6	38.8	n.d.[f]	n.d.[f]
Profile 2														
C1	0–4	17.0	15.8	16.4	78.7	1.51	42.6	19.9	22.6	57.4	22.3	20.3	41.1	1.5
C2	4–10	5.2	4.9	5.0	24.2	1.53	42.2	20.9	21.3	57.8	12.7	29.6	37.4	4.9
C3 upper[e]	10–25	7.6	6.2	6.9	33.1	1.62	38.8	26.6	12.2	61.2	8.3	30.5	40.4	–1.5
C3 lower[e]	25–40	2.6	2.4	2.5	12.0	1.62	38.8	27.6	11.2	61.2	8.5	30.3	40.8	–2.0
C4	40–60	6.6	5.9	6.3	30.0	1.59	39.9	25.6	14.3	60.1	8.7	31.1	41.8	–2.0
C5	60–80	5.2	4.6	4.9	23.5	1.56	41.0	27.6	13.4	59.0	9.3	31.8	45.9	–4.9

C6	80–100	9.0	9.9	9.5	45.4	1.43	46.1	25.5	20.6	53.9	11.6	34.5	42.9	3.2
C7	100–130	9.9	9.1	9.5	45.4	1.45	45.3	25.4	19.9	54.7	10.0	35.3	45.1	0.2
C8	130–150	16.4	15.1	15.7	75.4	1.45	45.2	25.4	19.9	54.8	11.5	33.7	47.5	–2.3
2C	158–175+	80.0	73.9	77.0	369.4	1.53	41.8	5.7	36.1	58.2	25.3	16.5	38.4	3.4

[a] Permeability data show the respective values measured after 5 and 15 min from the experiment start and the average values for both

[b] Porosity data show the measured values according to the porous plate method (Kawada and Kojima 1976)

[c] The negative value of the minimum air capacity is caused by the swelling of soil volume with water saturation treatment

[d] C2 horizon in profile 1 has both strong and weak gleying spots, so these areas are sampled and analyzed separately

[e] C3 horizons in both profiles 1 and 2 are thick horizons, so the soils are sampled separately from the top and bottom of each C3 horizon

[f] not determined

(Table 5.2). The depths of the 2C horizons differ between the two profiles, caused by the difference in original ground level, but they are both the same soils from the original ground layer of the coastal forest before the tsunami. Volume percentages of the solid phases in the berm soils range from approximately 50–60 vol% throughout the soil profiles. Total porosity of the soils tends to be ca. 40 vol%, and porosity is lower in upper horizons, increasing to more than 45 vol% in the lower horizons. The volume percentage of coarse pores in the topsoil in profile 1 at less than 10 vol% is quite low. The coefficient of permeability is also quite low, 15 mm h^{-1} at the gley layer of the C2 horizon in profile 1 and 12 mm h^{-1} at upper C3 horizon in profile 2. This implies that these layers are strongly affected by compaction of soils by heavy machinery used to build the berms.

The general chemical properties in soil profiles 1 and 2 are shown in Table 5.3. Soil pH (H_2O) shows values from weakly acidic to neutral in the topsoil and from neutral to alkaline in the lower soils. Electric conductivity (EC) is generally low, less than 10 mS m^{-1} throughout the soils in both profiles. Total carbon (TC) and nitrogen (TN) contents in the soils are also low in both profiles. The capacities of exchangeable cations (CEC) in the berm soils in both profiles range from 12.7 to 16.6 $cmol_c$ kg^{-1}, although those in the soils of the 2C horizons, which represent the

Table 5.2 Particle size distribution of the berm soils in the Matsu-Bayashi National Forest District (Arahama area)

Sample ID	Depth (cm)	Coarse sand	Fine sand	Silt	Clay
		(%)			
Profile 1					
C1	0–8	71.0	18.6	4.7	5.7
C2 (weak gleying)[a]	8–25	66.3	20.3	7.7	5.8
C2 (strong gleying)[a]	8–25	69.2	20.6	3.7	6.5
C3 upper[b]	25–40	69.0	20.1	3.9	6.9
C3 lower[b]	40–60	66.1	22.1	3.9	7.9
C4	60–93	63.2	27.2	4.8	4.8
C5	93–98	68.5	26.5	3.0	2.0
2C	100–120+	88.2	9.9	0.9	0.9
Profile 2					
C1	0–4	70.9	18.3	6.9	3.9
C2	4–10	67.2	21.3	3.9	7.7
C3	10–40	72.2	19.9	1.0	6.9
C4–C5	40–80	79.0	13.2	5.8	1.9
C6	80–100	76.0	16.1	6.9	1.0
C7	100–130	77.4	16.7	2.0	3.9
C8	130–150	73.4	14.7	5.9	5.9
2C	158–175+	94.7	4.3	0.0	1.0

[a] Soil samples of the C2 horizon in profile 1 are observed to partly present both the strong and weak gleying spots, so separate samples from each area were taken

[b] The soils of the C3 horizon in profile 1 are sampled from both the top and bottom of the C3 horizons

Table 5.3 Chemical characteristics of the berm soils in Matsu-Bayashi National Forest District (Arahama area)

Sample ID	Depth (cm)	EC (mS m^{-1})	pH (H_2O)	TC (g/kg)	TN	C/N	CEC (cmol$_c$ kg^{-1})	Exchangeable cation (cmol$_c$ kg^{-1})				Water-soluble cation (cmol$_c$ kg^{-1})			
								Ca^{2+}	Mg^{2+}	Na^+	K^+	Ca^{2+}	Mg^{2+}	Na^+	K^+
Profile 1															
C1	0–8	1.60	6.55	2.77	0.09	31.2	13.8	5.35	2.70	0.40	0.55	0.005	0.016	0.066	0.021
C2 (weak gleying)[a]	8–25	2.32	6.52	1.52	0.07	21.8	16.6	5.61	2.71	0.52	0.35	0.006	0.003	0.072	0.015
C2 (strong gleying)[a]	8–25	2.16	7.00	1.72	0.07	24.3	13.9	5.12	2.51	0.76	0.35	0.005	0.002	0.081	0.010
C3 upper[b]	25–40	7.52	5.99	1.47	0.10	14.4	13.0	5.40	2.63	0.30	0.33	0.069	0.023	0.061	0.033
C3 lower[b]	40–60	4.50	5.84	0.25	0.16	1.6	13.8	4.96	2.46	0.25	0.34	0.054	0.018	0.057	0.030
C4	60–93	3.52	7.06	0.87	0.12	7.2	13.1	6.59	1.73	0.29	0.48	0.032	0.006	0.047	0.029
C5	93–98	6.66	8.05	3.07	0.08	40.5	14.2	7.63	2.06	0.55	0.54	0.045	0.009	0.108	0.042
2C	100–120+	1.95	6.88	1.22	0.10	12.0	6.3	0.23	0.51	0.43	0.24	0.000	0.000	0.064	0.005
Profile 2															
C1	0–4	4.24	6.51	2.21	0.14	15.8	13.8	5.56	2.34	0.41	0.37	0.020	0.006	0.072	0.022
C2	4–10	2.67	7.00	0.50	0.14	3.5	14.1	6.69	2.57	0.43	0.36	0.006	0.002	0.054	0.017
C3	10–40	3.19	7.08	0.24	0.13	1.9	12.7	6.05	2.19	0.30	0.35	0.022	0.006	0.040	0.021
C4–C5	40–80	3.33	7.18	0.37	0.15	2.5	14.9	6.37	2.07	0.21	0.38	0.027	0.006	0.046	0.025
C6	80–100	4.47	7.37	0.31	0.09	3.4	15.0	6.77	2.02	0.30	0.39	0.046	0.010	0.048	0.024
C7	100–130	5.03	7.48	0.32	0.15	2.2	13.5	6.83	2.15	0.20	0.40	0.067	0.015	0.057	0.031
C8	130–150	7.27	7.07	0.31	0.13	2.4	12.8	6.55	0.50	0.23	0.30	0.098	0.024	0.071	0.029
2C	158–175+	1.61	7.22	0.48	0.12	3.9	3.2	0.79	0.44	0.11	0.15	0.010	0.004	0.019	0.012

[a] For C2 horizon in profile 1, the soils were sampled from the strong and weak gleying spots

[b] The soils of C3 layer in profile 1 are sampled from the top and bottom of C3 layers

original ground surface before the tsunami, are 3.2 and 6.3 $\mathrm{cmol_c\ kg^{-1}}$ in both profiles. This is because of lower silt and clay contents in the original soils than those in soils of the constructed berms (Table 5.2). Exchangeable calcium in berm soils forms the largest proportion of the exchangeable cations, followed by magnesium. The exchangeable sodium and potassium contents in berm soils are minor. These results imply that the materials used to build berms did not have any vegetation covering at the source pits.

5.3 Dai National Forest District (Natori Area)

5.3.1 Geological Information and Planted Vegetation

Dai National Forest District (Natori area), located to the east of the Sendai International Airport in Natori and Iwanuma, is also one of the tsunami-hit forests along the northeast Pacific coast (Figs. 5.5 and 5.6). Here the berms have been created from soil materials brought from hills adjacent to the urban areas of Yamamoto and Iwanuma, which lie to the south of Miyagi Prefecture. The geological origin of the berm soil materials is unconsolidated sediment from the Miocene and Pliocene Epochs (Economic Planning Agency 1972a). Berm building was completed in March 2014. The addition of a 2.4 m thickness of soil fill layer above ground water level was applied to allow planted trees to develop deep vertical roots. Before

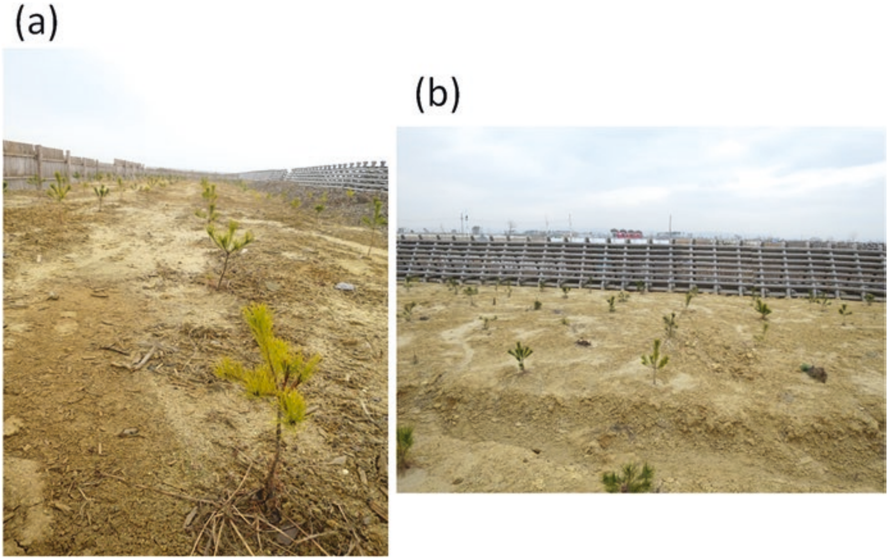

Fig. 5.5 Overview of the Dai National Forest District, photographed in March 2016. Photograph (**a**) faces north and (**b**) faces west

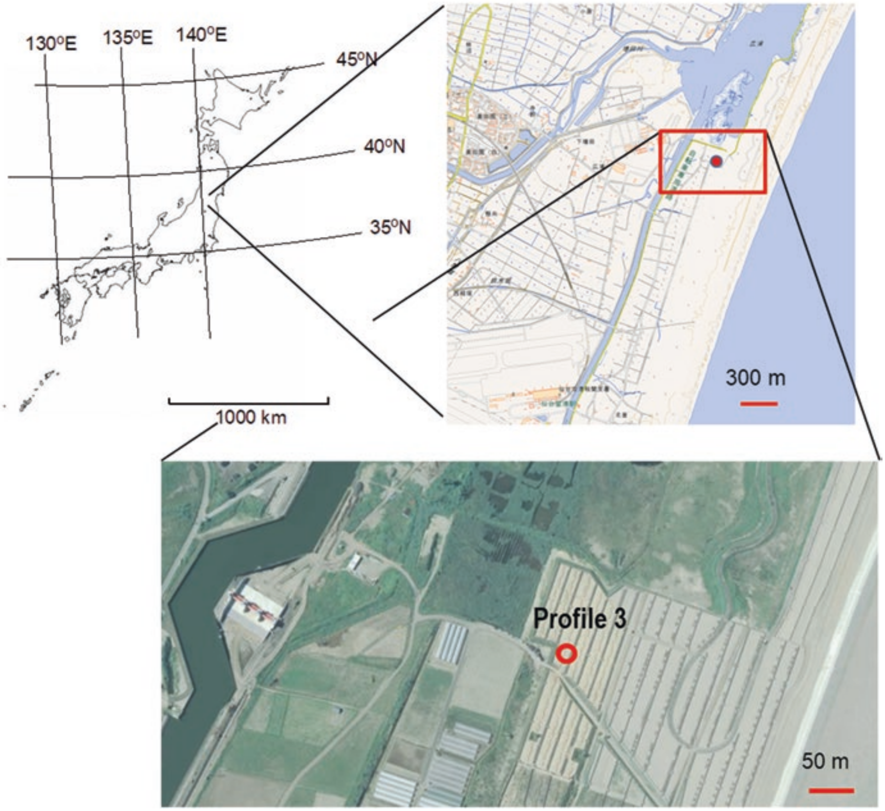

Fig. 5.6 Location of the survey point (red open circle) in Dai National Forest District, Natori City, Miyagi Prefecture. The terrain map and the aerial photograph (photographed in July 2015) was obtained from the GSI website. (Geospatial Information Authority of Japan 2017)

planting, tillage was carried out using an excavator with a skeleton bucket to prevent soil compaction and water stagnation in the berms. Japanese red pine (*Pinus densiflora*) seedlings were planted in June 2015, behind the coastal forest planted with black pine seedlings. Planting of coastal disaster prevention forests over a total of 114 km started in 2015. Citizen participation in the planting and tending of trees as part of the recovery work is being promoted for most sites.

5.3.2 Soil Description and Physical Properties

Berm material: Sandy soils originating from Pliocene to Miocene-aged marine and non-marine sediments brought from adjacent hills at Yamamoto Town and Iwanuma City. These were used for building all C horizons as a man-made growth medium of the coastal forest

Location: Shimo-Masuda, Natori City, Miyagi Pref. (38°9′18″ N, 140°56′49″ E)
Elevation: T.P. 3 m ASL
Topography: Top of the berm built on the back shore at ca. 300 m from shoreline
Soil classification: Immature Soil (Forest Soil Division 1976), Spolic Technosol (FAO 2014)
Vegetation: recently planted Japanese red pine (*Pinus densiflora*) seedlings

5.3.2.1 Description of Soil Profile 3 (Survey Date: July, 9, 2015): Fig. 5.7

No wood chip layer (No L horizon)

C1: 0 to 10 cm, yellowish brown (10YR 5/8), sandy loam, moist, very few medium rounded weathered gravel, very weak blocky structure, loose-very friable, compactness of 10.8*, interstitial voids, none living roots, clear smooth boundary,

C2: 10 to 35 cm, yellowish brown (10YR 5/6), sand-sandy loam (with clods of clay; dull yellowish brown 10YR 4/6), moist, very few medium and coarse rounded weathered gravel, very weak blocky structure, friable, compactness of 20.0* (21.4* in the clay texture part), interstitial voids, none living roots, few charcoal, gradual irregular boundary,

C3: 35 to 65 cm, bright brown-yellowish brown (7.5–10YR 5/6), sandy clay loam, moist, very few medium subrounded weathered gravel, very weak blocky structure, very friable, compactness of 14.4*, interstitial voids, none living roots, clear irregular boundary,

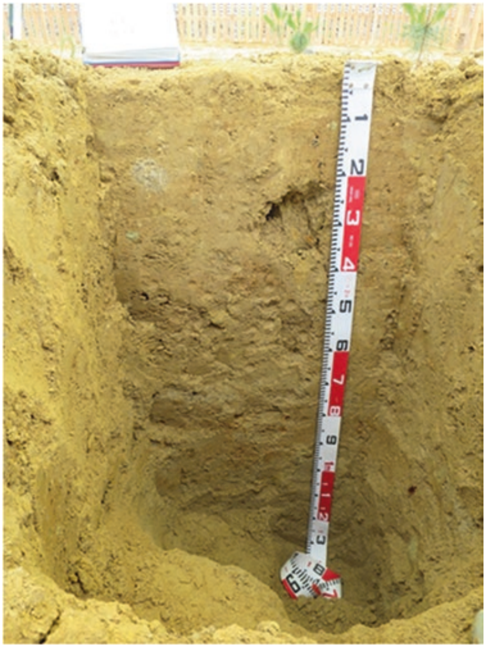

Fig. 5.7 Photo of soil profile 3, a newly constructed berm for planting red pine seedlings, on June 2015 to restore the coastal disaster prevention forest. Clods and cracks that were made by tillage after constructing the berm are observed in this profile. Wood chips were not found spread on the soil surface. Profile depth is 130 cm

C4: 65 to 85 cm, bright brown (7.5YR 5/6), sandy clay loam, moist, very few medium subrounded gravel (dull reddish brown 2.5YR 5/3), no structure, very friable, compactness of 18.0*, interstitial voids, none living roots, gradual irregular boundary,

C5: 85 to 110 cm, bright brown (7.5YR 5/8), clay, moist, none gravel, no structure, very friable, compactness of 16.4*, none voids, none living roots, gradual smooth boundary,

C6: 110 to 130+ cm, bright yellowish brown (10YR 6/6), sand, moist, none gravel, no structure, compactness of 15.6*, none voids, none living roots.

*: Compactness (Unit: mm) means the averages of five measured values of Yamanaka's soil compactness tester.

5.3.2.2 Soil Physical Properties

The general physical properties of soil profile 3 are shown in Tables 5.4 and 5.5. Soils in the berm in the reforestation area in Natori are generally high density, but have better water permeability and are not as hard compared with soil profiles 1 and 2 in Arahama due to tillage by an excavator with a skeleton bucket after construction of the berm. Topsoil has a weak blocky structure in profile 3, although the lower soils have no structure or massive structures. Soil profile 3 is classified as Immature Soil according to the Classification of Forest Soils in Japan (Forest Soil Division 1976). This soil can be classified as Spolic Technosol according to the WRB 2014 (IUSS Working Group WRB 2015), mainly due to the high content of artefacts (i.e., usage of a different sources of land-filling soil material obtained from adjacent hills with the natural soils in the original coastal forest for constructing the berms). The major particle components of soils in profile 3 are coarse sands (approximately 50%). However, the soils in profile 3 have a reasonably high proportion of fine particles such as silt and clay in comparison with those in profiles 1 and 2 (Tables 5.2 and 5.3). The volume percentages of the solid phase in the berm soils range from approximately 50–60 vol% throughout the soil profile. These values are similar to those in the Arahama berms. Total porosity of soils tends to be ca. 40 vol% throughout the soil profile. The volume percentage of coarse pores in horizons with relatively low permeability is low at less than 10 vol%. The coefficient of permeability ranges from 43 to 90 mm h^{-1}. These results indicate that tillage after berm construction can effectively eliminate the compacted soil layer in berms.

5.4 Rikuzen-Takata District (Otomo)

5.4.1 *Background Information on the Planted Forest*

Rikuzen-Takata District, located in the southern part of the Sanriku coast facing the Pacific Ocean, is one of the most famous rias coastlines in Japan (Figs. 5.8 and 5.9). Rikuzen-Takada had an extensive pine-covered area, what is called

Table 5.4 Physical characteristics of the berm soils (Profile 3) in Dai national forest District (Natori area)

Sample ID	Depth (cm)	Permeability[a] 5 min (ml/min)	Permeability[a] 15 min (ml/min)	Permeability[a] Average (ml/min)	Hydraulic conductivity (mm/h)	Bulk density (Mg/m^3)	Soil pore composition[b] Total (vol%)	Soil pore composition[b] Fine (vol%)	Soil pore composition[b] Coarse (vol%)	Three phase distribution Solid (vol%)	Three phase distribution Liquid (vol%)	Three phase distribution Gas (vol%)	Max. WHC (vol%)	Min. air capacity[c] (vol%)	Field moisture (wt%)	Field moisture (vol%)
Profile 3																
C1–1	0–4	18.2	17.2	17.7	85.0	1.47	45.6	25.4	20.1	54.4	25.2	20.4	44.6	1.0	18.2	25.2
C1–2	8–12	9.4	8.4	8.9	42.8	1.65	39.0	29.6	9.4	61.0	31.0	8.0	42.2	–3.2	20.4	31.0
C2–1	18–22	9.7	9.3	9.5	45.6	1.56	42.2	28.1	14.1	57.8	31.5	10.6	41.9	0.2	21.3	31.5
C2–2	28–32	19.7	17.7	18.7	89.8	1.64	39.2	27.6	11.6	60.8	32.2	7.0	41.2	–2.0	21.1	32.2
C3	48–52	16.6	16.6	16.6	79.6	1.49	45.0	26.9	18.1	55.0	33.4	11.6	41.8	3.2	24.2	33.4
C4	68–72	15.9	14.5	15.2	73.0	1.62	40.0	19.5	20.5	60.0	27.2	12.8	39.1	0.8	17.8	27.2
C5	88–92	9	8.7	8.9	42.5	1.72	36.4	28.3	8.0	63.6	32.0	4.4	38.5	–2.1	22.2	32.0

[a] Permeability data shows the respective values measured after 5 and 15 min from experiment start and the average values for both

[b] Porosity data shows the measured values according to the porous plate method (Kawada and Kojima 1976)

[c] Negative value of the minimum air capacity is caused by swelling of soil volume with water saturation treatment

Table 5.5 Particle size distribution of the berm soils in Dai National Forest District (Natori area)

Horizon	Depth (cm)	Coarse sand (%)	Fine sand	Silt	Clay
Profile 3					
C1–1	0–4	49.2	25.4	12.7	12.7
C1–2	8–12	47.4	24.3	13.7	14.7
C2–1	18–22	47.0	27.9	14.0	11.0
C2–2	28–32	45.9	27.6	11.8	14.7
C3	48–52	55.5	19.6	11.9	12.9
C4	68–72	52.2	18.4	11.8	17.7
C5	88–92	60.6	20.3	10.5	8.6

Takada-Matsubara, wvalong the seashore of Hirota Bay. According to a tradition here, there were approximately 70,000 red and black pine trees within 2 km of the Hirota Bay shoreline before the tsunami (City of Rikuzentakata 2017). The mega-tsunami completely wiped out an extensive portion of Takada-Matsubara except for one tree that weathered the tsunami; known as the “Miracle Pine” by local people it is a symbol of their regional rehabilitation. The rehabilitation of Takada-Matsubara also has been conducted according to the advice mentioned above (Committee on Regeneration of Coastal Disaster Prevention Forests related to the Great East Japan Earthquake 2012). To ensure the restoration of the coastal disaster prevention forest in Takada-Matsubara that helped to reduce the damage from the tsunami, an experimental site with a pine-planting berm (size: 30 m × 20 m) was created near the Takada-Matsubara damaged and restoration area by the Japan Greenery Research and Development Center (Hasegawa and Inomata 2015). Here, berms have been constructed from loamy soils with some gravel and rock brought from adjacent hills in Otomo, located to the south of Rikuzen-Takata City, into which seedlings of red and black pine species have been experimentally planted. The geological origin of the berm soil materials is weathered granite from the early Cretaceous Period. The berm was built on a paddy field in April 2015. A soil fill layer, 1 m above the original ground level, was emplaced to allow planted trees to develop deep vertical roots. The following three plots were created at this experimental site; Plot A (Compaction: berm built using machinery), Plot B (Tillage: berm with 50 cm depth tillage excavator treatment after building with machinery), and Plot C (No compaction: berm built without machinery compaction). The summary of plot building methods shown in Fig. 5.10 is a modification of the diagram made by the Japan Greenery Research and Development Center (from the Japan Greenery Research and Development Center website 2017). The planting of red and black pine on each site was conducted at the end of April 2015.

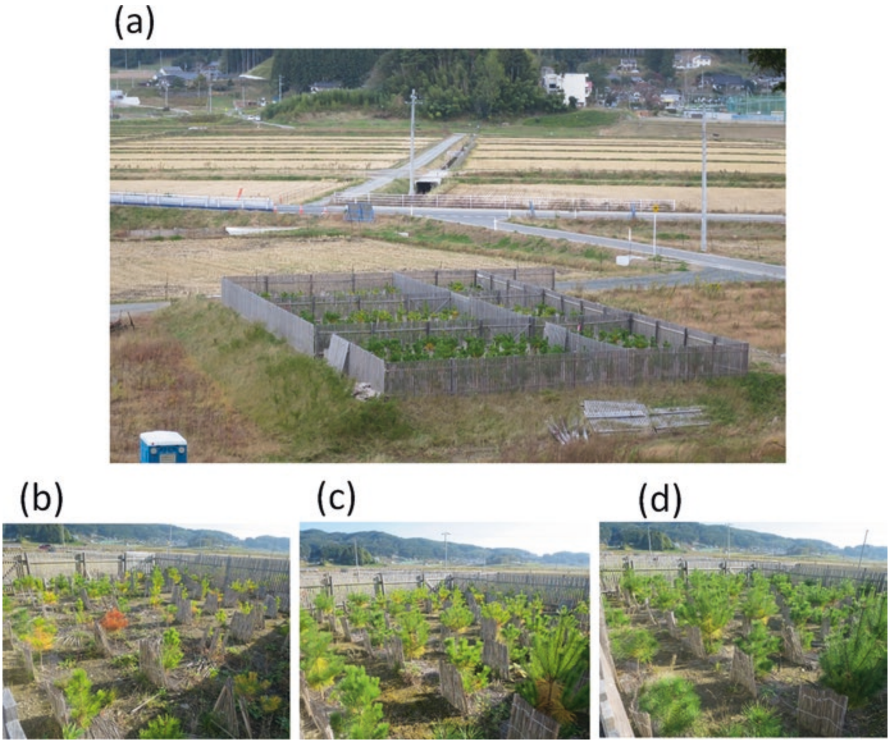

Fig. 5.8 Photographs of the experimental site in Rikuzen-Takata City, Iwate Prefecture, photographed in October 2016: (**a**) Overview, (**b**) Plot A (Compaction), (**c**) B (Tillage), and (**d**) C (No compaction) at the study site

5.4.2 Soil Description and Physical Properties

Berm material: loamy soils with some gravel and rock brought from adjacent hills in Otomo located to the south of Rikuzen-Takata City, originating from weathered granite from the early Cretaceous period (Economic Planning Agency 1972b; Hasegawa and Inomata 2015)

Location: Otomo, Rikuzen-Takata City, Iwate Prefecture (38°39′33″ N, 141°41′32″ E)

Elevation: T.P. 3 m ASL

Topography: Berm built in the tsunami-hit paddy field at ca. 1 km from shoreline

Soil classification: For profiles 4 and 5 from Plot A (Compaction) and B (Tillage), respectively, Immature Soil (Forest Soil Division 1976), Linic Spolic Technosol (FAO 2014), For profile 6 from Plot C (No compaction), Immature Soil (Forest Soil Division 1976), Spolic Technosol (FAO 2014)

Vegetation: 2-year-old Japanese black pine (*Pinus thunbergii*) and Japanese red pine (*P. densiflora*)

Fig. 5.9 Location of the experimental site (red circles) in Rikuzen-Takata City, Iwate Prefecture. The terrain map and the aerial photograph (photographed in May 2015) were obtained from the GSI website. (Geospatial Information Authority of Japan 2017)

5.4.2.1 Description of Soil Profile 4 in Plot A (Compaction) (Survey Date: October 27, 2016): Fig. 5.11

L, F, H horizon: 0 cm in thickness, no litter, few withered grasses,

C1: 0 to 12 cm, dark olive (5Y 4/3), sandy clay loam, dry, few fresh subrounded and angular coarse gravel or few stones, no structure, very friable, compactness of

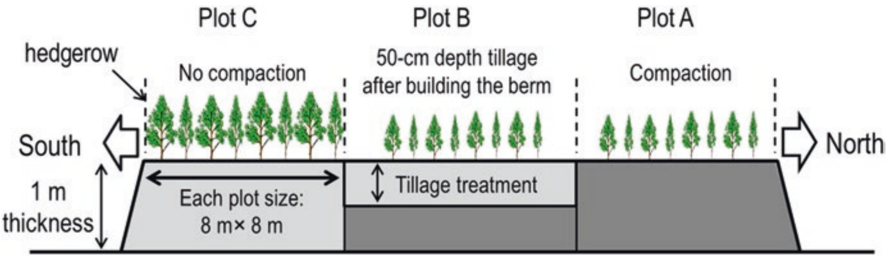

Fig. 5.10 Summary of the experimental site built by the Japan Greenery Research and Development Center in 2015 at Rikuzen-Takata City, Iwate Prefecture (size: 600 m^2, volume of soil fill materials: 562 m^3). This diagram is based on a modified illustration from the Japan Greenery Research and Development Center website (2017)

19.6*, interstitial voids, none living roots, some mycelium with dead roots of withered grasses, diffuse smooth boundary,

C2: 12 to 34 cm, olive brown (2.5Y 4/6), sandy clay loam, moist, common fresh angular stones, boulders and large boulders, no structure, very friable, compactness of 25.0*, interstitial voids, none living roots, diffuse irregular boundary,

C3: 34 to 56 cm, olive brown (2.5Y 4/3), sandy clay loam, moist, common fresh angular stones, boulders and large boulders, no structure, very friable, compactness of 21.2*, interstitial voids, none living roots, diffuse irregular boundary,

C4: 56 to 70+ cm, olive brown (2.5Y 4/4), sandy clay loam, moist, abundant fresh angular rock, boulders and large boulders, no structure, very friable, compactness of 20.8*, interstitial voids, none living roots.

*: Compactness (Unit: mm) means the averages of five measured values of Yamanaka's soil compactness tester.

5.4.2.2 Description of Soil Profile 5 from Plot B (Tillage) (Survey Date: October 27, 2016): Fig. 5.12

L, F, H horizon: 0 cm in thickness, no fresh or decomposed litter, little withered grass,

C1: 0 to 17 cm, olive brown (2.5Y 4/3), sandy loam, moist, few fresh angular coarse gravel and stones, no structure, very friable, compactness of 18.4*, interstitial voids, very few very fine and fine living roots, diffuse smooth boundary,

C2: 17 to 35 cm, olive brown (2.5Y 4/4), sandy clay loam, wet, few fresh angular stones, boulders and large boulders, no structure, very friable, compactness of 13.4*, interstitial voids, very few fine living roots, diffuse irregular boundary,

C3: 35 to 60 cm, olive brown (2.5Y 4/4), sandy clay loam, wet, few fresh angular stones, boulders and large boulders, no structure, very friable, compactness of 15.0*, interstitial voids, none living roots, diffuse irregular boundary,

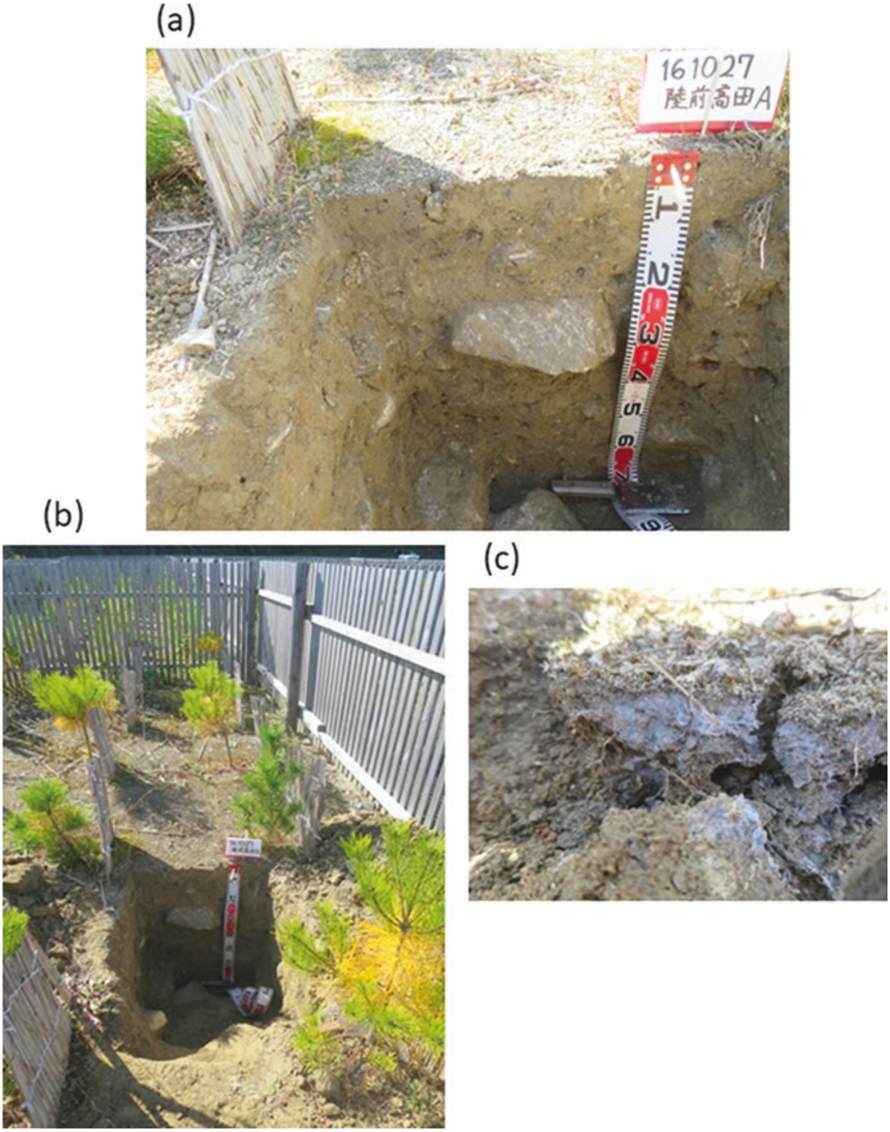

Fig. 5.11 Pictures of soil profile 4 in Plot A (Compaction) of the experimental site which was built in a tsunami-hit paddy field by the Japan Greenery Research and Development Center in 2015. (**a**) Soil profile 4 in Plot A, to a depth of 70 cm, (**b**) planted seedlings near the survey pit in Plot A, (**c**) mycelium on the surface of dead fine roots in topsoil

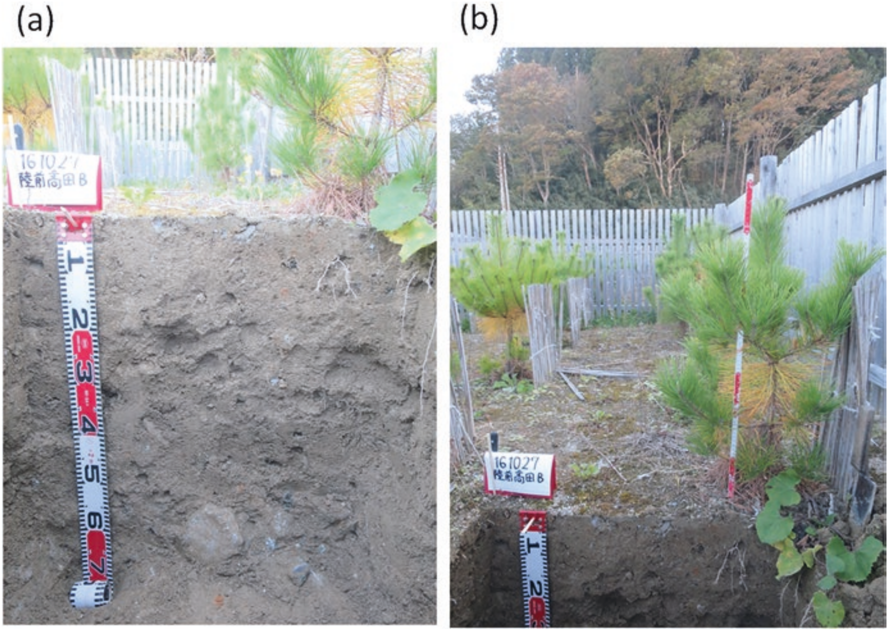

Fig. 5.12 Picture of soil profile 5 in Plot B (Tillage) of the experimental site which was built in a tsunami-hit paddy field by the Japan Greenery Research and Development Center in 2015. (**a**) soil profile 5 in Plot B, to a depth of 75 cm, (**b**) planted seedlings near the survey pit in Plot B

C4: 60 to 75+ cm, olive brown (2.5Y 4/3), sandy clay loam, wet, common fresh coarse angular stones, boulders and large boulders, no structure, very friable, compactness of 21.0*, interstitial voids, none living roots.

*: Compactness (Unit: mm) means the averages of five measured values of Yamanaka's soil compactness tester.

5.4.2.3 Description of Soil Profile 6 at Plot C (No compaction) (Survey Date: October 28, 2016): Fig. 5.13

L, F, H horizon: 0 cm in thickness, no fresh or decomposed litter, few withered grasses,

C1: 0 to 13 cm, dark olive brown-olive brown (2.5Y 3–4/3), sandy loam, moist, very few fresh subrounded and angular fine, medium, and coarse gravel, no structure, very friable, compactness of 17.6*, interstitial voids, very few very fine and fine living roots, diffuse smooth boundary,

C2: 13 to 30 cm, olive brown (2.5Y 4/4), sandy clay loam, moist, few fresh angular coarse gravel and stones, no structure, very friable, compactness of 13.4*, interstitial voids, very few very fine living roots, diffuse irregular boundary,

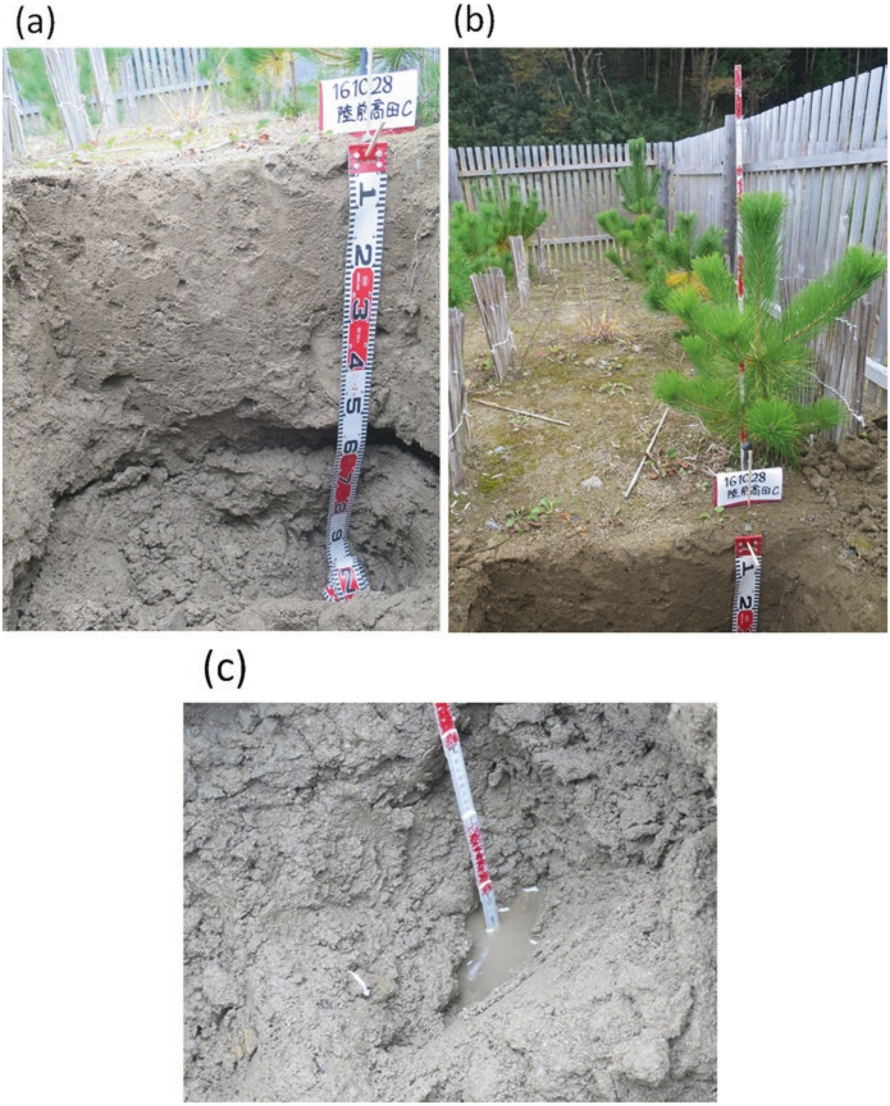

Fig. 5.13 Picture of soil profile 6 in Plot C (No compaction) of the experimental site which was built in the tsunami-hit paddy field by the Japan Greenery Research and Development Center in 2015. (**a**) soil profile 6 in Plot C, to a depth of 115 cm, (**b**) planted seedlings near the survey pit in Plot C, (**c**) observation of spring water from soil profile 6 in approximately 90 cm depth

C3: 30 to 52 cm, olive brown (2.5Y 4/4), sandy clay loam, wet, few fresh angular coarse stones and boulders, no structure, very friable, compactness of 10.2*, interstitial voids, very few very fine living roots, diffuse irregular boundary,

C4: 52 to 90 cm, olive brown (2.5Y 4/4), sandy clay loam, damp, common fresh angular coarse stones, boulders and large boulders, no structure, loose, compactness (no data: impossible to measure)*, interstitial voids, none living roots, gradual irregular boundary,

C5: 90 to 105 cm, olive brown (2.5Y 4/3), sandy loam, damp, abundant fresh angular boulders and large boulders, no structure, loose, compactness (no data: impossible to measure)*, interstitial voids, none living roots, abrupt smooth boundary,

2C: 105 to 115+ cm, brown (10YR 4/4), sandy clay, wet, none gravel, no structure, very friable, none living roots.

*: Compactness (Unit: mm) means the averages of five measured values of Yamanaka's soil compactness tester.

5.4.2.4 Soil Physical Properties

General physical properties of soil profiles 4, 5, and 6 in the respective plots of the experimental site in Rikuzen-Takata District are shown in Table 5.6. Soils at this site are generally composed of sandy loam with many rocks and boulders. Soils in all horizons of profile 4 and the lower horizon of profile 5 generally show high compactness values, due to an influence of machinery compaction when building the berm. Bulk densities of soils in all profiles with high contents of gravels tend to be quite high, generally greater than 1.5 g cm^{-3}. Therefore, the volume percentages of the solid phase are high, ranging from 55 to 67 vol% throughout all soil profiles. Although total soil porosities are relatively similar, the compositions of soil pores differ among the profiles, depending on the degree of machinery compaction. Thus, highly compacted soil horizons, such as the upper soils in profiles 4 and 5, are of limited composition with coarse pores, although the soil of profile 5 in Plot B was deeply tilled by an excavator after being built with machinery. Hydraulic conductivities range from 21 to 207 mm h^{-1}, thus the permeability of these soils is better throughout both profiles, perhaps being due to the deep-tillage treatment after building the berm at Plot B, high content of gravels in the berm soil materials in all soil profiles, and no machinery compaction for profile 6. All soils are classified as Immature Soil according to the Classification of Forest Soils in Japan (Forest Soil Division 1976). Also, the soils at both plots A (Compaction) and B (Tillage) can be classified as Linic Spolic Technosol according to the WRB 2014 (IUSS Working Group WRB 2015). This classification is mainly due to both the existence of the quite low permeable horizons (C3 and C2 horizons in profiles 4 and 5, respectively) and the high content of artefacts (i.e., usage of different sources of fill soil materials obtained from adjacent hills with the original soils in the tsunami-hit paddy field for building the experimental site). Soil at plot C (No compaction) can be classified as Spolic Technosol, due to the high content of artefacts in profile 6 without a low permeable horizon.

Table 5.6 Physical characteristics of the berm soils (Profiles 4–6) in Takada-Matsubara experimental site in Rikuzen-Takada City, Iwate Prefecture

Sample ID	Depth (cm)	Permeability[a]				Bulk density (Mg/m^3)	Soil pore composition[b]			Three phase distribution			Maximum water holding capacity (vol%)	Minimum air capacity[c] (vol%)
		5 min	15 min	Average	Hydraulic conductivity		Total	Fine	Coarse	Solid	Liquid	Gas		
		(ml/min)			(mm/h)		(vol%)	(vol%)	(vol%)	(vol%)	(vol%)	(vol%)		
Profile 4 (A plot)														
C1	0–12	10.1	9.6	9.8	47.2	1.72	36.1	28.9	7.1	63.9	29.8	6.2	42.5	–6.4
C2	12–34	35.2	27.9	31.6	151.6	1.75	34.9	25.2	9.7	65.1	28.4	6.6	40.4	–5.5
C3	34–56	4.5	4.3	4.4	21.2	1.76	34.5	29.2	5.4	65.5	32.1	2.4	40.7	–6.1
C4	56–70+	n.d.[d]	n.d.[d]	n.d.[d]	n.d.[d]	1.61	40.3	23.0	17.3	59.7	30.9	9.4	37.2	3.1
Profile 5 (B plot)														
C1	0–17	27.1	24.8	26.0	124.7	1.49	44.8	24.5	20.3	55.2	27.0	17.8	42.5	2.3
C2	17–35	4.6	4.4	4.5	21.8	1.71	36.5	27.8	8.7	63.5	33.8	2.7	41.8	–5.3
C3	35–60	12.9	10.6	11.7	56.3	1.78	33.9	29.8	4.1	66.1	39.3	–5.3	40.8	–6.9
C4	60–75+	n.d.[d]	n.d.[d]	n.d.[d]	n.d.[d]	1.75	34.9	21.5	13.4	65.1	29.1	5.8	35.0	–0.1
Profile 6 (C plot)														
C1	0–13	17.6	16.8	17.2	82.5	1.59	41.2	23.7	17.5	58.8	26.6	14.6	42.4	–1.2
C2	13–30	45.3	41.0	43.2	207.1	1.49	44.7	24.3	20.4	55.3	27.1	17.6	46.3	–1.6
C3	30–52	13.5	12.1	12.8	61.5	1.56	42.3	25.4	16.9	57.7	31.7	10.6	45.5	–3.2
C4	52–90	n.d.[d]	n.d.[d]	n.d.[d]	n.d.[d]	1.63	39.4	22.4	17.0	60.6	41.2	–1.8	42.1	–2.7
C5	90–105	n.d.[d]	n.d.[d]	n.d.[d]	n.d.[d]	1.52	43.5	19.0	24.6	56.5	39.4	4.2	41.0	2.6

[a] Permeability data shows the respective values measured after 5 and 15 min from the experiment start and the average values for both

[b] Porosity data shows the measured values according to the porous plate method (Kawada and Kojima 1976)

[c] Negative value for the composition of gaseous phase and the minimum air capacity is caused by swelling of soil volume with water saturation treatment

[d] not determined

5.5 Conclusion

Sandy soil materials brought from adjacent hills have been used to construct berms along the Pacific Coast in Miyagi Prefecture. The soil on the berm is usually compacted using heavy machinery, resulting in a hard subsoil impeding vertical water percolation and root growth. Filamentous iron mottles in soil profiles are evidence of low soil permeability and reducing conditions in subsoils. Buried wood chips in subsoil horizons promote reduction of ferric iron to form iron mottles. Slightly alkaline soil reactions are also a common soil property due to mixing with artefacts. Soils with these properties can be classified as Linic Spolic Technosol. Tillage using an excavator is an effective technique to promote aeration for plant root respiration. Performance of tillage processes on soils may promote relatively high water permeability and effectively eliminate the compacted soil layer in berms.

References

City of Rikuzentakata (2017) The miracle pine tree from Rikuzentakata City website. http://www.city.rikuzentakata.iwate.jp/kategorie/fukkou/ipponmatu/ipponmatu.html

Committee on Regeneration of Coastal Disaster Prevention Forests related to the Great East Japan Earthquake (2012) On regeneration of coastal disaster prevention forests in the future, p 80 (in Japanese)

Economic Planning Agency (1972a) Land classification map (Miyagi Prefecture). Surface geological map (in Japanese)

Economic Planning Agency (1972b) Land classification map (Iwate Prefecture). Surface geological map (in Japanese)

Forest Soil Division (1976) Classification of forest soils in Japan 1975. Bull Gov For Exp Stn 280:1–28 (in Japanese with English summary)

Forestry Agency of Japan (2013) Annual report on forest and forestry in Japan Fiscal Year 2012. Forestry Agency of Japan, p 226 (in Japanese with English summary)

Forestry Agency of Japan (2015) Annual Report on Forest and Forestry in Japan Fiscal Year 2014. Forestry Agency of Japan, p 225 (in Japanese with English summary)

Forestry Agency of Japan (2016) Annual report on forest and forestry in Japan Fiscal Year 2015. Forestry Agency of Japan, p 225 (in Japanese with English summary)

Geospatial Information Authority of Japan (2017) GSI web site. http://mapps.gsi.go.jp/maplibSearch.do#1

Hasegawa S, Inomata K (2015) Experiments of the embankment works for regenerating coastal pine forest at Rikuzen-Takata. In "Roles of revegetation for preventing sediment disaster". J Japn Soc Reveget Technol 41:336–340 (in Japanese)

Hoshino D (2012) Coastal forest and town damage in Iwate Prefecture, Japan, following the 2011 Tohoku Earthquake Tsunami. Jpn J For Soc 94:243–246 (in Japanese with English summary)

Ito T (2015) Procedures for recovery of coastal disaster prevention forests with the construction of berms as a growth foundation. Proceedings of Chisan Kenkyu Happyoukai 56:83–89 (in Japanese)

IUSS Working Group WRB (2015) World Reference Base for Soil Resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps, World soil resources reports no. 106. FAO, Rome

Japan Greenery Research and Development Center (2017) Japan greenery research and development center Web site. http://www.jpgreen.or.jp/

Kawada H, Kojima T (1976) Environmental measurement methods IV. – forest soils. Kyoritsu Shuppan Co. Ltd., Tokyo, p 210 (in Japanese)

Nakamura K, Kodani E, Ono K (2012) Debilitation and death of trees in tsunami-affected coastal forests. For Sci 66:7–12 (in Japanese)

Noguchi H, Sato H, Torita H, Masaka K, Abe T, Kimura K, Sakamoto T (2012) Numerical simulation of effect of inundation flow caused by the 2011 Tohoku earthquake tsunami on the Pinus thunbergii coastal forest. – a case study of Misawa City in Aomori Prefecture. J Jpn Soc Coast For 11:47–51 (in Japanese with English summary)

Ohta T (2015) The present state of coastal disaster prevention forests and its future. J Jpn Soc Reveg Technol 41:332–333

Sakamoto T (2012) Regeneration of coastal forests affected by tsunami. Research benchmark of the 3rd midterm plan 29 (Enhancement of Forest Function – 20). Forestry and Forest Products Research Institute, Japan, p 24

Tamura H (2012) Uprooting damages in coastal forests in the Sendai Plain. For Sci 66:3–6 (in Japanese)

The Asahi Shinbun Company (2015) A morning edition of the Asahi on December 12, 2015. The Asahi Shinbun Company, Tokyo, p 38

Watanabe K, Ebina H, Furukawa K, Horigome H, Otsuki K, Ueno M, Miyashita T, Sakamoto T (2014) Relationship coastal forest damage in the Sendai Plain caused by the 2011 off the pacific coast of Tohoku Earthquake Tsunami, the relationship between depth of groundwater and tree size. J Jpn Soc Coast For 13(1):7–14 (in Japanese with English summary)

Chapter 6
Infilling of Swamplands Behind Coastal Sand Dunes to Mitigate Coastal Disasters

Kenji Ono, Akihiro Imaya, and Akane Komoriya

Abstract Japanese black pines in the coastal forests of Kujukuri and Futtsu-Misaki in the Chiba Prefecture have often withered under water-logged conditions due to impediment of gas exchange through tree roots. Such damp subsoil conditions could influence root development of planted seedlings. To successfully accomplish the reforestation of coastal forests, ensuring high disaster prevention, addition of soil to the lowlands is strongly recommended before planting seedlings. Taking into consideration the settlement of filled land, it is necessary to ensure that a minimum 180 cm-thick layer of fill materials is added. Common fill materials are composed of sandy soils excavated from adjacent hills, dredged soils from river mouths, and surplus soils generated from construction. In soil foundations constructed in this way, the root systems of planted trees are restricted to the shallow top layers. Few roots of 10-year-old trees are seen to extend more than 50 cm deep, likely due to the compactness of fill soils. Soil formation processes will also change with time. Thus, it is important to collect pedogenesis information in these coastal forests built on landfill for optimum success in reforestation efforts. Most of the soils in the land fill area of the Matsugaya coastal forest have high bulk density with low porosity and low water permeability. Sandy soil texture is uniformly distributed through the entire profile. Filamentous mottling occurs in all mineral soil horizons except for the top horizon, due to high humidity conditions in mineral soils. These soils are classified as Linic Spolic Technosol, mainly due to both the existence of the quite low permeability horizons and the high content of artefacts. Another research site,

---

K. Ono (✉)
Tohoku Research Center, Forestry and Forest Products Research Institute, Morioka, Japan
e-mail: don@ffpri.affrc.go.jp

A. Imaya
Japan International Research Center for Agricultural Sciences, Tsukuba, Japan
e-mail: imaya@affrc.go.jp

A. Komoriya
Northern Forestry Administrative Office, the Department of Agriculture, Forestry and Fishery, Chiba Prefectural Office, Sanmu, Japan
e-mail: a.ogw5@pref.chiba.lg.jp

M. Watanabe, M. Kawahigashi (eds.), *Anthropogenic Soils in Japan*,
International Perspectives in Geography 9,
https://doi.org/10.1007/978-981-13-1753-8_6

Shirako town, located along the Kujukuri forest having stand ages of 21–22 years, has been infilled using sandy soils containing buried rice straws at fixed depth and constant intervals. At the 21-year old forest stand site, deep tillage was carried out at constant intervals before planting. Soils are classified as Spolic Technosol. Relatively high permeability was achieved at both sites despite of their high bulk densities, and many roots were found to spread both horizontally and vertically.

Keywords Land fill · Soil compaction · Tillage · Water permeability · Sandy soil materials

6.1 Introduction

Japanese black pines in the coastal forests of Kujukuri and Futtsu-Misaki in Chiba Prefecture often wither in low lying areas (less than 5 m above sea level, or ASL) behind coastal sand dunes. This is caused by impediment to gas exchange in tree roots by the continual water-logged conditions of the soils. Even willows (*Salix spp*.) and alders (*Alnus* sp.), species resistant to soil saturation, have withered and died (Oda 2001). Such damp subsoil conditions could influence root development of planted seedlings. To successfully achieve the reforestation of coastal forests to ensure high disaster prevention, the Forestry Research Institute in the Chiba Prefectural Agriculture and Forestry Research Center strongly recommended that the planting base for coastal forests be constructed by infilling the damp lowlands before planting seedlings. It also proposed a new method of reforestation using these methods (Oda 2001). This might be a crucial proposal because "the right tree for the right land" is a fundamental principle for traditional forestation methods in Japan (Morisada 1993). Since then, planting foundations for black pine forests have been developed by infilling the damp lowlands along the Kujukuri coastline (Nohara and Takahashi 2007). At this reforestation site, thick soil fill is used to ensure deep-rooted tree growth, which can help realize the disaster prevention capacity of the forest, as the stand age goal in reforested sites is 50 years. It is necessary to ensure a soil thickness of 120 cm for 50-year-old coastal forests (Oda 2000). Taking into consideration the settlement of filled land, it is necessary to utilize a 180 cm-thick layer of fill materials (Nohara and Takahashi 2007). Sandy soil cut from adjacent hills, soils dredged from river mouths, and surplus soils generated from construction are used as landfill materials. In soil foundations constructed using these materials, the root system of planted trees is primarily distributed in the shallow top layers. Even with development of shallow root systems, reforestation in areas infilled with the components noted above generally show high survival rates and satisfactory growth rates for aboveground plant structures for the first decade after planting. Few roots of 10-year-old trees are seen to extend more than 50 cm deep, which may inhibit aboveground growth thereafter. It is considered that one of the reasons why roots do not develop may be the compactness of fill soils (Nohara and Takahashi 2007). The saturated lowland areas of coastal forest with high levels of groundwater cover 235 ha of the 1400 ha coastal forest in the Chiba Prefecture. Of these, 81 ha of the area was treeless land (Chiba Prefecture 1997). Therefore, infilled coastal forests have historically grown in Chiba. Moreover, even under these conditions, soil formation processes will also change with time. Thus, it is important to collect pedogenesis information in these coastal forests built on infilled areas. Here, the physico-chemical properties of the soils are introduced from observations in three infilled coastal forests along the Kujukuri shoreline in Chiba Prefecture.

6.2 Matsugaya Coastal Forest

6.2.1 Construction of the Growth Foundation

One of the coastal disaster prevention forests introduced here is located 300 m inland from the shoreline in Sanmu City, Chiba Prefecture (Figs. 6.1 and 6.2). The growth foundation of this coastal forest was constructed by infilling the swamp areas between sand dunes using soils dredged from the mouth of the Sakuta River, and surplus soils generated by construction of road and housing lots in 2008. The initial thickness of the infill was ca. 1.3 m. In the filled area, black pine and some shrub species, e.g., *Myrica rubra*, *Quercus phillyraeoides*, *Pittosporum tobira*, and *Euonymus japonicas*, were planted as bare-root seedlings. Stand age and density was 7 years old and ca. 4000 trees per hectare, respectively, when the soil survey was carried out in 2015. Tree heights ranged from 1.2 to 3.1 m (average: 2.1 m) and the diameters of the tree bases ranged from 2.5 to 13.3 cm (average: 6.6 cm) in April 2015.

6.2.2 Soil Description and Soil Classification Using Soil Physico-chemical Properties

6.2.2.1 Site Description

Berm material: Soils dredged from the Sakuta River in Kujukuri Town, and surplus soils generated by construction of a road in Chiba Prefecture (part of the Metropolitan Inter-City Expressway in Chiba Prefecture and the Chousei Green-Line road; Forestry Research Institute, Chiba Prefectural Agriculture and Forestry Research Center, personal communication), which were used for building all C horizons as man-made planting foundations for the coastal forest,

Location: Matsugaya, Sanmu City, Chiba Pref. (35°33′52″ N, 140°28′49″ E),

Elevation: 2.5 m above sea level (ASL)

Topography: Top of the planting foundation of infilled swamplands behind the coastal sand dunes at ca. 300 m from shoreline,

Soil classification: Immature Soil (Forest Soil Division 1976), Linic Spolic Technosol (IUSS Working Group WRB 2015)

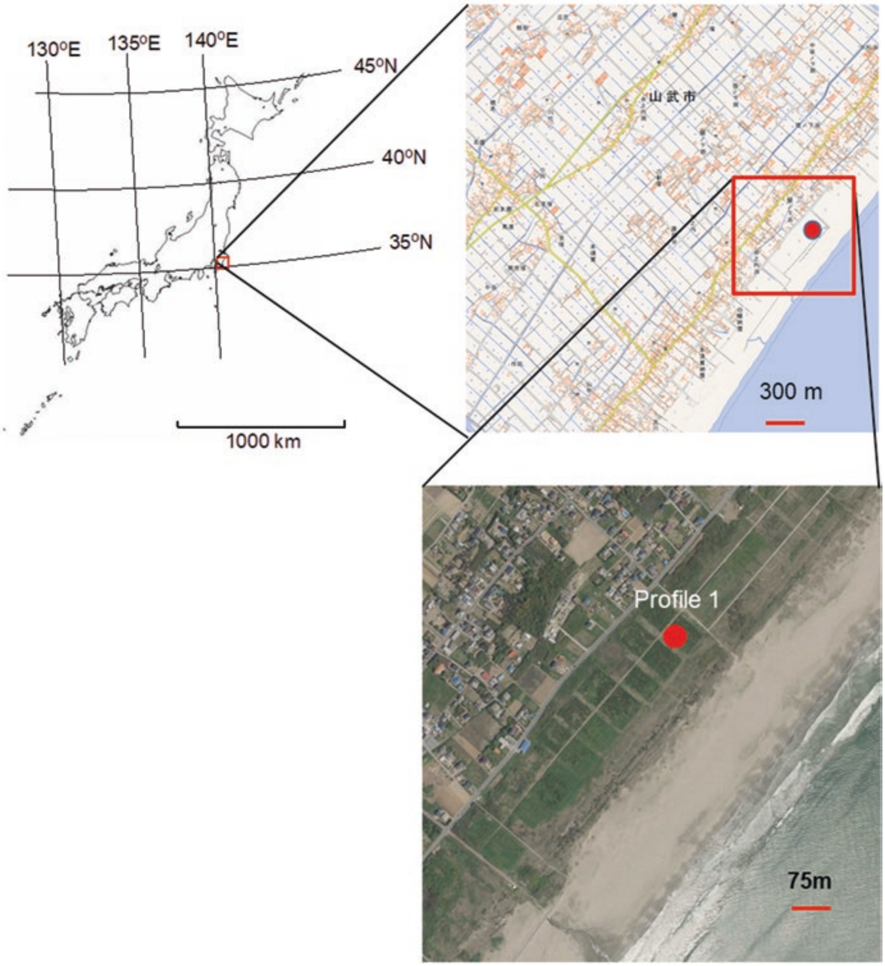

Fig. 6.1 Location of the survey point (red circle) in Matsugaya coastal forest, Sanmu City, Chiba Prefecture. The terrain map and the aerial photograph (photographed in May, 2015) was obtained from the GSI website. (Geospatial Information Authority of Japan 2017)

Vegetation: 7-year-old Japanese black pine (*Pinus thunbergii*), bayberry (*Myrica rubra*), ubame oak (*Quercus phillyraeoides*), Japanese mockorange (*Pittosporum tobira*), and Japanese spindle (*Euonymus japonicas*)

6.2.2.2 Description of Soil Profile 1 (Survey Date: February 17, 2015): Fig. 6.3

L: +2 to +4 cm thickness of fresh foliage litter of black pine, some hardwoods and weeds

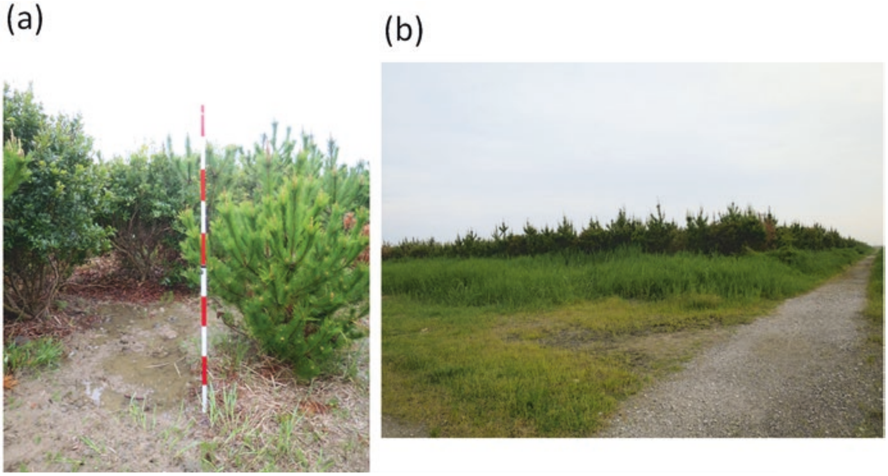

Fig. 6.2 Overview of the Matsugaya coastal forest in Sanmu City, Chiba Prefecture. Photographs were taken in (**a**) April 2015, facing the interior of the berm, and (**b**) May 2015, external appearance of the berm

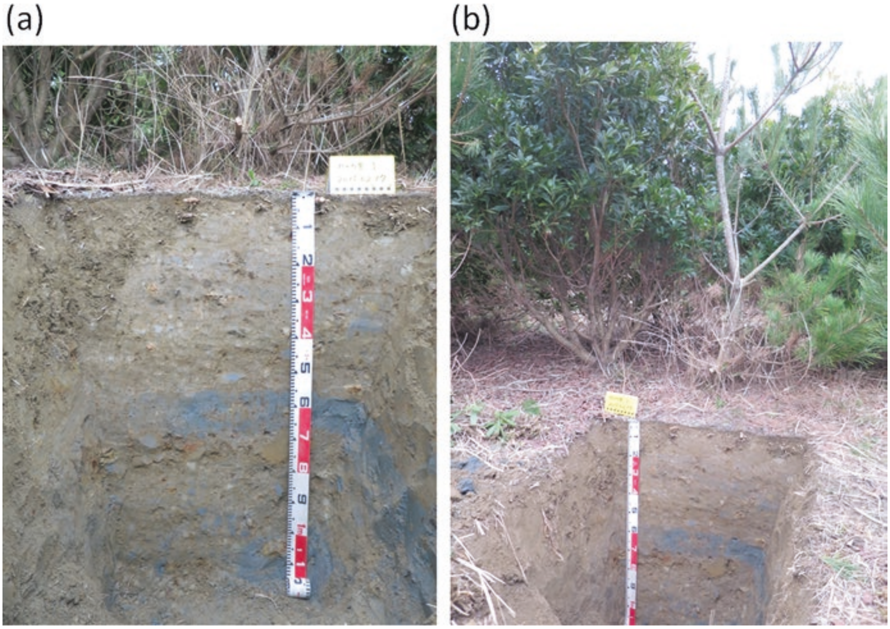

Fig. 6.3 Photos (**a**), (**b**) of soil profile 1, consisting of newly constructed infilled swamp areas as planting foundations for coastal forests. Black pine and some shrub seedlings were planted in 2009

F-H horizon: 0.5 cm thickness of decomposed foliage litter

AC: 0 to 2 cm, grayish yellow brown (10YR 4/2), silty loam, moist, none gravel, no structure, very friable, compactness of 9.2*, none voids, few fine living roots, many fine charcoal particles ($\phi < 1.0$ mm), abrupt smooth boundary,

C1: 2 to 25 cm, dark grayish yellow # (2.5Y 5/2), silty loam, few fine distinct and sharp filamentous brown (7.5YR 4/4) mottling, moist, very few sub-rounded strongly weathered stones, no structure, friable, compactness of 29.8*, none voids, few very fine and fine living roots and very few medium and coarse living roots, many fine charcoal particles ($\phi < 1.0$ mm), gradual irregular boundary,

C2: 25 to 40 cm, yellowish brown (2.5Y 5/3), silty clay loam, very few fine prominent and sharp filamentous brown (7.5YR 4/6) mottling, moist, few sub-rounded strongly weathered stones and few medium fresh angular gravel, no structure, friable, compactness of 28.0*, none voids, very few very fine living roots, many fine charcoal particles ($\phi <1.0$ mm), clear smooth boundary,

C3: 40 to 55 cm, grayish yellow (2.5Y 6/2), silty loam, few fine distinct and sharp filamentous dark reddish brown (5YR 3/6) mottling, moist, very few sub-rounded strongly weathered stones, no structure, friable, compactness of 25.2*, none voids, very few very fine living roots, many fine charcoal particles ($\phi < 1.0$ mm), clear irregular-smooth boundary,

C4: 55 to 65 cm, dark olive gray (2.5GY 4/1), silty clay loam, few fine distinct and sharp filamentous brown (7.5YR 4/4) mottling, moist, none gravel, no structure, friable, compactness of 26.2*, no voids, very few fine living roots, clear irregular-smooth boundary,

C5: 65 to 90 (−100) cm, dark grayish yellow (2.5Y 4/2), silty clay loam, few fine distinct and sharp filamentous brown (7.5YR 4/4) mottling, wet-moist, very few sub-rounded strongly weathered stones, no structure, friable, compactness of 22.2*, none voids, very few very fine living roots, few buried dead woody timbers, roots or stumps damaged by huge tsunamis, diffuse irregular boundary,

C6: 90 (−100) to 120+ cm, dark grayish yellow (2.5Y 5/2), silty clay loam, few fine distinct and sharp filamentous brown (7.5YR 4/4) mottling, moist, few sub-rounded strongly weathered stones, no structure, firm-friable, compactness of 25.6*, few dead roots.

*: Compactness (Unit: mm) means the averages of five measured values of Yamanaka's soil compactness tester.

6.2.2.3 Soil Physico-chemical Properties

General physical properties of soil profile 1 of the Matsugaya coastal forest are shown in Table 6.1. Soil in the planting foundations here is tightly packed. Bulk densities of all soils except for the C1 horizon are generally high, more than 1.25 g cm^{-3}. Volume percentages of the solid phase are relatively high, ranging from 40 to 55 vol%, throughout the soil profile, thus soil porosities are low, at less than 60 vol%. Especially in the C1 and C4 horizons, coarse pores in the soils are scarce,

Table 6.1 Physical characteristics of the soils of the planting base in Matsugaya coastal forest along Kujukuri shoreline in Sanmu City, Chiba Prefecture

Sample ID	Depth (cm)	Permeability[a]				Bulk density (Mg/m^c)	Soil pore composition[b]			Three phase distribution			Maximum water holding capacity (vol%)	Minimum air capacity[c] (vol%)
		5 min (ml/min)	15 min (ml/min)	Average (ml/min)	Hydraulic conductivity (mm/h)		Total (vol%)	Fine (vol%)	Coarse (vol%)	Solid (vol%)	Liquid (vol%)	Gas (vol%)		
Profile 1														
AC	0–2	7.6	6.8	7.2	34.5	1.05	59.6	30.0	29.6	40.4	35.0	24.5	56.3	3.3
C1	2–25	0.2	0.1	0.2	0.9	1.46	45.4	44.0	1.4	54.6	44.1	1.3	48.8	−3.5
C2	25–40	4.6	4.8	4.7	22.6	1.35	49.2	n.d.[d]	n.d.[d]	50.8	42.7	6.5	49.0	0.2
C3	40–55	1.6	1.3	1.4	6.9	1.25	53.1	39.3	13.8	46.9	44.4	8.7	51.0	2.1
C4	55–65	3.7	3.2	3.5	16.7	1.41	47.3	46.5	0.8	52.7	44.4	2.9	49.9	−2.6
C5	65–90(−100)	25.6	19.9	22.8	109.3	1.25	53.4	44.2	9.2	46.6	46.1	7.3	54.8	−1.4

[a] Data of permeability show the respective measured values after 5 and 15 min from the beginning of the experiment and the average values of them

[b] Data of porosity shows the measured values according to the porous plate method (Kawada and Kojima 1976)

[c] Minus value of minimum air capacity is caused by swelling of soil volume with water saturation treatment

[d] Not determined

Table 6.2 Particle size distribution of the soils of the planting foundation in the Matsugaya coastal forest along Kujukuri shoreline in Sanmu City, Chiba Prefecture

Horizon	Depth (cm)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)
Profile 1					
AC	0–2	1.4	69.4	17.1	12.1
C1	2–25	1.8	65.7	19.7	12.8
C2	25–40	1.1	65.5	21.3	12.1
C3	40–55	0.8	66.2	20.0	13.0
C4	55–65	1.7	64.7	18.8	14.8
C5	65–90(–100)	2.5	66.5	18.4	12.6
C6	90(100)–120+	0.5	66.3	19.5	13.6

at approximately 1 vol%. The coefficient of permeability ranges from 1 to 110 mm h^{-1}. Filamentous mottling occurs in all mineral soil horizons except for the AC horizons, perhaps as a result of constant saturated conditions in the mineral soils. No structure throughout the profile showed progress of pedogenesis. This soil is classified as an Immature Soil according to the Classification of Forest Soils in Japan (Forest Soil Division 1976). Also, they can be classified as Linic Spolic Technosol according to the WRB 2014 (IUSS Working Group WRB 2015), mainly due to both the existence of the quite low permeability horizons, especially C1–C4 horizons, and the high content of artefacts (i.e., usage of various sources of man-made soil materials for infilling, including soils dredged from the Sakuta River in Kujukuri Town, and surplus soils generated by construction of road in Chiba Prefecture). Major particle components in this soil are fine sand, generally over 60%, followed by silt, clay, and coarse sand (Table 6.2). Throughout the profile, soil particle distributions are quite similar and have relatively homogeneous properties. General chemical properties in soil profile are shown in Table 6.3. Soil pH (H_2O) generally shows (weak) acidic values, ranging from 4.1 to 6.8. Electric conductivity (EC) of mineral soil horizons is relatively high, contrary to expectations, except for the AC topsoil and horizon 2C. EC values in the C2 and C3 are noticeably higher, at approximately 80 mS m^{-1}. Total carbon content in soils is also low throughout the profile. Capacities of exchangeable cation in soils are ca. 20 $cmol_c$ kg^{-1}. The largest content for this soil was of exchangeable calcium in the exchangeable cations (7.0–10.9 $cmol_c$ kg^{-1}, with a considerably lower value of 0.2 for horizon 2C), followed by magnesium (4.3–11.5 $cmol_c$ kg^{-1}, horizon 2C much lower at 0.51), sodium (0.4–5.1 $cmol_c$ kg^{-1}), and potassium (0.2–1.2 $cmol_c$ kg^{-1}). It is not clear how the original quality of infilling materials for the planting foundation might affect the physico-chemical properties of the soils. Therefore, it is essential to gather more information on the characteristics of soils profiles built by infilling and use of heavy machinery.

Table 6.3 Chemical characteristics of the soils of the planting foundation in Matsugaya coastal forest along Kujukuri shoreline in Sanmu City, Chiba prefecture

Sample ID	Depth (cm)	EC (mS m^{-1})	pH (H_2O)	TC (g/kg)	TN (g/kg)	C/N	CEC ($cmol_c$ kg^{-1})	Exchangeable cation ($cmol_c$ kg^{-1})				Water-soluble cation ($cmol_c$ kg^{-1})			
								Ca^{2+}	Mg^{2+}	Na^+	K^+	Ca^{2+}	Mg^{2+}	Na^+	K^+
Profile 1															
AC	0–2	3.84	6.54	15.14	1.05	14.4	19.0	7.05	4.34	0.40	1.16	0.06	0.06	0.13	0.06
C1	2–25	23.20	4.91	3.58	0.33	10.7	20.7	8.44	4.94	0.56	0.93	0.37	0.41	0.22	0.06
C2	25–40	80.80	4.38	3.36	0.32	10.4	20.7	10.85	7.35	0.64	1.06	2.66	2.46	0.36	0.14
C3	40–55	74.90	4.14	3.17	0.32	9.9	20.2	10.24	5.39	0.58	1.03	3.27	2.24	0.44	0.19
C4	55–65	34.30	6.59	4.18	0.40	10.4	21.1	9.28	5.99	0.63	0.97	0.59	0.77	0.27	0.07
C5	65–90(−100)	24.10	5.21	2.89	0.27	10.6	21.1		11.48	4.99	0.59	0.98	0.83	0.60	0.27
C6	90(100)-120+	15.27	4.62	2.58	0.28	9.2	22.3		6.15	5.08	0.57	1.02	0.23	0.37	0.21
2C	100–120+	1.95	6.88	1.22	0.10	12.0	6.3	0.23	0.51	0.43	0.24	0.000	0.000	0.064	0.005

6.3 Ushigome Coastal Forest

6.3.1 Construction of the Growth Foundation with and without Tillage

Coastal disaster prevention forests of the Ushigome coastal forest introduced here are located ca. 150 m inland from the shoreline in Shirako Town, Chiba Prefecture (Figs. 6.4 and 6.5). The growth foundation of the coastal forest was constructed by infilling the swamp areas behind the sand dunes in 1994 and 1995 (Nohara and

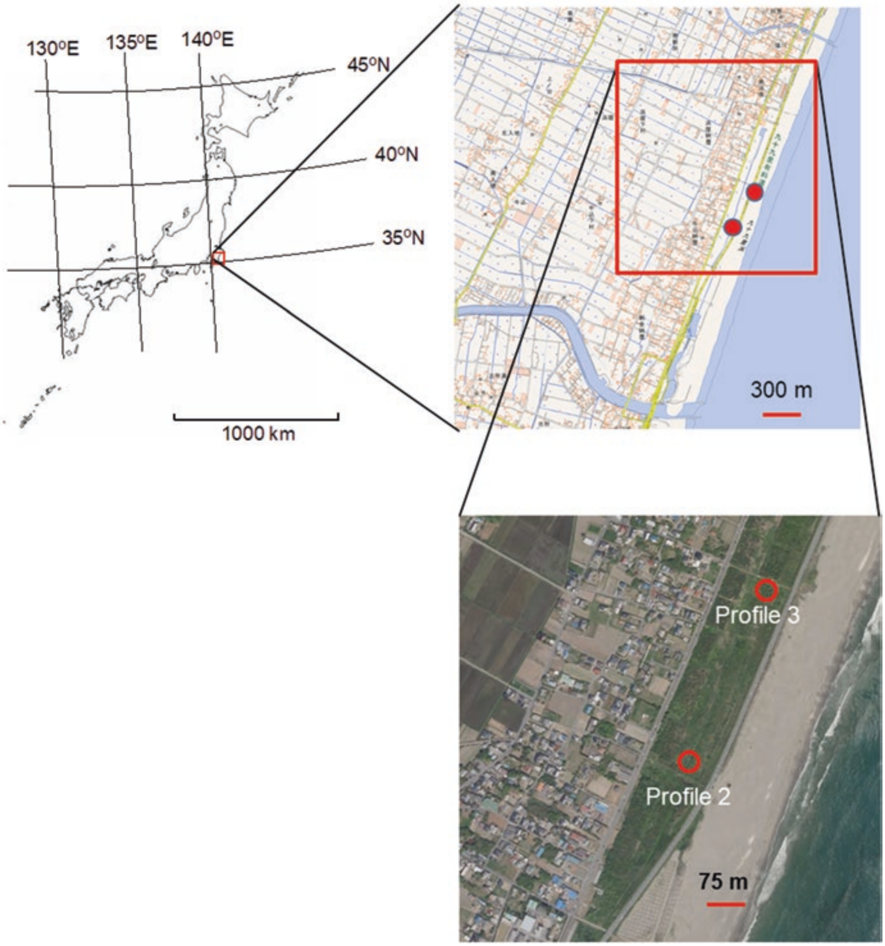

Fig. 6.4 Location of the survey points (Red circles) in Ushigome coastal forest, Shirako Town, Chiba Prefecture. The terrain map and the aerial photograph (photographed at May 2015) were obtained from the GSI website. (Geospatial Information Authority of Japan 2017)

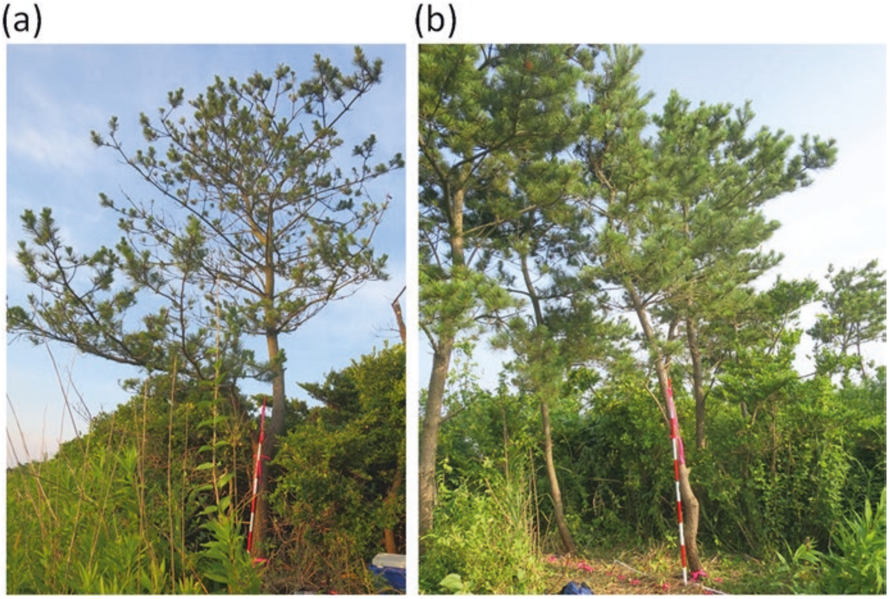

Fig. 6.5 Overview of the Ushigome coastal forest in Shirako Town, Chiba Prefecture, photographed in July 2016. Photos show the representative types of the black pine trees (**b**) the forest constructed in 1994, (**a**) the forest constructed in 1995

Takahashi 2007). During construction in 1994, soil at lower depths was compacted at each 30 cm-thickness horizon, followed by infilling using sandy soils purchased from a source pit in the adjacent hills for upper layers (which were 1.5–1.8 m in thickness). Afterwards, rice straw was buried at 30 cm in depth in the topsoil of the foundation at intervals of 1 m. The foundation constructed in 1995 utilized soils (originating from mudstones) generated by construction of road and housing lots for the bottom layers (0.8 m in thickness), compacted at 30 cm intervals, and was also infilled with the above-mentioned sandy soils for upper layers (1.1 m in thickness). Before planting, deep tillage (60 cm in width, 1 m in depth) was carried out at intervals of two meters, and rice straw was buried at both 30 and 100 cm depth in the topsoil of the foundation at intervals of one meter. In each foundation, black pine (*Pinus thunbergii*) and some types of shrub species, e.g., *Myrica rubra*, *Quercus phillyraeoides*, *Pittosporum tobira*, and *Euonymus japonicas*, were planted using bare-root seedlings in holes 30 cm in diameter, and 30 cm deep. The summary of the constructed foundation is shown in Fig. 6.6. Stand ages in the respective forests were 22 years and 21 years when the soil survey was carried out in 2016. Tree heights and diameters at breast height (1.3 m height) of trees grown near the pit of the July 2016 soil survey were 6.6 m and 20.3 cm at the 1994 site and 5.9 m and 9.9 cm at the 1995 site, respectively. Unfortunately, both sites are affected by pine wilt disease, so few trees survived there.

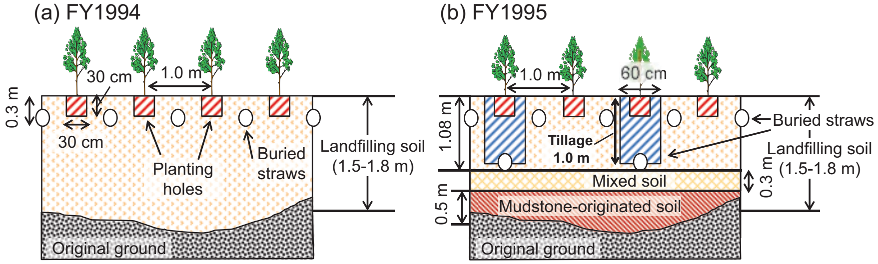

Fig. 6.6 Summary of the planting bases constructed in 1994 (**a**: Profile 2) and 1995 (**b**: Profile 3) at Ushigome coastal forest in Shirako Town, Chiba Prefecture This diagram is a modification of one in a previous report published by Nohara and Takahashi (2007)

6.3.2 Soil Description and Soil Classification Using Soil Physico-chemical Properties

6.3.2.1 Site Description for the Planting Base at the Site without Tillage (Fig. 6.6a)

Berm Material: Upper layer (1.08 m in thickness): Sandy soils purchased from borrow pit in the adjacent hills; Bottom layer (0.8 m in thickness): Surplus soils generated by construction of roads and housing lots (Nohara and Takahashi 2007), which were used for building all C horizons as a man-made planting foundation for the coastal forest

Location: Ushigome, Shirako Town, Chiba Prefecture (35°33′47″ N, 140°28′35″ E)

Elevation: T.P. 3 m ASL

Topography: Top of an embankment on the planting foundation on infilled swamplands behind the coastal sand dunes at ca. 150 m from shoreline

Soil classification: Immature Soil (Forest Soil Division 1976), Spolic Technosol (IUSS Working Group WRB 2015)

Vegetation: 22-year-old Japanese black pine (*Pinus thunbergii*), bayberry (*Myrica rubra*), ubame oak (*Quercus phillyraeoides*), Japanese mockorange (*Pittosporum tobira*), and Japanese spindle (*Euonymus japonicas*)

6.3.2.2 Description of Soil Profile 2 (Survey Date: July 15, 2016): Fig. 6.7

L: +1 cm in thickness of fresh foliage litters of black pine, some hardwoods and weeds

A: 0 to 5 cm, black (10YR 2/1), clay loam, dry, none gravel, no structure, very friable, compactness of 8.9*, interstitial voids, common very fine and fine living roots, clear smooth boundary,

C1: 5 to 20 cm, brown (10YR 4/6), silty loam, dry, none gravel, massive structure, very friable, compactness of 12.2*, interstitial voids, very few very fine, fine, and medium living roots, diffuse smooth boundary,

Fig. 6.7 Photo of soil profile 2 in newly constructed foundation in swamp areas to reforest the coastal forest in 1994. We can see two large horizontal roots in the profile

C2: 20 to 40 cm, brown (10YR 4/6), silty loam, moist, very few coarse sub-rounded weathered gravel and boulders (similar to shales), massive structure, very friable, compactness of 13.8*, interstitial voids, very few very fine, fine, and medium living roots, diffuse smooth boundary,

C3: 40 to 70 cm, brown (10YR 4/4), silty loam, moist, very few coarse sub-rounded weathered gravel and boulders (similar to shales), massive structure, very friable, compactness of 19.6*, interstitial voids, very few very fine and fine living roots, diffuse irregular boundary,

C4: 70 to 100 cm, brown (10YR 4/4), silty loam, moist, very few coarse subrounded weathered gravel, massive structure, very friable, compactness of 17.6*, interstitial voids, very few very fine and fine living roots, diffuse smooth boundary,

C5: 100+ cm, dull yellowish brown (10YR 4/3), silty loam, moist, none gravel, massive structure, very friable, compactness of 18.6*, interstitial voids, very few very fine and fine living roots.

* Compactness (Unit: mm) means the averages of five measured values of Yamanaka's soil compactness tester.

6.3.2.3 Site Description for the Planting Base at the Site with Deep Tillage (Fig. 6.6b)

Berm Material: Fill soil (1.5–1.8 m in thickness): Sandy soils purchased from borrow pit in the adjacent hills (Nohara and Takahashi 2007), which were used for building all C horizons as a man-made planting foundation for the coastal forest

Location: Ushigome, Shirako Town, Chiba Prefecture (35°27′58″ N, 140°24′41″ E)

Elevation: T.P. 3 m ASL

Topography: Top of the planting foundation for infilled swamplands behind the coastal sand dunes at ca. 150 m from shoreline

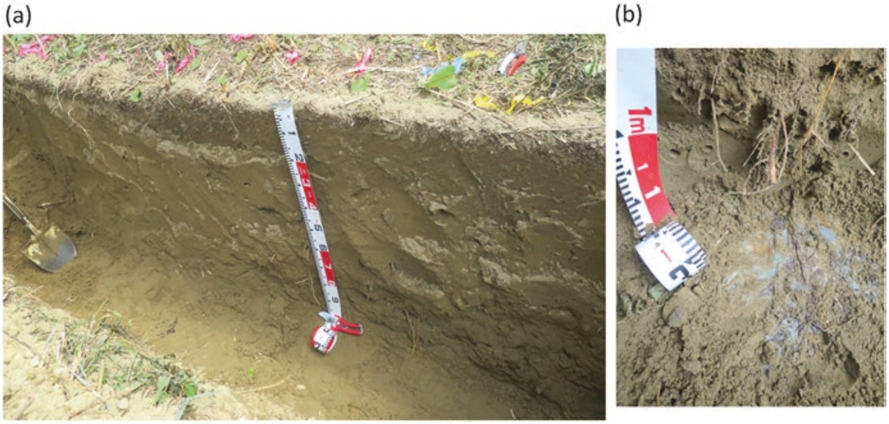

Fig. 6.8 Photos of soil profile 3 from (**a**) a newly constructed foundation made by infilling swamp areas to reforest the coastal forest in 1995, and (**b**) arrested vertical root development at the induration layer with grayish color on the bottom of the foundation

Soil classification: Immature Soils (Forest Soil Division 1976), Spolic Technosol (IUSS Working Group WRB 2015)

Vegetation: 22-year-old Japanese black pine (*Pinus thunbergii*), bayberry (*Myrica rubra*), ubame oak (*Quercus phillyraeoides*), Japanese mockorange (*Pittosporum tobira*), and Japanese spindle (*Euonymus japonicas*).

6.3.2.4 Description of Soil Profile 3 (Survey Date: July 15, 2016): Fig. 6.8

L: +2 cm in thickness of fresh foliage litter of black pine, some hardwoods, and weeds

A: 0 to 2 cm, brownish black (2.5Y 3/2), silty loam, dry, none gravel, very weak fine granular structure, very friable, compactness of 8.5*, interstitial voids, common very fine and fine living roots, clear smooth boundary,

C1: 2 to 20 cm, dull yellowish brown (10YR 4/3), silty loam, dry, none gravel, massive structure, very friable, compactness of 9.9*, interstitial voids, few very fine and fine living roots, diffuse irregular boundary,

C2: 20 to 40 cm, dull yellowish brown (10YR 5/3), silty loam, dry, none gravel, massive structure, very friable, compactness of 13.8*, interstitial voids, very few very fine and fine living roots, diffuse smooth boundary,

C3: 40 to 70 cm, dull yellowish brown (10YR 5/3), silty loam, moist, none gravel, massive structure, very friable, compactness of 13.4*, interstitial voids, very few very fine and fine living roots, clear smooth boundary,

C4: 70 to 100(−110) cm, brown (10YR 4/4), silty loam, moist, none gravel, massive structure, very friable, compactness of 16.3*, interstitial voids, very few very fine and fine living roots, clear smooth boundary, C5: 100(−110) to 120 cm, grayish yellow brown (10YR 5/2), silty loam, moist, none gravel, massive structure, very friable, compactness of 20.4*, interstitial voids, very few very fine and fine living roots, abrupt smooth boundary,

C6 120+ cm, gray (N 4/0), silty loam, induration, firm, compactness of 31.0*

* Compactness (Unit: mm) means the averages of five measured values of Yamanaka's soil compactness tester.

6.3.2.5 Soil Physico-chemical Properties

General physical properties of soil profiles 2 and 3 of Ushigome coastal forest are shown in Table 6.4. Soils of Ushigome coastal forest are generally composed of silty loam, not as tightly packed in comparison with that of Matsugaya coastal forest. Bulk densities of all soils except for the top soils (A and C1 horizon) are relatively high, more than 1.3 g cm^{-3}. The volume percentages of the solid phase ranges from 31 to 57 vol% throughout both soil profiles. Soil porosities tend to decrease with depth, to less than 50 vol%. Hydraulic conductivities range from 27 to 483 mm h^{-1}, thus the permeability of these soils is better throughout both profiles, especially profile 3 in which tillage treatment occurred after constructing the planting foundation. Both soils are classified as Immature Soil according to the Classification of Forest Soils in Japan (Forest Soil Division 1976). Also, they can be classified as Spolic Technosol according to the WRB 2014 (IUSS Working Group WRB 2015), mainly due to the high content of artifacts (i.e., usage of various sources of infill from man-made materials obtained from borrow pits in hilly areas together with the natural soils of the original coastal forest in swamp areas for constructing the planting bases) in profiles 2 and 3 without low permeable horizons. In both profiles, many roots have spread both horizontally and vertically (Figs. 6.9 and 6.10) over the past 20 years.

6.4 Conclusion

Soils beneath coastal forests constructed by infilling swamp areas have high bulk density and low water permeability due to compaction by heavy machinery, despite the incorporation of sandy soils. Fill materials including dredged sediment from the mouth of the Sakuta River, and materials obtained from construction of road and housing lots were compacted in the constructed berm, resulting in diminished soil conditions and prevention of vertical root extension. The soil is classified as Linic Spolic Technosol due to low permeability and the inclusion of artifacts. Tillage was shown to be an effective technic to improve the soil condition for reforestation efforts on berms. The tillage process results in a change of the soil name to Spolic Technosol because water permeability has been improved.

Table 6.4 Physical characteristics of the soils of the planting bases in Ushigome coastal forest along Kujukuri shoreline in Shirako Town, Chiba Prefecture

Sample ID	Depth (cm)	Permeability[a] 5 min (ml/min)	Permeability[a] 15 min (ml/min)	Permeability[a] Average (ml/min)	Permeability[a] Hydraulic conductivity (mm/h)	Bulk density (Mg/m³)	Soil pore composition[b] Total (vol%)	Soil pore composition[b] Fine (vol%)	Soil pore composition[b] Coarse (vol%)	Three phase distribution Solid (vol%)	Three phase distribution Liquid (vol%)	Three phase distribution Gas (vol%)	Maximum water holding capacity (vol%)	Minimum air capacity[c] (vol%)
Profile 2														
A	0–5	100.3	94.4	97.3	467.1	1.01	61.2	31.1	30.1	38.8	29.9	31.3	59.7	1.5
C1	5–20	25.2	22.5	23.9	114.6	1.18	55.8	23.6	32.2	44.2	19.3	36.5	56.5	−0.7
C2	20–40	22.5	21.2	21.8	104.8	1.33	50.2	20.4	29.8	49.8	21.1	29.1	56.4	−6.2
C3	40–70	35.8	35.5	35.6	170.9	1.53	43.3	22.3	21.0	56.7	28.8	14.5	47.9	−4.5
C4	70–100	5.8	5.2	5.5	26.6	1.44	45.2	19.9	25.3	54.8	16.9	28.3	44.2	1.0
Profile 3														
A	0–2	102.5	98.6	100.6	482.6	0.83	68.7	23.0	45.6	31.3	12.6	56.0	65.5	3.1
C1	2–20	32.7	30.5	31.6	151.7	1.19	56.2	27.1	29.1	43.8	15.5	40.7	58.1	−1.9
C2	20–40	10.4	6.5	8.5	40.7	1.47	45.6	23.2	22.4	54.4	17.8	27.8	49.8	−4.3
C3	40–70	30.2	25.7	27.9	134.1	1.41	47.8	17.4	30.4	52.2	19.1	28.7	51.2	−3.4
C4	70–100	n.d.[d]	n.d.[d]	n.d.[d]	n.d.[d]	1.36	49.8	n.d.[d]	n.d.[d]	50.2	16.6	33.2	41.0	8.8
C5	100–120	50.5	46.3	48.4	232.3	1.44	46.8	37.5	9.3	53.2	40.1	6.7	50.2	−3.5
C6	120+	n.d.[d]	n.d.[d]	n.d.[d]	n.d.[d]	1.30	52.5	41.5	11.0	47.5	51.5	0.9	53.6	−1.2

[a] Permeability data shows the respective measured values 5 and 15 min from experiment start and the average values for both

[b] Porosity data shows the measured values according to the porous plate method (Kawada and Kojima 1976)

[c] not determine

[d] The Negative value of the minimum air capacity is caused by swelling of soil volume with water saturation treatment

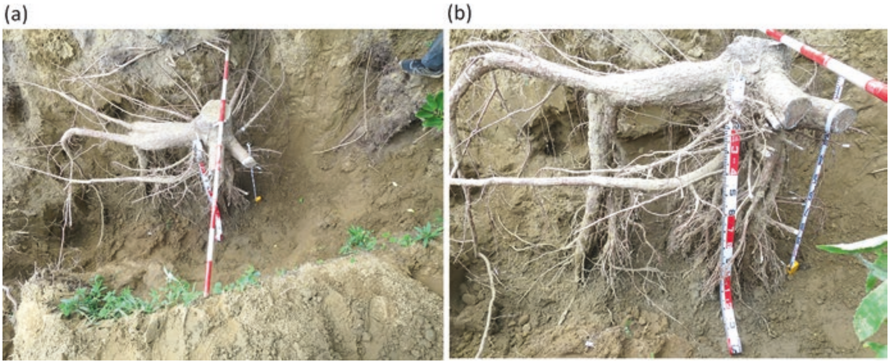

Fig. 6.9 Photos of the roots of a black pine planted in 1994, growing near Profile 2. In (**a**) horizontal root growth is observed, and in (**b**), the extent of vertical growth is seen

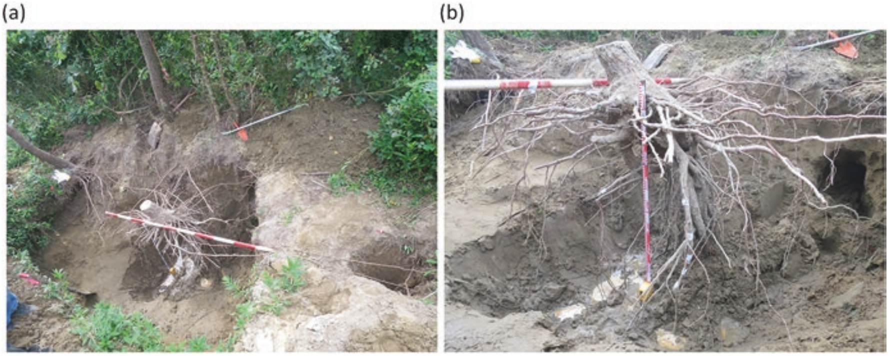

Fig. 6.10 Photos of the roots of a black pine planted in 1995, growing near Profile 3. The puddles in the pit were from rainfall on the day before the exploration. Photo (**a**) horizontal growth, (**b**) vertical growth

References

Chiba Prefecture (1997) Master plan of management for coastal protection forests. Chiba Prefecture, Chiba, p 330

Forest Soil Division (1976) Classification of forest soils in Japan 1975. Bull Gov For Exp Stn 280:1–28 (in Japanese with English summary)

GSI (Geospatial Information Authority of Japan) (2017) GSI web site. http://mapps.gsi.go.jp/maplibSearch.do#1

IUSS Working Group WRB (2015) World Reference Base for Soil Resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps, World soil resources reports no. 106. FAO, –Rome

Kawada H, Kojima T (1976) Environmental measurement methods IV. – forest soils. Kyoritsu Shuppan Co. Ltd., Tokyo, p 210 (in Japanese)

Morisada K (1993) “The right tree for the right land” and the fertility of forest soil. Shikoku Information, Shikoku Research Center, FFPRI 10 (in Japanese)

Nohara S, Takahashi T (2007) The effect of landfill on damp lowlands of coastal sand dunes: growth of the roots of 10 year-old black pines (Pinus thunbergii). Bull Chiba For Res Cent 2:1–6 (in Japanese)

Oda T (2000) Minimum filling thickness based on characteristics of distribution of Pinus thunbergii root systems in damp, lowlands sand dunes of the coastal forests. Sand Dune Res 47:102–110 (in Japanese)

Oda T (2001) Study on the reaction of planted tree root systems to water-logging and its application to developing forests in damp lowlands of coastal sand dunes. Spec Bull Chiba For Res Cent 3:1–78 (in Japanese with English summary)

Chapter 7
Geotechnical Issues for Developing Coastal Waste Landfills

Toru Inui and Takeshi Katsumi

Abstract Coastal landfilling has become one of the most important practices in the disposal of municipal solid waste incinerator ash (MSWIA) as well as industrial waste generated in megacities in Japan. Leachate generated from these waste materials may contain substances, particularly heavy metals, that are harmful to the environment. Mechanical properties of coastal waste landfills have not been comprehensively studied. Considering the post-closure use of landfill sites, both mechanical properties and long-term mobility of heavy metals are important geotechnical issues. This article addresses the results of large-scale column percolation and modified batch tests conducted to evaluate the mobility of heavy metals in coastal MSWIA landfills, based on heavy metal speciation using a sequential extraction method. The column percolation test was conducted to simulate the behavior of zinc (Zn), as a trace metal, in the waste-bottom marine clay system. Modified batch tests were employed to investigate the effects of pH and Eh on the forms of Zn in both MSWIA-leachate and leachate-marine clay systems. Zn was effectively immobilized by forming exchangeable and reducible fractions under moderately alkaline conditions or reducible and oxidizable fractions under highly alkaline conditions. However, Zn mobilization under neutral conditions was involved, since the formation of exchangeable compounds more predominantly contributed to immobilization. Test results on metal speciation in the marine clay-leachate system revealed that marine clay acted as an effective attenuation layer. These findings support the premise that Zn mobility is limited in the coastal MSWIA landfills. Secondly, a series of triaxial consolidated undrained (CU) compression tests were carried out on reconstituted waste samples before and after being cured in simulated coastal landfill leachate water for different periods in order to understand the aging effects

---

T. Inui (✉)
Graduate School of Engineering, Osaka University, Osaka, Japan
e-mail: inui@civil.eng.osaka-u.ac.jp

T. Katsumi
Graduate School of Global Environmental Studies, Kyoto University, Kyoto, Japan
e-mail: katsumi.takeshi.6v@kyoto-u.ac.jp

M. Watanabe, M. Kawahigashi (eds.), *Anthropogenic Soils in Japan*,
International Perspectives in Geography 9,
https://doi.org/10.1007/978-981-13-1753-8_7

on the mechanical properties of the landfilled waste layer. Peak shear strength and deformation modulus increased through curing. However, residual strength was not affected by differences in the curing periods. The waste mixture layer investigated in this study could possibly be used as a foundation layer with sufficient bearing capacity in post-closure use of coastal landfill sites.

Keywords Coastal landfill · Waste materials · Heavy metal mobility · Mechanical property

7.1 Introduction

Coastal landfilling is an important practice for disposal of municipal solid waste incinerator ash (MSWIA), slag, surplus soil, and other waste in Japan. According to the Ministry of the Environment in Japan, approximately 20% of MSW was disposed of in coastal landfill sites, and the weight ratio of MSWIA in landfilled wastes reached almost 78% in 2003. In general, coastal landfill sites are located at strategic points in the port areas of Tokyo, Nagoya, and Osaka, with relatively easy access from the metropolitan areas. Thus, there is potential for post-closure use of coastal landfill sites considering limited land availability in Japan (Fig. 7.1).

Concentrations of heavy metals such as lead (Pb), zinc (Zn), and cadmium (Cd) in MSWIA, particularly in fly ash, are quite high. Thus, understanding environmental impacts of the leaching of these toxic metals is crucial. A natural bottom layer of marine clay and cutoff seawalls maintain the leachate level inside the MSWIA layer at a height equal to the sea level, and minimizes water flow, as shown in Fig. 7.1. Such an environment specific to a coastal landfill enhances the anaerobic conditions within the landfill, which may reduce the mobility of these heavy metals (Plata et al. 2010). Little research is available on the mobility of the

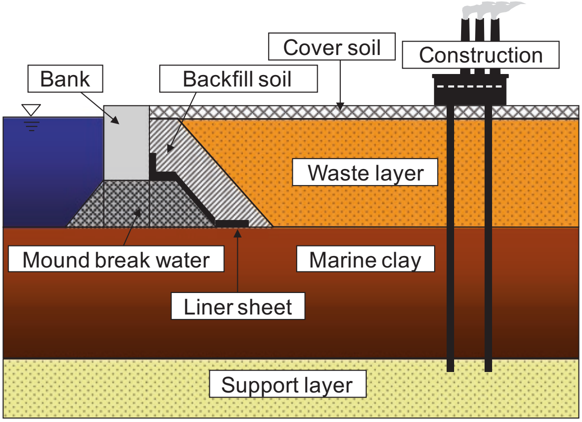

Fig. 7.1 Schematic view of post-closure use of coastal landfill site

heavy metals in a coastal MSWIA landfill during its lifespan. There are various factors affecting the mobility of heavy metals in coastal landfill, including biochemical factors related to microbial activity as well as chemical factors such as pH and redox potential (Kamon et al. 2002). However, in previous studies, there was little experimental data to clarify mechanisms and forms of heavy metals in the coastal landfill site. In particular, a complex MSWIA-seawater-clay bottom system in a coastal landfill may influence the chemical forms of heavy metals in various ways. Species that are water-soluble and exchangeable are mobile under slightly acidic conditions while metals in the residual fraction are stable even under weathering conditions (Huang et al. 2007; Sinan et al. 2007). Thus, the speciation of heavy metals is a key issue to determine both the biological and physico-chemical availability of trace metals.

It is also important to investigate the strength, bearing capacity, and deformation properties of the waste mixture layers deposited in the coastal landfill, given the high potential of post-closure use of the area. However, limited research is available regarding the geotechnical properties of the waste mixture layers in coastal landfill sites or the engineering properties of waste mixture that include incinerator ash, slag, and surplus soil.

This article presents previous research by the authors to address these geotechnical and geoenvironmental issues related to coastal waste landfills. First, a large-scale column test (Plata et al. 2010) and modified batch leaching tests (Inui et al. 2009) were conducted to investigate the forms and mobility of heavy metals in both MSWIA and marine clay layers. Based on the speciation of heavy metals using the sequential extraction method in the MSWIA-seawater and marine clay-leachate systems, the mobility of heavy metals in the coastal landfill is discussed.

Secondly, an aliquot of a waste mixture obtained immediately before being disposed of in a coastal landfill site was collected, and a series of triaxial consolidated undrained (CU) compression tests were carried out on the specimens before and after being cured in simulated leachate for different periods to simulate the effects of interactions with the leachate (Nguyen et al. 2015). Effects of aging on mechanical properties of the waste mixture reclaimed in coastal landfills are then discussed.

7.2 Testing Program to Investigate Heavy Metal Mobility in a Coastal Landfill

7.2.1 Materials

MSWIA was collected from a storage pit at a municipal MSW incinerator plant in Japan. It contains both bottom ash (residue produced from the incineration of MSW) and fly ash (fine particles captured from the flue gas by air pollution control devices). The fly ash had been treated with a chelating agent to reduce the leaching potential of heavy metals. Marine clay was excavated from the seabed at depths of approximately 10–13 m in Osaka Bay, Japan.

7.2.2 Large Column Test

A large column test was performed for 430 days to evaluate the influence of pH, Eh, and microbial activities on the mobility of trace metals within the MSWIA layer and bottom clay layer. Zinc (Zn) was selected as the monitored trace metal because it is generally found in leachate from hazardous and municipal solid waste. Figure 7.2 shows the experiment setup. The acrylic resin column with a 190 mm inner diameter and 1500 mm height had several sampling ports. Marine clay was consolidated at the bottom of the column under a consolidation pressure of 200 kPa. This pressure was maintained until the wet density reached 1860 kg/m^3, and its thickness was adjusted to 150 mm. An MSWIA layer having an 850-mm height and a 1110 kg/m^3 wet density was placed above the clay layer. The experimental setup included the preparation of simulated seawater as an influent. Simulated seawater was enhanced with 61.2 mg/L of Zn, which resulted in an initial pH value of 7.26. Zn enhancement was conducted to simulate the accumulated amount of Zn that might reach the middle and bottom of the coastal landfill site. The influent was stored above the MSWIA layer at a height of 100–150 mm. Pressure in the headspace of the column was maintained at 0.02 MPa using nitrogen gas, and eventually the average flow rate through the whole system reached 40 mL/d. Effluent and pore water were periodically collected at the bottom of the column and each sampling port. An MSWIA layer was extracted after the test and divided into nine fractions according to depth.

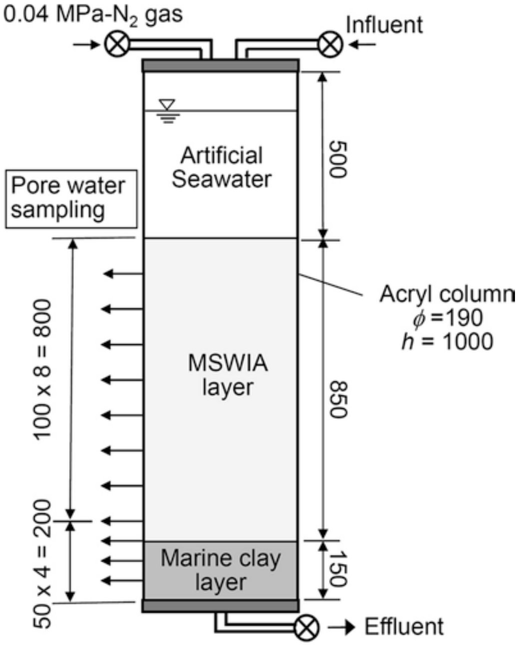

Fig. 7.2 Experimental setup of the large-scale column test. (Plata et al. 2010)

7.2.3 Batch Tests

A series of batch tests were conducted to evaluate the effect of pH and redox potential on the form of heavy metals in the coastal landfill. Two different systems were considered; (1) an MSWIA-seawater system in the MSWIA layer and (2) a clay-leachate system in the bottom clay layer. Zn was also selected as a trace metal in the batch test. In all cases, 150 g of solid material (MSWIA or marine clay with its natural water content) was mixed with the solvent. Cases simulating the clay-leachate system employed 1500 mL of the solvent, which had been obtained by mixing the MSWIA with the seawater in a solid to liquid ratio of 1:10 for 6 h using a shaking table and then filtered with a 0.45 μm-opening membrane filter. In other words, it was a simulated leachate in the coastal landfill receiving the MSWIA. In the test cases simulating the MSWIA-seawater system, 150 g of MSWIA was mixed with 1500 mL of seawater in a reaction vessel. The sample was suspended in a reaction vessel to expose it to aerobic or anaerobic conditions during the test. MSWIA and clay layers inside the coastal landfill are generally subject to anaerobic conditions. However, the surface and shallow layers as well as the zone where rain infiltration takes places will be subject to aerobic conditions over the long-term. In the aerobic case, the suspended sample was exposed to the atmosphere, while nitrogen gas was used to replace the head space of the reaction vessel at the beginning of the test and then continuously bubbled into the suspension in the anaerobic cases. During the test, the sample suspended in the reactor was constantly mixed with the magnetic stirrer at 200 rpm. Approximately 40 mL of the suspended sample was taken periodically as a sample.

7.2.4 Speciation of Heavy Metals

Zn in the solid samples (MSWIA after the column test and the solid fraction in the batch test) was quantified using the modified Community Bureau of Reference (BCR) sequential extraction procedure certified by the Commission of the European Communities and the Community Bureau of Reference (Filgueiras et al. 2002). The modified BCR sequential extraction procedure can partition the metal contained in the solid phase into four defined chemical fractions: exchangeable, reducible, oxidizable, and residual. Each fraction is extracted after treating a sample with a series of reagents selected for their ability to react with different components of the matrix. The four fractions are briefly outlined as follows: (1) exchangeable fraction consisting of exchangeable metals and others bound to carbonates, including weakly-absorbed metal species, which can be released by ion-exchange processes, or that are susceptible to pH decreases, (2) reducible fraction made up of metals bound to hydrous oxides of iron and manganese that are thermodynamically unstable under reduced conditions, (3) oxidizable fraction, which includes metals bound to organic matter and sulphides, and tends to degrade under aerobic conditions, and (4) residual fraction, which mainly consists of primary and secondary minerals that retain heavy metals within their crystal structure.

7.3 Testing Program to Investigate Mechanical Properties of a Coastal Landfill

7.3.1 Materials

The waste mixture used in this study was collected at a coastal landfill site in the Osaka Bay area of Japan, immediately before reclamation. Composition of this mixture was approximately 50% MSWIA, 30% gravel material (like slag), and 20% surplus soil, based on the waste acceptance record. Approximately 200 kg of the wet waste mixture was collected and then air-dried in a laboratory at a constant temperature of 20 °C. Next, large pieces of debris such as glass and rocks were removed and the mixture was sieved with a 9.5 mm-opening sieve. After sieving, the sample was considered a mixture of MSWIA and soil containing small fragment slag and gravel. The material was well graded with a particle size distribution corresponding to SG-F (gravelly sand with fine fraction), according to the JGS 0051 (2009). The specific gravity of the waste mixture sample was 2.67. Chemical composition of the waste sample determined with X-ray fluorescence spectroscopy (XRF) is shown in Table 7.1. The XRF shows that calcium oxide is the main component (51.6% CaO), which indicates a certain hydration capacity of the sample.

To prepare a simulated leachate to be used for submerged curing of the specimens with a chemical composition equivalent to that of the leachate in a coastal landfill site, 30 L of seawater was collected in Osaka Bay and mixed with the waste mixture sample in a tank, with a weight ratio of the waste mixture to seawater of 0.1. The mixture was stirred daily for 7 days and then filtered through a sieve with a 75 µm opening. Then, the pH and calcium concentration of the simulated leachate were measured, resulting in values for the calcium concentration and pH of 1850 mg/L and 7.95, respectively. To simulate the aging effects in a coastal landfill site, the specimens were cured in the simulated leachate for up to 180 days.

Table 7.1 Chemical composition of the waste mixtures sample (Nguyen et al. 2015)

Chemicals	CaO	Fe_2O_3	SiO_2	Al_2O_3	TiO_2	SO_3	K_2O	ZnO	Others
Content (%)	51.6	20.4	9.1	4.3	3.3	2.8	1.7	1.9	4.9

7.3.2 Consolidated-Undrained (CU) Triaxial Compression Test

Araike et al. (2010) reported that the in situ saturated density of waste mixture reclaimed from the coastal landfill site of Osaka Bay is approximately 1.6 Mg/m^3. Here the waste mixture was prepared with its optimum water content and degree of compaction at 80%, which is equivalent to a saturated density of 1.6 Mg/m^3. All the specimens were prepared by compacting five layers into a split cylindrical mold (50 mm in diameter and 100 mm in height) with a degree of compaction of 80% (ρd = 1.02 Mg/m^3) and optimum water content of 34.5%.

Consolidated-undrained (CU) triaxial tests with pore water pressure measurements were conducted for two series of specimens: series A, for samples without curing and series B, for samples that were cured in seawater for certain periods (7, 14, 28, 60, 90, 120, 150, or 180 days). The specimens were prepared according to JGS 0520 (2009), and saturated by applying a vacuum procedure under a constant effective confining pressure of 20 kPa (Rad and Clough 1984). According to the Japanese Ministry of the Environment, approximately 90% of coastal landfill sites in Japan have reclamation depths of less than 15 m. Considering that the wet unit weights of waste layers were about 17 kN/m^3 above the water table and 16 kN/m^3 below the water table, which lies 2 m below the ground level on the coastal landfill site of Osaka Bay (Araike et al. 2010), the effective overburden pressure at 5 m, 10 m, and 15 m depths was approximately 53 kPa, 84 kPa, and 115 kPa, respectively. With the assumption that the lateral effective pressure was equal to the vertical effective pressure, the confining pressures, σc, of 50, 100, and 150 kPa were employed in the triaxial tests. After each specimen was consolidated with a designated effective confining pressure, it was compressed at a constant axial strain rate of 0.5%/min until the cumulative axial strain reached 15%.

7.4 Summary of Testing Results

7.4.1 Heavy Metal Mobility in a Coastal Landfill

Under the reduced-alkaline conditions observed in the MSWIA layer, dominant fractions of Zn were in the exchangeable and reducible forms, and mobility was limited only in the surface layer. Figure 7.3 presents the distributions of Zn fractions along the MSWIA layer before and after the test.

The percentage of the exchangeable and reducible fractions with regard to total Zn increased particularly at 25 mm depth. This increase confirmed that Zn was immobilized at the top surface by forming hydroxides and carbonates. However, an increase in the exchangeable fraction may pose a risk to the environment because this fraction is the most weakly-bonded to the sediment, and sudden changes in Eh or pH could promote the release of considerable quantities of heavy metals. In addition, the percentage of Zn retained in more insoluble forms such as reducible and

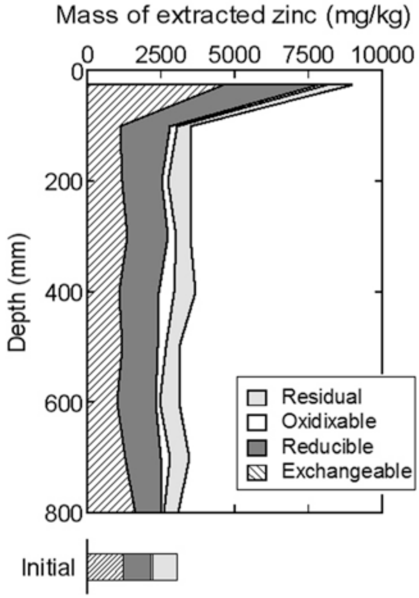

Fig. 7.3 Total mass and speciation of zinc in the MSWIA at different depths. (Modified from Plata et al. 2010)

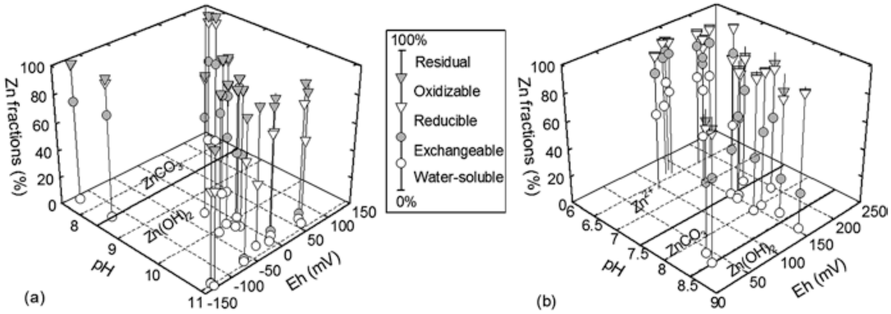

Fig. 7.4 Zn fractions affected by pH and Eh values in batch leaching test: (**a**) MSWIA-seawater system, (**b**) Clay-leachate system (Inui et al. 2009)

oxidizable fractions increased in the middle MSWIA layer. Considering that the oxidizable fraction was not detected in the ash before the test, the transformation into sulphide and/or organic compounds under chemical conditions specific to the MSWIA coastal landfill was considered another important attenuation mechanism, since degradation tends to occur only under aerobic conditions.

Figure 7.4 shows the distributions of Zn fractions, including the water soluble fraction, affected by pH and Eh in the (a) MSWIA-seawater system and (b) clay-leachate system. Data were obtained by analyzing samples taken periodically from all the reactors. On the pH-Eh plane, the expected Zn forms affected by pH and Eh in the aqueous system are presented as a reference according to Hem (1972). In the MSWIA-seawater system, no water-soluble Zn existed and Zn was effectively immobilized when pH values ranged from 7.5 to 10.5, mainly through the formation of an exchangeable fraction, such as $ZnCO_3$ and $Zn(OH)_2$. This suggests the possibility that Zn in the MSWIA will be dissolved when the pH drops to neutral. In fact, in the column test, Zn was dissolved at the surface of the layer where pH decreased to neutral and Eh increased. At pH > 10.5, the percentages of the reducible and oxidizable fractions were higher. This increase corroborates well with the distributions of Zn fractions observed in the middle MSWIA layer after the column test (Fig. 7.3). Increases in residual and oxidizable fractions indicate the formation of Zn compounds with iron, phosphorous, manganese, and sulphides, which are more stabilized in the coastal landfill compared to the exchangeable form.

In the clay-leachate system, approximately 50% of the total content of Zn was soluble and up to 40% was present in exchangeable form at pH < 7.0. In contrast, at pH > 7.5, Zn formed predominantly less-soluble fractions as the exchangeable fraction at lower Eh values and the reducible fraction at higher Eh values, since the reducible fraction was less stable and converted to exchangeable fractions when Eh values were relatively low. These observations agree with the expected Zn forms affected by pH and Eh according to Hem (1972) (see the pH-Eh plains, Fig. 7.4), and with the conclusion that the possibility and mechanism of the heavy metal attenuation by marine clay were greatly dependent on pH and Eh. However, under anaerobic conditions, as in the bottom clay layer in the coastal landfill, pH values remained at approximately 8.0, equal to the pH of seawater. In conclusion, the marine clay layer can immobilize Zn even when the leachate from the MSWIA layer contained soluble Zn.

7.4.2 Mechanical Properties of a Coastal Landfill

Overall, the peak shear strength as well as dilatancy of the waste mixture increases with curing time. Processes responsible for this behavior could be explained by changes in the microstructure of the waste mixture, which was densified through formation of hydration products (ettringite and calcium silicate hydrates, or CSH), and the generation of negative excess pore water pressure (PWP). Densification of the waste mixture samples associated with curing led to an increase in the negative pore pressure during shearing due to the dilatancy effect. Accordingly, the higher peak deviator stress, qp, is attributed to the higher mean effective stress, p′, mobilized by the generation of negative excess PWP (Nguyen et al. 2015).

Relationships between the stress ratio, q/p′, and the axial strain, εa, obtained in the CU tests ($\sigma_c = 150$ kPa) are illustrated in Fig. 7.5. While the peak q/p' value was about 1.7 for the initial specimen, peak q/p' values gradually increased to about 2.3 after 150 and 180 days curing. A similar trend was also observed under $\sigma_c = 50$ kPa and 100 kPa, although the peak q/p' values were slightly different. However, the q/p' values at the residual state for larger ε_a were almost constant (1.7–1.8), regardless of the curing periods and confining pressures. These observations indicate that there were no changes in cohesion and friction angles in the specimen cured in simulated

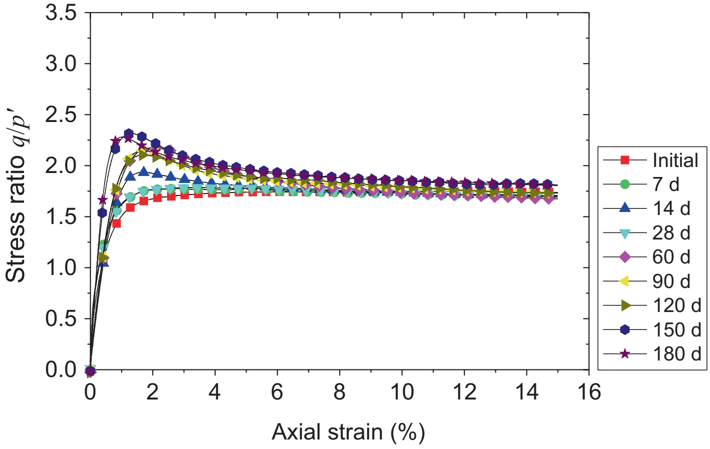

Fig. 7.5 Stress ratio q/p′ versus axial strain at σc = 150 kPa. (Nguyen et al. 2015)

leachate. Effects of curing are clearly observed only in the small strain region and the higher q/p′ values were mobilized by curing. However, in the large strain region, the residual q/p′ was almost constant and not influenced by curing. This indicates an overconsolidation effect with aging. Athanasopoulos (1993) posited that overconsolidation ratio increases linearly with duration of aging for remolded clay. Representative q/p′-strain curves for the waste mixture after curing are consistent with those provided by Åhnberg (2007) for overconsolidated stabilized soil. The author pointed out that the specimens of stabilized soil exhibited brittle behavior, with a significant reduction in strength after failure under undrained conditions. Either way, the waste mixture layer investigated in this study could possibly be used as a foundation layer with its sufficient bearing capacity in post-closure use of coastal landfill sites.

7.5 Conclusion

Disposal of municipal solid wastes and incinerator ashes in coastal landfills area is an important practice to manage them. It is necessary to assess chemical and mechanical properties of the waste landfill for post-closure utilization of the site. Fate and transport of zinc, which is representative of heavy metals contained in the municipal solid incinerator ash (MSWIA), were evaluated by conducting batch leaching tests and a large-scale column percolation test. An MSWIA layer percolated with seawater retains high-alkaline and reducing conditions, resulting in zinc being stabilized as reducible and oxidizable fractions in compounds with iron, phosphorous, manganese and sulphides. These testing results support that coastal landfillswith solid wastes can be managed well without pollution by release of heavy metals. The waste mixture has a certain hydration capacity, and formation of hydration products (e.g., ettringite and CSH) with interactions with seawater can mobilize higher peak shear strength due to densified effects, and coastal landfills reclaimed by waste materials can be used as a foundation layer with its sufficient bearing capacity in the post-closure use phase.

References

Åhnberg H (2007) On yield stresses and the influence of curing stresses on stress paths and strength measured in triaxial testing of stabilized soils. Can Geotech J 44(1):54–66

Araike H, Kambara H, Maeda H, Nonami S, Watanabe Y (2010) Physical and density characteristics of Kobe offshore reclamation disposal site. In: Proceedings of the 45th Japan national conference on geotechnical engineering, pp 471–472 (in Japanese)

Athanasopoulos G (1993) Effects of ageing and overconsolidation on the elastic stiffness of a remoulded clay. Geotech Geoenviron Eng 11(1):51–65

Filgueiras AV, Lavilla I, Bendicho C (2002) Chemical sequential extraction for metal partitioning in environmental solid samples. J Environ Monit 4(6):823–857

Hem JD (1972) Chemistry and occurrence of cadmium and zinc in surface water and groundwater. Water Resour Res 8:661–678

Huang S, Chang C, Mui D, Chang F, Lee M, Wang C (2007) Sequential extraction for evaluating the leaching behavior of selected elements in municipal solid waste incineration fly ash. J Hazard Mater 149:180–188

Inui T, Oya Y, Plata H, Katsumi T, Kamon M (2009) Speciation and mobility assessment of heavy metals in the coastal municipal solid waste incinerator ash landfill. J ASTM Int 6(8):1–12

JGS 0051 (2009) Method of classification of geomaterials for engineering purposes. Jpn Geotech Soc

Kamon M, Zhang H, Katsumi T (2002) Redox effects on heavy metal mobility in landfill sites. Soils Found JGS 42(3):115–126

Nguyen CL, Inui T, Ikeda K, Katsumi T (2015) Aging effects on the mechanical property of waste mixture in coastal landfill sites. Soils Found 55(6):1441–1453

Plata H, Inui T, Katsumi T, Oya Y, Kamon M (2010) Speciation and mobility of zinc in coastal landfill sites with MSW incinerator ash. J Environ Eng ASCE 136(8):762–768

Rad NS, Clough GW (1984) New procedure for saturating sand specimens. J Geotech Eng 110(9):1205–1218

Sinan Bilgili M, Demir A, Ince M, Özkaya B (2007) Metal concentrations of simulated aerobic and anaerobic pilot scale landfill reactors. J Hazard Mater 145:186–194

Chapter 8
Soils on Man-Made Islands in Tokyo Bay

Hayato Matsudaira

Abstract Man-made islands occupy about 230 ha in Tokyo Bay. Surface soil for green spaces covering the reclaimed land consists of bark compost brought from greenery areas in the Tokyo Metropolis. Limited amounts of degradable organic wastes are also mixed with the surface soil. Surface soil is usually top-dressed to a depth of 30 cm, to ensure root growth of the planting base. The deep soil layer is strongly compacted during the construction process by the use of heavy machines, and contains miscellaneous artificial materials such as asphalt, concrete, bricks, and dredged materials. Even with complicated soil composition, early stages of the soil development process are recognized in soil properties with time and/or depth. On the man-made island established on 1987, artificial soils covered with trees planted within this decade gradually develop as Urbic Spolic Technosols due to high contents of artifacts derived from rubble and refuse of human settlements and industrial waste. The boundary in the soil profile, which changes from abrupt to diffuse with the passage of time from afforestation, suggests soil mixing process by development of plant root systems at the boundary. Land improvement works using heavy machines strongly influences the physical difference between surface and deeper horizons. Soil development processes were verified through analysis of the chemical properties of the surface horizons, which have higher contents of organic carbon and nitrogen, and lower pH values, common properties of soils beneath well-developed vegetation. Development of soil on the man-made islands definitely increases with the growth of vegetation.

Keywords Artifacts · Soil boundary · Soil compaction · Root system · Alkaline soil reaction

---

H. Matsudaira (✉)
Department of Geography, Tokyo Metropolitan University, Tokyo, Japan
e-mail: matsudaira-hayato@ed.tmu.ac.jp

M. Watanabe, M. Kawahigashi (eds.), *Anthropogenic Soils in Japan*,
International Perspectives in Geography 9,
https://doi.org/10.1007/978-981-13-1753-8_8

8.1 Introduction

Ongoing construction of man-made islands has occurred inside the bay areas of Japan, especially close to highly populated water-front cities on Tokyo Bay, Ise-Bay, and Osaka-Bay. Some islands in Tokyo Bay have been developed along with population increases. Japan has made new lands especially in the Tokyo Bay area since the Edo era. Edo minato (the former name for Tokyo Port) was enlarged in the days of the Tokugawa shogunate during the seventeenth to nineteenth centuries. Gradually the landfill areas were expanded with increasing garbage produced by over 1,000,000 people living in Edo. After the opening of Japan, the Tokyo port area was not considered important by the Japanese government because the Yokohama port had already opened to foreign countries beforehand. The Tokyo port area evolved rapidly after World War II, especially during the period of high economic growth (1954–1973), in order to manage increasing transportation and traffic. Population growth during the period produced tremendous waste, resulting in demand for space for landfills. Dredged sand and rock from the shallow sea-bottom in Tokyo Bay, required to maintain sea lanes, also needed to be repurposed. To provide a solution to accumulating waste from increasing population and to repurpose dredged materials from the sea lanes, man-made islands were constructed in the Tokyo Bay area. The Tokyo port surface area has been expanded by infilling with such waste. Man-made islands are mainly used for industry.

People living along the sea coast submitted a request for green space in the Tokyo area to the Tokyo government in the 1960s. The Tokyo metropolitan government planned the Tokyo metropolitan marine park in 1970. This plan had three basic goals: (1) to preserve and recover fresh air, and a deep green-blue water surface and, (2) to provide energy, and (3) to provide a space for and to provide relaxation to citizens of Tokyo. The Tokyo metropolitan government started to construct marine parks in 1972. Initially, 13 marine parks, covering a total of 27.1 ha, opened in 1975. By 2016, the area had increased to 790.4 ha, hosting a total of 38 marine parks.

At present, man-made islands occupy about 230 ha in Tokyo Bay. Many islands consist of a deep land basement made with incineration garbage and demolition debris. Surface soil for green spaces covering the basement consists of wastes from pruning branches in the urban greenery area. Some organic waste, such as paper and fabric, leather, and, timber, is degradable due to its origin. Greater moisture concentration enables methane emission from the organic waste (Bureau of Port and Harbor, Tokyo Metropolitan Government 2001). Buried waste decomposes well over a 25-year period (Mori 2012). A serious problem is the potential for methane emission from the land surface during the waste decomposition under anoxic conditions (Matsufuji 1995). A tubing system is usually installed underground to reduce methane escaping from the land surface (Bureau of Port and Harbor, Tokyo Metropolitan Government 2001). Surface soil is usually dressed to 30 cm to ensure adequate root growth in the planting base (Research Committee of Japanese Institute of Landscape Architecture 2001. On man-made islands, the deep soil layer is strongly compacted during the construction process by heavy machinery, and contains many different types of materials, including artifacts such as asphalt, concrete, bricks, and dredged materials (Sakagami 1978). Compaction of the deep soil prevents root penetration, with the result that only the surface dressed soil needs to physically support vegetation. Organic wastes including bark compost are also mixed in to improve the soil.

The origin of soil materials and composition of materials in the mounded soil is unknown. Soils in the Tokyo port area have been delivered from different places to the artificial island for its construction. During the construction process of the island, different materials were mixed depending on the construction period. Even with a complicated soil composition, early stages of the soil developmental process will be found from differences in soil properties with time and/or depth. This study considers soils in the greenery area in man-made islands with different construction ages.

8.2 Soil on the Man-Made Island, “The Uminomori Park”

8.2.1 The Plan for Greenery Land Use in Tokyo Bay

Uminomori Park, located in Tokyo Bay with an area of 76 ha (Figs. 8.1 and 8.2) has been created on an artificial island constructed by solid waste including concrete, asphalt, and cut soil materials, mixed with 12.3 million tons of urban waste. The landfill started in 1973 and terminated in 1987. A plan for greenery land use on part

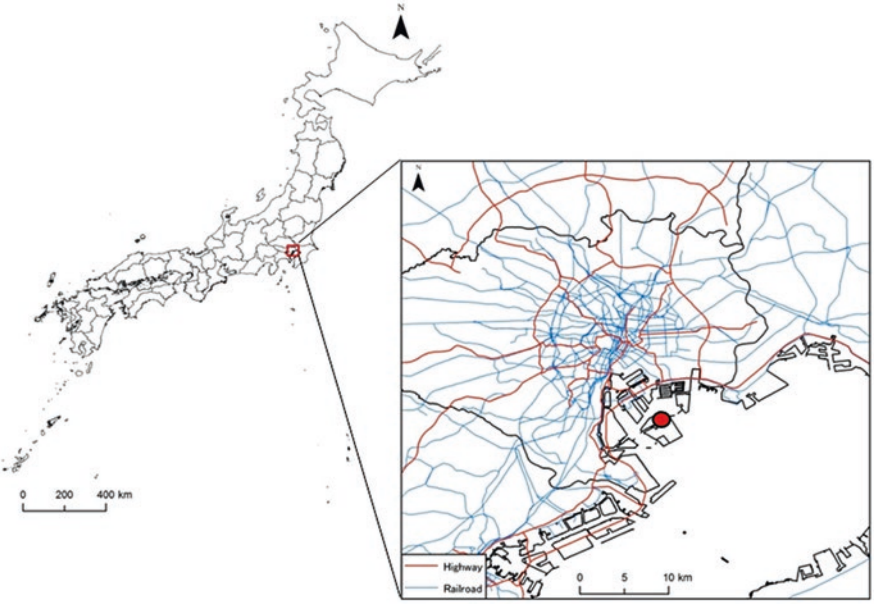

Fig. 8.1 Location of the Uminomori park. (N.35°36′20.42″, E139°48′32.12″)

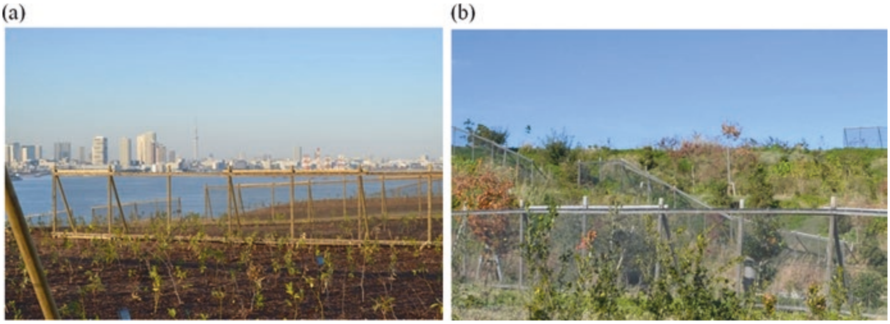

Fig. 8.2 Overview of the Uminomori planting areas of 2014 (**a**) and 2012 (**b**)

of this island was proposed in 2005, under the concept of "recovering nature from a garbage mountain", and was launched in 2007. The covered soil layer has a 1.5 m depth and uses soil material cut at another constructed area mixed with solid waste. Surface soil with 30 cm thickness is maintained especially for plant growth by mixing with bark compost, composted from branches and leaves from urban parks in Tokyo. Tree seedlings were planted in a small area in 2008. Planting sites rotated from one place to another on the man-made island every year. In 2016, the plan for planting trees was ended. Also, an area designated for the next Olympic Games in 2020 is still under construction on the island.

In 2008, the Tokyo metropolitan government released a report on potential vegetation, bird, insect, aquatic organism, and soil fauna changes (Bureau of Port and Harbor, Tokyo Metropolitan Government 2010. According to this report, some birds that are on the endangered species list make their habitat on this artificial land.

8.2.2 Soil Description and Properties at the 2014 Planting Site

Afforestation was completed 2 years after the preparation of the planting base.

^C: 0 to 30 cm, brown (7.5YR 4/6), clay loam, massive structure, moderately dry, compactness 25, no gravels, very few organic matter, positive NaF soil reaction, clear abrupt boundary,

^C2: 30 to 38 cm, black (5Y 2/1), sandy loam, massive structure, moderately dry, compactness 22, frequent angular and/or round gravels (ϕ 1–10 cm), moderate organic matter, slightly positive NaF soil reaction, smooth gradual boundary,

^C3: 38 to 80 cm, dark brown (5Y 3/2), sandy loam, massive structure, moderately dry, compactness 26, frequent angular and/or round gravels (ϕ 1–10 cm), moderate organic matter, slightly positive NaF soil reaction, smooth gradual boundary,

^C4: 80 to 100+ cm, black (5Y 2/1), sandy loam, massive structure, moderately dry, compactness 25, frequent angular and/or round gravels (ϕ 1–10 cm), moderate organic matter, slightly positive NaF soil reaction.

Fig. 8.3 Soil profile of the newly constructed soil to plant young trees in November 2014

The soil profile shown in Fig. 8.3 shows a clearly different material in the surface layer compared to the rest of the profile.

8.2.2.1 Soil Properties at the 2014 Planting Site

General physico-chemical properties for the 2014 planting area are shown in Table 8.1. Large amounts of organic matter derived from bark compost is responsible for 3–4% of total soil weight. Gravel-sized artifacts were numerous at deeper soil levels, exceeding over 40% of soil weight. The soils in Uminomori Park can be classified as Urbic Spolic Technosol, according to the world reference base for soils (WRB; IUSS Working Group WRB 2014), mainly due to the high content of artifacts. Soil reaction was slightly to moderately alkaline. Deeper soils display higher pH and electric conductivity (EC). Total carbon and nitrogen were evenly distributed with depth. Inorganic carbon in the soil ranged from 2.22–8.99 g/kg, with an increasing trend in the deeper horizons. A relatively lower ratio of carbon to nitrogen (C:N) indicates over-estimation of inorganic carbon originating from artifacts. High bulk density reaching 1.4 indicates heavy soil compaction especially in horizons deeper than 30 cm, probably due to machinery loading during construction for the planting base.

Table 8.1 Physico-chemical properties of the Uminomori soil constructedplanted in 2014

Horizon (cm)	EC (mS/m)	pH (H_2O)	Gas (%)	Liquid (%)	Solid (%)	Bulk Density	TC (g/kg)	TOC (g/kg)	IC (g/kg)	TN (g/kg)	TOC/TN
^C1 (0–30)	14.6	7.04	0.0	71.8	29.3	0.78	18.90	16.72	2.22	1.30	12.9
^C2 (30–38)	32.1	8.10	8.0	41.2	50.8	1.35	18.20	11.24	6.91	0.90	12.5
^C3 (38–80)	39.2	8.51	13.0	34.4	52.7	1.40	17.40	9.44	7.99	0.80	11.8
^C4 (80–100)	34.8	8.47	9.0	37.3	53.7	1.42	17.90	10.46	7.45	0.90	11.6

8.2.3 Soil Description and Properties at the 2012 Planting Site

^A1: 0 to 5 cm, brownish black (10YR 2/3), clay loam, crumb structure, moderately dry, compactness 8, few angular gravels (ϕ 5–10 cm), high organic matter, weak NaF soil reaction, clear smooth boundary,

^C1: 5 to 20 cm, brownish black (10YR 2/2), clay loam, crumb structure, moderately dry, compactness 23, few angular and/or sub-rounded gravels (ϕ 5–10 cm), high organic matter, weak NaF soil reaction, smooth gradual boundary,

^C2: 20 to 30 cm, black (10YR 2/1), clay loam, angular structure, moderately dry, compactness 21, common angular (ϕ 5–10 cm), medium organic matter, slightly positive NaF soil reaction, smooth gradual boundary,

2^C3: 30 to 58 cm, dark olive brown (2.5Y 3/3), sandy loam, sub-angular blocky structure, moderately dry, compactness 13, few angular gravels (ϕ 10–20 cm), moderate organic matter, no NaF soil reaction, smooth diffuse boundary,

3C4: 58 to 80 cm, brownish black (2.5Y 3/2), loam, sub-angular blocky structure, moderately dry, compactness 18, common angular gravels (ϕ 10–20 cm), moderate organic matter, no NaF soil reaction, smooth diffuse boundary,

4^C5: 80 to 100+ cm, dark brown (10YR 3/3), loam, sub-angular blocky structure, moderately dry, compactness 13, few angular and/or round gravels (ϕ 1–5 cm), moderate organic matter, weak NaF soil reaction.

8.2.3.1 Soil Properties at the 2012 Planting Site

General physico-chemical properties for the 2012 planting area are shown in Table 8.2. The boundary between the surface and the subsurface horizons was unclear (Fig. 8.4), differing from the soil profile constructed in 2014. The soil constructed in 2012 is also classified as Urbic Spolic Technosols by the WRB (IUSS Working Group WRB 2014). Soil reaction was slightly to moderately alkaline, except for the surface soil which had an acidic soil reaction. Electric conductivity

Table 8.2 Physico-chemical properties of the Uminomori soil constructed in 2012

Horizon (cm)	EC (mS/m)	pH (H_2O)	Gas (%)	Liquid (%)	Solid (%)	Bulk Density	TC (g/kg)	TOC (g/kg)	IC (g/kg)	TN (g/kg)	TOC/TN
^A1 (0–5)	14.6	6.59	29.0	47.1	23.9	0.61	84.3	81.5	2.79	6.12	13.3
^C1 (5–30)	10.0	7.16	16.4	56.7	26.9	0.73	33.1	30.3	2.75	2.64	11.5
^C2 (30–58)	10.8	7.27	22.1	52.1	25.7	0.70	37.0	34.3	2.70	2.92	11.8
2^C3 (58–80)	15.6	7.34	23.6	48.3	28.1	0.76	25.4	22.6	2.77	2.01	11.2
2^C4 (80–100)	19.5	7.85	15.5	46.2	38.3	0.99	15.9	13.1	2.86	1.30	10.0
4^C5 (100+)	24.3	7.86	–	–	–	–	16.9	13.5	3.35	1.18	11.5

Fig. 8.4 Soil profile of the newly constructed soil to plant young trees in 2012

was also relatively high in the surface horizon. Relatively abundant production of grass promotes acidification along with decomposition of organic substances. Total carbon and nitrogen content was greater in the upper 80 cm. Wood within the bark compost had decreased to approximately 1% of soil weight, indicating that bark compost functioned as soil conditioner and was decomposed by soil fauna. High pH and EC has been maintained at deep horizons probably due to less reaction of artifacts with soil water.

8.2.4 Soil Description and Properties at the 2008 Planting Site

^A1: 0 to 7 cm, brownish black (10YR 2/2), loam, crumb and/or sub-angular blocky structure, moderately dry, compactness 6, few gravels (ϕ 1–10 cm), high organic matter, weak NaF soil reaction, clear diffuse boundary,

^A2: 7 to 32 cm depth, brownish black (10YR 2/3), silty clay loam, crumb and/or sub-angular blocky structure, moderately dry, compactness 14, few gravels (ϕ 1–10 cm), moderate organic matter, weak positive NaF soil reaction, smooth abrupt boundary,

^C1: 32 to 50 cm, brownish black (10YR 3/2), clay loam, sub-angular blocky structure, moderately dry, compactness 23, common gravels (ϕ 1–10 cm) and/or few gravels (ϕ 10–20 cm), moderate organic matter, weak positive NaF soil reaction, smooth diffuse boundary,

^C2: 50 to 68 cm, dark brown (10YR 3/3), clay loam, angular blocky and/or sub-angular blocky structure, moderately dry, compactness 17, few gravels (ϕ 1–5 cm) and/or many gravels (ϕ 5–30 cm), moderate organic matter, weak positive NaF soil reaction.

^C3: 68 to 95+ cm, dark black (10YR 3/4), clay loam, angular blocky and/or sub-angular blocky structure, moderately dry, compactness 21, many gravels (ϕ 1–5 cm) and/or few gravels (ϕ 5–10 cm) and/or common gravels (ϕ 10–20 cm) and/or few gravels (ϕ 20–30 cm), moderate organic matter, weak positive NaF soil reaction.

8.2.4.1 Soil Properties at the 2008 Planting Site

General physico-chemical properties of the 2008 planting area are shown in Table 8.3. The clear smooth boundary between the surface horizon and the sub surface was not observed, indicating dredged materials and construction wastes were completely mixed in (Fig. 8.5). The soil in the Uminomori Park at this site was also classified as Urbic Spolic Technosols using the WRB (IUSS Working Group WRB 2014), and is characterized by the high content of artifacts. Soil reaction was slightly to moderately alkaline. High proportions of solid phases and soil compactness in deeper soil horizons reflected strong initial compaction at the beginning of the construction. The high organic carbon content reaching up to 60 g kg^{-1} indicates that applied organic matter, such as bark compost, was broken down into fragments with

Table 8.3 Physico-chemical properties of the Uminomori soil constructed in 2008

Horizon (cm)	EC (mS/m)	pH (H_2O)	Gas (%)	Liquid (%)	Solid (%)	Bulk Density	TC (g/kg)	TOC (g/kg)	IC (g/kg)	TN (g/kg)	TOC/TN
^A1 (0–7)	15.24	7.28	38.0	36.7	25.3	0.72	66.8	63.2	3.6	4.6	13.7
^A (7–32)	16.13	7.77	24.3	32.1	43.6	1.19	43.9	39.5	4.5	3.1	12.8
^C1 (32–50)	17.13	7.94	29.6	31.9	38.5	1.06	17.4	13.3	4.1	1.1	12.4
^C2 (50–68)	19.40	7.89	13.4	35.7	50.9	1.37	17.4	13.7	3.7	1.1	12.7
^C3 (68–95+)	20.50	7.94	–	–	–	–	17.0	13.0	4.0	1.1	12.0

smaller size, followed by their stable accumulation in soil pores due to soil fauna activity. Total carbon and nitrogen were lower in the deeper horizon, though inorganic carbon content was evenly distributed in all soil horizons. Electric conductivity increases with depth due to the presence of mixed artifacts.

8.3 Greenery Area for Golf and Amusement Facilities in the Wakasu Seaside Park

8.3.1 Construction of a Man-Made Island with Municipal Waste

The Wakasu Seaside Park is also located in the Tokyo Bay area (Fig. 8.6). The basement of this park was constructed using municipal waste with construction debris from 1960 until 1969. This is the first park constructed by the sandwich construction method, which is repetition of a unit consisting of a garbage layer (3.0 m) interbedded between two soil layers (0.5 m). The garbage layer reaches to about 20 m. The covered soil on the garbage is partly waste soil which was excavated to build a new Tokyo metropolitan office. Soil cover construction on the northern section of the island was conducted from November 1974 through May 1975, and the southern region was completed by May 1977. Wakasu Seaside Park opened in a limited fashion in 1990. Today, Wakasu Seaside Park offers many types of amusement facilities, including a bicycle path, a golf course, camping sites, fishing areas, playground equipment, and a yacht harbor (Fig. 8.7). The park occupies 100.1 ha (Takani 2001).

Fig. 8.5 Soil profile of the constructed soil in November 2008

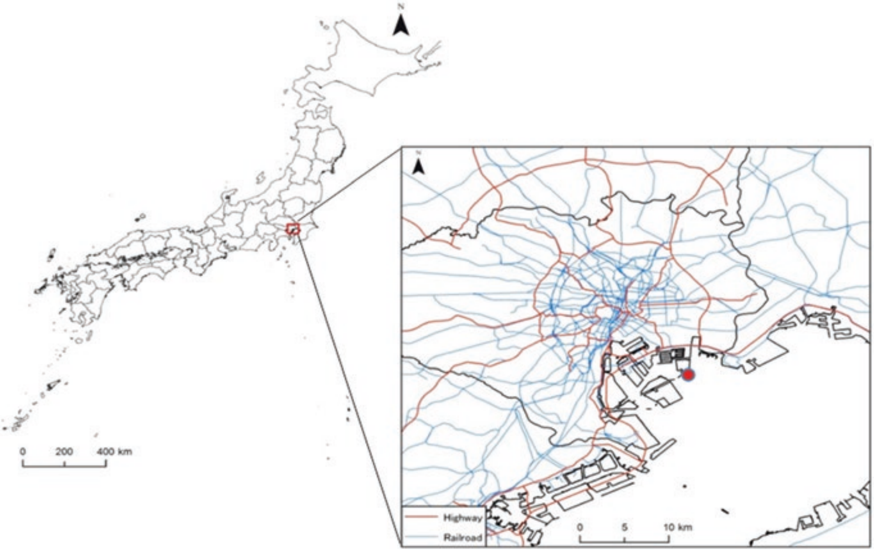

Fig. 8.6 Location of Wakasu Seaside Park (35°37′39.9″N, 139°50′13.3″E)

Fig. 8.7 Landscape of the survey point in Wakasu Seaside Park

8.3.2 *Soil Description and Soil Properties 40 Years After Construction*

^A: 0 to 2 cm, dark brown (7.5YR 3/3), silty clay loam, crumb structure, dry, compactness 5, no gravels, high organic matter, positive NaF soil reaction, clear abrupt boundary,

^Bw: 2 to 25 cm, brown (10YR 5/6), clay loam, sub-angular blocky structure, dry, compactness 22, frequent angular and/or round gravels (ϕ 1–10 cm), low organic matter, slightly positive NaF soil reaction, smooth gradual boundary,

^BC: 25 to 40 cm, yellowish brown (10YR 5/6), silty loam, sub-angular blocky structure, dry, compactness 23, few gravels (ϕ 1–2 cm), low organic matter, strongly positive NaF soil reaction, smooth abrupt boundary,

2^C1: 40 to 55 cm, brown (10YR 4/6), sandy loam, massive structure, dry, compactness 30, dominant gravels, low organic matter, positive NaF soil reaction, diffuse abrupt boundary,

3^C2: 55 to 80 cm, dark blown (10YR 3/3), loamy sand, massive structure, dry, compactness 31, frequent angular and/or round gravels (ϕ 1–10 cm), low organic matter, slightly positive NaF soil reaction, diffuse abrupt boundary,

4^C3: 80+ cm depth, black (10YR 2/1), loamy sand, massive structure, dry, compactness 26, dominant gravels, low organic matter, no NaF soil reaction.

Table 8.4 Chemical properties of soil in the Wakasu Seaside Park

Horizon (cm)	EC (mS/m)	pH (H_2O)	TC (g/kg)	TN (g/kg)	C/N
^A (0–2)	13.7	5.85	107.7	7.49	14.4
^Bw (2–25)	9.53	5.80	23.4	1.95	12.0
^BC (25–40)	12.5	7.13	18.5	1.49	12.4
2^C1 (40–55)	15.8	7.83	11.7	0.53	22.2
3^C2 (55–80)	13.1	8.07	13.4	0.55	24.4
4^C3 (80+)	11.7	8.60	11.5	0.62	18.5

Fig. 8.8 Soil profile in Wakasu Seaside Park

8.3.2.1 Soil Properties at the Wakasu Seaside Park

General physico-chemical properties are shown in Table 8.4. The soil profile shown in Fig. 8.8 shows a clear distinction between the surface soil (0–40 cm) and deeper soil (40–90 cm) consisting of different materials. The deep horizon includes many artifacts such as bricks, concrete, and asphalt, and remains highly compacted below 40 cm due to heavy machine construction despite its age of 40 years. The soil in the Wakasu Seaside Park is classified as Urbic Technosols by the WRB (IUSS Working Group WRB 2014) because of the high content of artifacts.

Both the surface and first sub-surface horizon had acidic soil reactions, which differed from the four deeper horizons affected by artifacts. Acidic soil reaction in the upper two horizons indicates leaching of alkaline components due to vertical water percolation during its land management as grassland. Electric conductivity was relatively small at the Bw horizon with depth.

8.4 Urban Bird Sanctuary: The Tokyo Wild Bird Park

8.4.1 History of the Tokyo Wild Bird Park

A bird sanctuary is located in southern Tokyo Bay, near Haneda Tokyo International airport (Fig. 8.9). The Bureau of Ports and Harbors, Tokyo Metropolitan Government planned to use this area as a new market site in 1960. However, after construction, a wetland developed in the landfill area. A tidal flat area at the edge of the fill provided an advantageous nesting site for wild birds, resulting in the establishment of a wild bird park in this area. In 1989, the Tokyo Wild Bird Park opened, with an allocation of 24.2 km^2 (land site, 21.8 km^2; wetland site, 2.4 km^2), near the new Tokyo market which initially been planned to occupy the entire area. On June 17, 2000, the park became part of a vital ecosystem network for sandpipers and plovers, which led to international recognition for the park. Every year, the park provides nesting grounds for seabirds and small birds including sandpipers, plovers, and seagulls, as well as hawks (Fig. 8.10). Annually, some 120 different species inhabit the park, and, as of June, 2013, 226 species of wild birds have been recorded there.

8.4.2 Soil Description and Physico-chemical Properties

^A: 2 to 5 cm, black (10YR 2/1), loam, weak crumb structure, moderately dry, compactness 3, no gravels, high organic matter, slightly positive NaF soil reaction, clear smooth boundary,

^CA: 5 to 15 cm, dark brown (10YR 3/3), loam, weak crumb structure, moderately dry, compactness 12, common gravels (ϕ 0.2–1.0 cm) and/or few gravels (ϕ 1–5 cm), medium organic matter, positive NaF soil reaction, slightly clear smooth boundary,

^C1: 15 to 23 cm depth, dark brown (10YR 3/4), clay loam, weak crumb structure, moderately dry, compactness 18, common gravels (ϕ 0.2–-5 cm), very few organic matter, positive NaF soil reaction, gradual wavy boundary,

^C2: 23 to 40 cm, dark brown (10YR 3/4), clay loam, weak crumb structure, moderately dry, compactness 23, common gravels (ϕ 1–10 cm) and/or few gravels (ϕ 10–20 cm), very few organic matter, positive NaF soil reaction, gradual wavy boundary,

^C3: 40 to 60 cm depth, brown (10YR 4/4), clay loam, weak crumb structure, moderately dry, compactness 23, common gravels (ϕ 1–10 cm) and/or few gravels (ϕ 10–20 cm), very few organic matter, positive NaF soil reaction, gradual wavy boundary,

^C4: 60 to 80 cm, brown (10YR 4/3), loam, weak crumb structure, moderately dry, compactness 20, few gravels (ϕ 1–5 cm) and/or common gravels (ϕ 5–10 cm) and/or common gravels (ϕ 10–20 cm), very few organic matter, positive NaF soil reaction, wavy diffuse boundary,

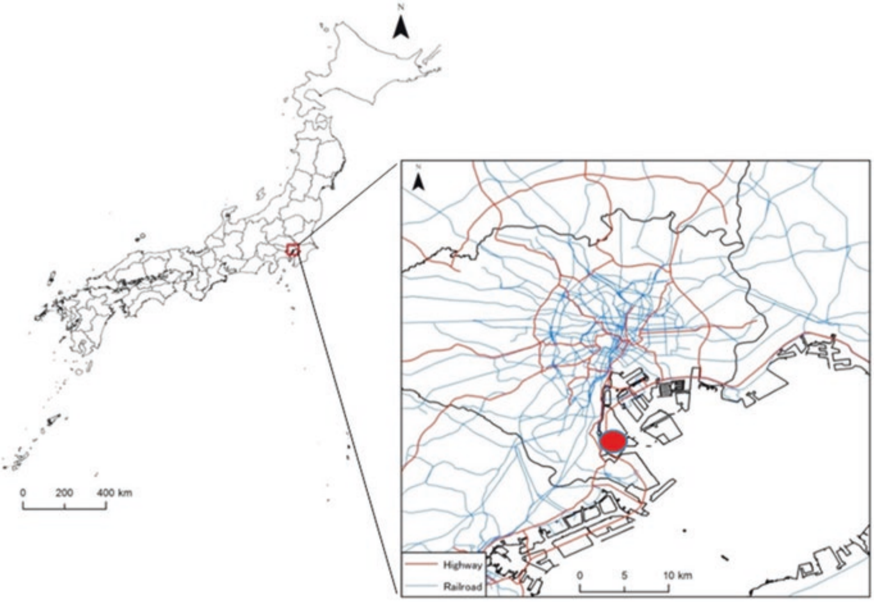

Fig. 8.9 Location of the Tokyo Port Wild Bird Park. (35°35′0.5″N, 139°45′47.7″S)

Fig. 8.10 Artificial tidal flat and a group of wild birds (Japanese Cormorant)

Table 8.5 Physico-chemical properties of the Tokyo Port Wild Bird Park

Horizon (cm)	EC (mS/m)	pH (H_2O)	Gas (%)	Liquid (%)	Solid (%)	Bulk Density	TC (g/kg)	TN (g/kg)	C/N
^A (2–5)	62.67	6.67	39.8	39.3	20.9	0.53	134.4	11.2	12.0
^CA (5–15)	20.47	6.22	37.4	41.0	21.6	0.58	46.7	3.88	12.0
^C1 (15–23)	6.90	6.42	26.7	46.2	27.2	0.69	27.2	2.11	12.9
^C2 (23–40)	7.94	6.58	24.8	46.9	28.3	0.73	32.7	2.24	14.6
^C3 (40–60)	6.87	7.18	–	–	–	–	22.1	1.56	14.1
^C4 (60–80)	8.52	7.68	–	–	–	–	17.6	1.27	13.8
2^C5 (80+)	12.06	8.89	–	–	–	–	6.80	0.41	16.6

2^C5: over 80 cm depth, brown (10YR 4/1), sandy loam, weak crumb structure, moderately dry, compactness 23, no gravels, very few organic matter, slightly positive NaF soil reaction.

8.4.2.1 Soil Properties at the Tokyo Wild Bird Park

General physico-chemical properties of a profile at the Wild Bird Park are shown in Table 8.5, and the soil profile itself is shown in Fig. 8.11. The bottom horizon in the soil profile shows different colors along with high EC and pH, indicating that the soil material differed from the upper horizons in terms of the construction material. The soil in the Wild Bird Park is classified as Urbic Technosols by the WRB (IUSS Working Group WRB 2014) mainly because of the high content of artifacts throughout the profile. Although the upper 40 cm exhibited a slightly acidic soil reaction, the deeper horizons below this level are alkaline, due to contaminated artifacts. Surface soils displayed high EC and total carbon content, supplied by litter from trees and biological activity through organic matter decomposition, resulting in an acidic soil reaction and an organic-rich horizon. High gas phase values indicate large pore spaces, which were maintained due to richness of soil aggregates at the surface horizon. The bottom horizon is the basement of this man-made island, showing alkali conditions with low organic matter content.

8.5 Conclusion

Surface soils on the man-made islands in Tokyo Bay, which are commonly characterized by dark color due to relatively high organic carbon content, develop quickly along with growth of planted trees. Litter supply and artificially mixed bark

Fig. 8.11 Soil profile in Tokyo Port Wild Bird Park

compost promote accumulation of humus, resulting in development of A horizons. This is also confirmed from the vertical distribution of organic carbon. Organic carbon, distributed at constant levels in the profile at the beginning of the construction, showed a decreasing trend from the surface horizon downwards after several years. Inorganic carbon originating from mixed artifacts decreases with time due to percolation of water. Acidification seems to progress with stand age, and soil bulk density decreases along with development of vegetation. Weak development of soil structure is confirmed in the profile of the Wakasu Seaside Park, 45 years after construction. Changes in moisture content and biological activity were vertically developed in the soil in the man-made island.

References

Bureau of Port and Harbor, Tokyo Metropolitan Government (2001) The survey of stabilization in garbage basement in Tokyo port. Bureau of Port and Harbor, Tokyo Metropolitan Government, Tokyo, pp 1–17 (in Japanese)

Bureau of Port and Harbor, Tokyo Metropolitan Government (2010) Web page for “The progress report of forestation in Uminomori-park”. http://www.kouwan.metro.tokyo.jp/seisakujouhou/h22/saisakujouhoupageindex8.html. Latest citation on 2nd, Feb, 2017 (in Japanese)

IUSS Working Group WRB (2014) World Reference Base for Soil Resources 2014. International soil classification system for naming soils and creating legends for soil maps, World soil resources reports no. 106. FAO, Rome

Matsufuji Y (1995) Purification mechanism by activated cover soil and new waste disposal system. J Mater Cycles Waste Manag 6:278–284 (in Japanese with English abstract)

Mori H (2012) Stability indices of refuse landfill in Tokyo Port. Trans Jpn Soc Irrig Drain Rural Eng 80:549–554 (in Japanese with English abstract)

Research Committee of Japanese Institute of Landscape Architecture (2001) Ground maintenance manual in landscape planting. J Jpn Inst Landsc Archit 63:224–241 (in Japanese)

Sakagami K (1978) Soils of reclaimed land along Tokyo Port area: a case with construction discharge. J Jpn Soc Pedol 22:115–126 (in Japanese with English abstract)

Takani Y (2001) Consideration on the formation process of parks and open spaces as a case study on Wakasu Seaside Park in Port of Tokyo. J Jpn Inst Landsc Archit 64:719–722 (in Japanese with English summary)

Chapter 9
Soils in Reclaimed Land After Drainage in Isahaya Bay

Masayuki Kawahigashi, Shunsuke Shinagawa, and Kenshi Ishii

Abstract Development of polder along water front regions in Japan to create new agricultural areas has occurred since the Medieval Ages. In Nagasaki Prefecture, reclamation in the Isahaya Bay area began in 1330AD, and has grown to 3500 ha, making it the largest farmland in Nagasaki Prefecture until modern times. The recent reclamation project in the bay area started in 1992 and was finished in 1999, with the project as a whole being completed in 2008. After the provisional closing of the tidal gate for construction of the tidal embankment in April 1997, the site became a stretch of dry land about 0.5 m above the water level of the regulation reservoir. In addition, artificial modifications, such as cutting ditches, were allowed for part of the dry lands. The annual flooding frequency is about four times per year, with a flood duration of no more than 24 h. As a result, pioneering vegetation developed at the investigation site during at least the first five years following the provisional gate closure. In the reclaimed area, there are sporadically dry fields covered with goldenrod vegetation. A moderate amount of angular blocky soil structure was observed below the water table in the soil profile, indicating that the subsoil was relatively dry due to a lowering of the groundwater table. Frequent repetition between wet and dry conditions due to changes in the water level can promote the formation of a blocky structure. During the sedimentation process the changes in depth of the water at some specific locations presumably promoted the formation of angular blocky soil structures. The reclaimed land along the seacoast

---

M. Kawahigashi (✉)
Department of Geography, Graduate School of Urban Environmental Sciences,
Tokyo Metropolitan University, Hachioji, Tokyo, Japan
e-mail: kawahigashi-masayuki@tmu.ac.jp

S. Shinagawa
Geology and Geotechnical Engineering Research Group, Public Works Research Institute,
Tsukuba, Japan
e-mail: sinagawa@pwri.go.jp

K. Ishii
Environmental Research Unit, Nagasaki Agricultural and Forestry Technical
Development Center, Nagasaki, Japan
e-mail: ishiken@pref.nagasaki.lg.jp

M. Watanabe, M. Kawahigashi (eds.), *Anthropogenic Soils in Japan*,
International Perspectives in Geography 9,
https://doi.org/10.1007/978-981-13-1753-8_9

can be considered a specific environment that forms a specific soil structure at a relatively fast rate.

Keywords Polder · Tide · Soil structure · Vegetation change

9.1 Introduction

The Isahaya Bay polder is located along the inner section of Isahaya Bay in the central part of Nagasaki Prefecture (Fig. 9.1). The land is surrounded by the Tara Mountain range on the northwest, and by the Shishikuraidake and Azumadake mountain ranges on the southwest. The polder is also an estuary area for various rivers such as the Honmyo River, Sakai River, and Ariake River. As it is located in the warmer climatic zone of the southwest, the climate is relatively warm and features a large amount of rainfall. However, compared to peripheral areas of the prefecture, the winters are colder and the summers are hotter (Fig. 9.2).

The purpose of the Isahaya Bay reclamation project is to enhance disaster prevention capabilities, including measures against high tides and floods, in the interest

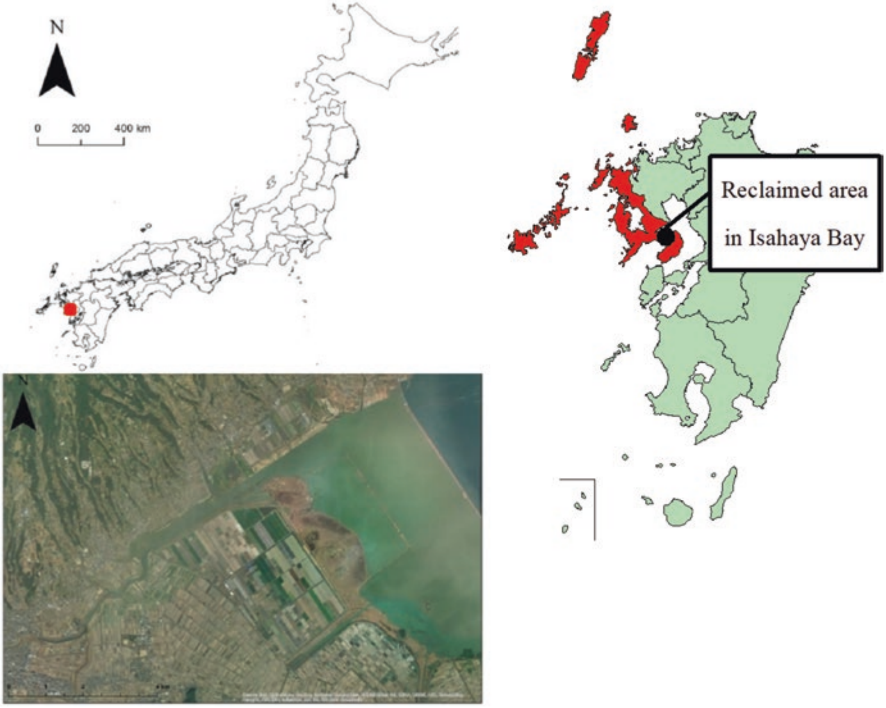

Fig. 9.1 Location of reclaimed area in Isahaya Bay

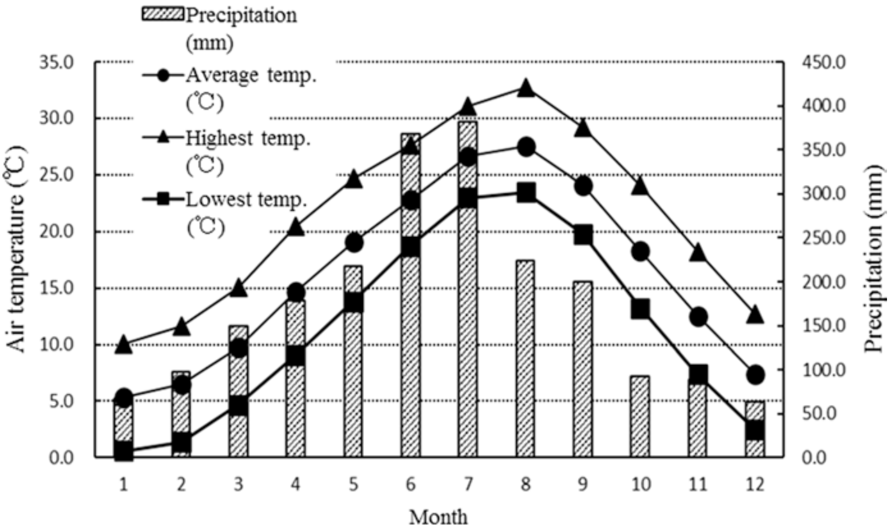

Fig. 9.2 Thirty years averaged annual precipitation and temperature of Isahaya-city (1981–2010). Filled circles represent average temperatures, filled triangles represent recorded high temperatures, filled squares represent recorded low temperatures

of constructing high-grade, large-scale, flat farmland in the lowlands behind the historically managed farmlands. The project started in 1986, tidal embankment construction started in 1992 and was finished in 1999 (Kyusyu Regional Agricultural Administration Office (KRAAO) 2007), with the project as a whole being completed in 2008.

Reclamation has a long history, according to literature on the subject entitled "Fukae Documents (Fukae bunsho)", which began in 1330 (Kawachi 1999). The current Isahaya plain is said to be a polder built over many years by the people living in the coastal area of the Isahaya Bay (Fig. 9.3). The inhabitants of the area have been building up the embankment and drying the land for ~400–500 years. The polder has an area of about 3500 ha (Isahaya Bay Regional Improvement Fund 1993). It is the largest crop area in Nagasaki Prefecture with many steep slopes and very little flat ground.

From 2008, the constructed 672 ha of farmland was leased by the Nagasaki Prefectural Agricultural Promotion Agency to the farmers to start cultivation and agricultural management (Nagasaki Prefecture 2016). Gley soils with fine soil texture are distributed in the agricultural area (Table 9.1). The soils are characterized by moderate to strong stickiness, with a gley horizon appearing at shallow depth. Immediately after construction, the gley horizon appeared from the ground surface to the shallow depth of the soil, but following the installation of underground conduits, the gley horizon moved deeper down into the soil profile. The concentration of water-soluble chlorine which had been high also immediately decreased after construction.

In 2016, cultivation of 477 ha of open field vegetables such as lettuce, onions, carrots, etc., together with 14 ha of greenhouse-grown vegetables and flowering

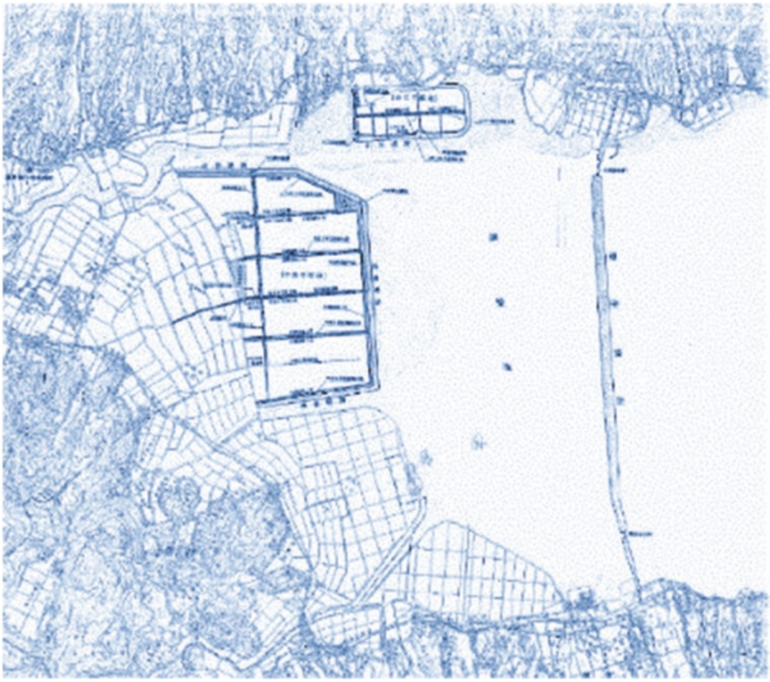

Fig. 9.3 Map of reclaimed area in Isahaya Bay

Table 9.1 Soil properties of the top gley horizon in the farmland locating reclaimed area in Isahaya Bay (Nagasaki Prefecture 2011)

Year	Depth from soil surface (cm)	pH (H_2O)	EC (mS/cm)	Cl^- (g/l)
2006–2007	49.4	7.2	0.39	1.83
2010	57.2	7.3	0.09	0.57

2006–2007: Data collected from 16 farming sites
2010: Data collected from 12 farming sites

trees/shrubs such as Japanese mustard spinach, tomatoes, chrysanthemums, etc., 169 ha of forage crops, and 20 ha of soybeans and wheat were cultivated by 40 management bodies (18 individual management bodies and 22 agricultural production cooperatives). An important aspect of the operations is that all farmers obtain certifications to manage the land and also be certified as eco-farmers, and that conservation tillage is conducted to achieve criterion of certification as special agricultural products and organic products under the Japanese Agricultural Standard (JAS; Nagasaki Prefecture 2016).

In the farmlands of Isahaya and Unzen cities on the periphery of the Isahaya Bay polder, crops such as rice, onions, potatoes, and broccoli, etc., are cultivated, forming a prominent production area in the Prefecture. Paddy fields are scattered across the Ono district and Moriyama district in Isahaya City, as well as in the

Fig. 9.4 Fertilizer application along rice seedlings

Yamada district in Unzen City. Most of these areas are former reclaimed areas. The soils are clayey, and consist of so-called “gata-soil” that is, primarily gley soils with fine texture and clay-loamy to clayey properties, having a gley layer appearing in the shallow depth. Numerous onion fields extend across the Nagata district of Isahaya City, potato fields in the Aino district of Unzen City, and broccoli fields in the Azuma district of Unzen City. The soil mainly consists of clay-loamy to clayey fine textured red soils and fine textured yellow soils.

In the peripheral areas, in order to reduce negative environmental impacts at the same time as promoting production, application of shallow water puddling, side-dressing fertilizing, and controlled availability of fertilizer are being introduced for paddy rice cultivation (Fig. 9.4). In open field vegetable cultivation, planting of cover crops (green manure crops, Fig. 9.5), localized fertilizer application, and introduction of low concentration fertilizer with reduced phosphate and potassium are being promoted to suppress turbid water inundation during the rainy season.

9.2 Investigation of Isahaya Bay Polder Soils

9.2.1 Management of the Water Level in Isahaya Bay

Our investigation site is the former tideland of Isahaya Bay, an emerged land segment in the regulating reservoir of the Isahaya Bay polder. The elevation here is about −0.5 m, according to the 5-m mesh map of the Japanese Geospatial Information Authority. Since the provisional closing of the tidal gate in April 1997,

Fig. 9.5 Plantation and plowing-in of cover crop to reduce chemical fertilizer application

the water level is managed at Tokyo Peil (TP), the mean sea level of Tokyo Bay, equal to −1.0 m, and what used to be sea water is transformed into fresh water. Although the flooding frequency of the investigation site is unknown, the water level has been recorded to exceed the standard of −0.5 m about 15 times, between May 1997, the launch date for maintaining the water level at −1.0 m, and December 2000 (Ministry of Agriculture, Forestry and Fisheries Rural Promotion Bureau (MAFF RPB) 2001). The maximum water level during the large-scale flood (daily rainfall of 342 mm, maximum hourly rainfall of 101 mm) on July 23, 1999, was 0.0 m in elevation, and the time period over which the elevation exceeded −0.5 m was about 24 h (MAFF RPB 2003).

According to past aerial photographs (GSI website) taken by the Japanese Geospatial Information Authority in October 1992, the shape of the embankment in the Oe polder is visible, and we observed that while construction started on both ends of the tidal embankment, the investigated site is completely submerged below sea level. In March 1998, straight ditches were constructed in part of the former tideland that was devoid of vegetation. In May 2003, grooving was carried out on a wider scale in parts of the former tideland. At this time, vegetation was growing thickly. Furthermore, in a photo taken in May 2010, tracks from heavy machinery were noted over a wide area, and disturbances in parts of the surface soil could be observed outside the construction site.

9.2.2 Soil Descriptions of the Former Tidal Land

The following is a description of the environment of the investigation site based on materials and aerial photographs.

1. Prior to April 1997, the site consisted of tidal flats affected by large tidal changes in the Ariake Sea, as well as being a seawater environment and a vegetation-free site.
2. After the provisional gate closing for construction of the tidal embankment in April 1997, the site became a stretch of dry land with a water level approximately +0.5 m higher than the water level of the regulation reservoir. In addition, artificial modifications such as cutting ditches were allowed for part of the dry lands. The annual flooding frequency is about four times per year, and the duration of flooding persists for a maximum of 24 h. As a result, vegetation colonized the investigation site during the first 5 years after the provisional closing the gate.

9.2.2.1 Soil Description of the Area Occupied by Reed Community (Fig. 9.6)

Oi: +12 to 0 cm, grayish olive (5Y 4/2), root mat with very fine roots, common fine and medium roots, clear smooth boundary,

Gr1: 0 to 11 cm, olive gray (2.5GY 5/1), heavy clay, weak crumb structure, compactness 2–3, no gravels but abundant broken shells, many very fine and fine roots, many rhizome, slightly positive reaction of dipyridyl test, gradual smooth boundary,

Gr2: 11 to 38 cm, greenish black (7.5GY 2/1), heavy clay, massive structure, compactness 2–3, no gravels but abundant broken shells, many very fine and fine roots, many large size rhizome, diffuse wavy boundary,

Gr3: 38 to 58+ cm, olive gray (5GY 5/1), heavy clay, massive structure, compactness 2–3, no gravels but many large shells, many very fine and fine roots, many large rhizome, strongly positive reaction of dipyridyl test.

Remarks: one crawfish inhabited the Gr1 horizon. A plastic sheet used for a fishing rod label (Regno Light 2256 produced by Ryobi) was found at a depth of 70 cm.

9.2.2.2 Soil Description of the Area Covered by a Goldenrod Community (Fig. 9.7)

A: 0 to 6 cm, brownish black (2.5Y 3/1), heavy clay, weak crumb structure, compactness 3, no gravels but many broken small shell fragments, many very fine and fine root and few medium roots, gradual smooth boundary,

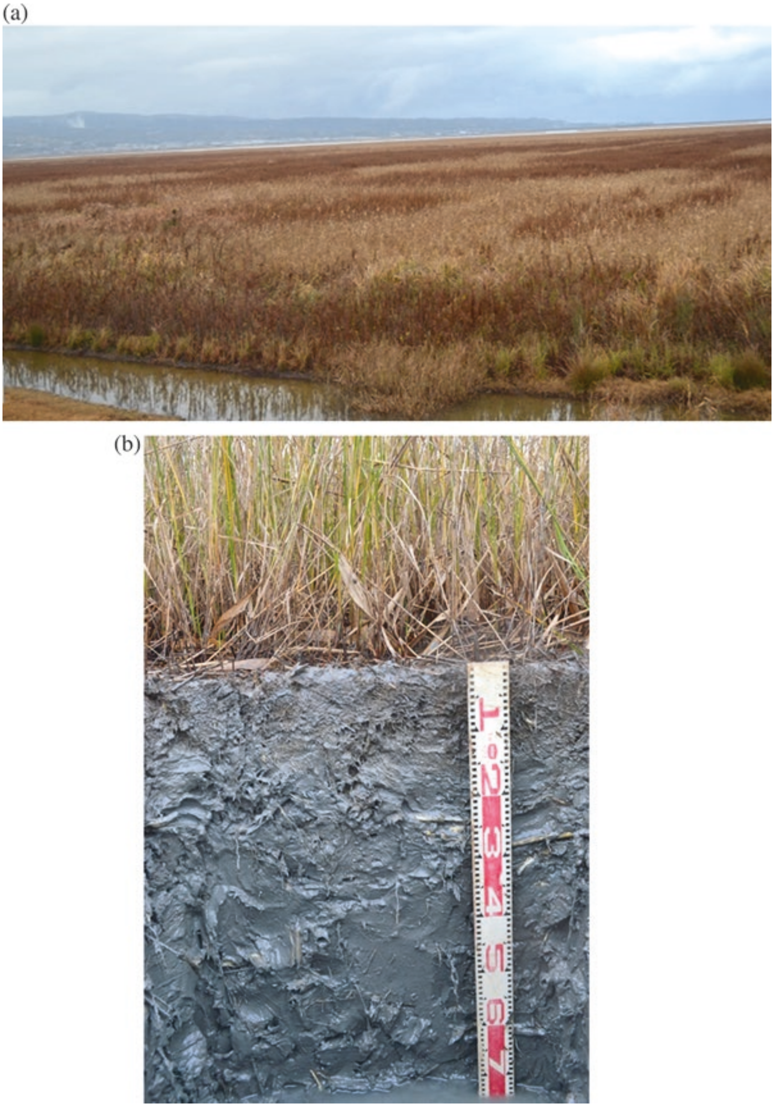

Fig. 9.6 Overview (**a**) and profile photo (**b**) of the area occupied by reed community

Bg1: 6 to 16 cm, olive black (5Y 3/2), heavy clay, medium sub-angular blocky structure, compactness 10, no gravels but many broken small shell fragments, few very fine and fine roots, few thread like root mottles (7.5YR 4/4), gradual smooth boundary,

Bg2: 16 to 40+ cm, gray (7.5Y 4/1), heavy clay, medium angular blocky structure, compactness 12, no gravels but abundant broken small shell fragments, few

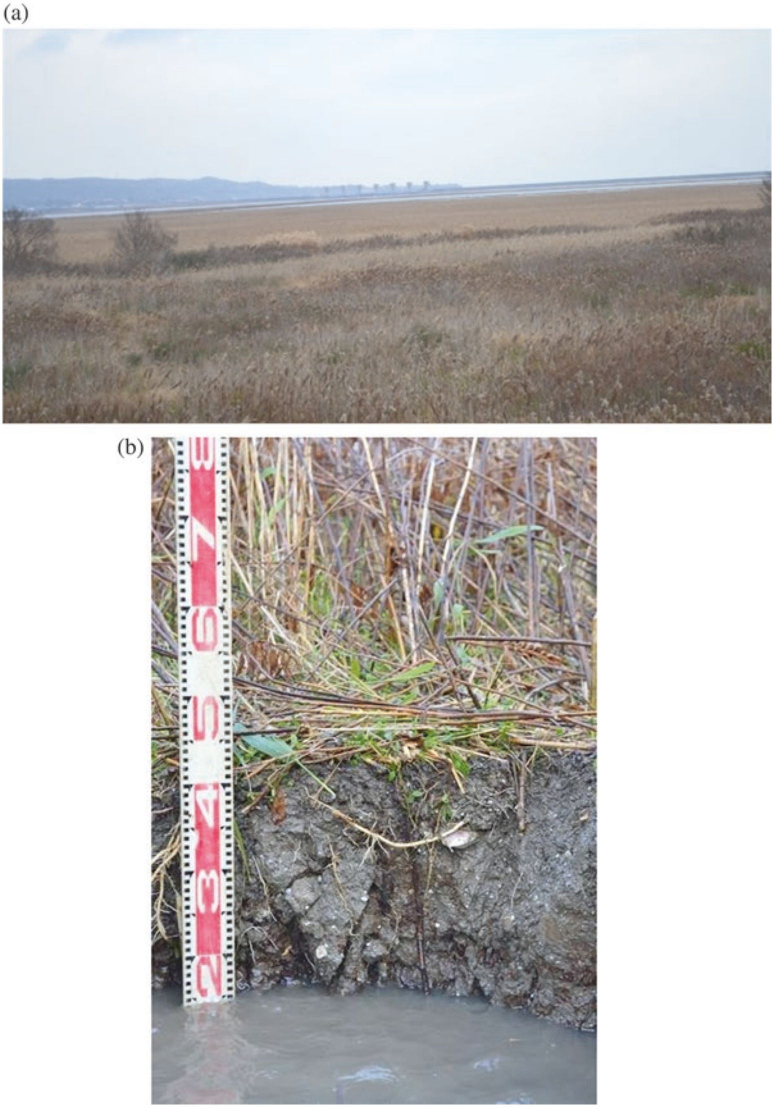

Fig. 9.7 Overview (**a**) and profile photo (**b**) of the area covered by the goldenrod community

medium roots, few medium rhizome, few thread-like root mottling, many organic matter cutans (7.5YR 3/4), strongly positive reaction of dipyridyl test.

Remarks: Ground water table was at 20 cm depth. An earthworm was found at the surface horizon.

9.3 Comparison of Soil Properties Developed Under Different Vegetation in the Reclaimed Land

The two soil profiles of the reclaimed land have different properties. A medium amount of angular blocky soil structure was observed below the water table in soil covered with goldenrods, thereby indicating that the subsoil was relatively dry due to an unexplained decrease in the ground water table. The formation of thread-like root mottles in soil peds beneath the goldenrod community also supports the relatively dry condition of the soil because of aeration. Frequent repetition between wet and dry conditions due to changes in groundwater level can promote the formation of a blocky structure and mottles. Small dry areas sporadically distributed through the reclaimed land are accompanied by an invasion of goldenrod vegetation into the reed community. The reed grass community has spread through the reduced soil with a massive structure due to constant inundation in contiguity with the goldenrod community. Soil beneath the reed community has remained in a very reductive condition. Sporadic dry areas on the reclaimed land presumably enabled the establishment of the goldenrod community on the reduced soil in forming the soil structure.

A plastic commodity label was dug out from 70 cm in depth of the soil profile at the reed site, indicating that the rate of sediment accumulation on the reclaimed land was relatively fast and could be expected to progress at a rate of about 4–5 cm/y. During the sedimentation process, changes in depth of the water table at some specific locations presumably promoted the formation of angular blocky soil structures. The reclaimed land along the seacoast can be considered a specific environment that forms a specific soil structure of angular blocky soil peds at a relatively fast rate.

9.4 Conclusion

Reclamation of Isahaya Bay has long history, extending back to the fourteenth century. The reclaimed area is a polder, created for use as an agricultural area for the past 400–500 years. The research site on the coastal area of the polder has a history of alternating dry and wet condition since the provisional closing of the tidal gate in 1997. Construction of many ditches promotes drying of the land. Processes of alternating dry and wet conditions influences the physical and chemical properties of the soil. Strongly reductive soil with massive soil structure was observed under the reed vegetation. In contrast, angular blocky soil structure has developed under the goldenrod vegetation, probably due to repetition of drainage and flood conditions. Soil mottles formed by aeration are also a sign of dry conditions in the subsoil beneath goldenrod vegetation. The decrease of groundwater level after following closure of the tidal gate can sporadically form dry areas covered with goldenrod vegetation within the reed community. From the sedimentation speed estimated by a buried plastic waste, angular blocky soil structure can develop quickly under the specific conditions characterized by the repetition of dry and wet soil.

References

GSI (Geospatial Information Authority of Japan) Map/aerial photograph viewing service. Website of GSI http://mapps.gsi.go.jp/ (in Japanese)

Isahaya Bay Regional Improvement Fund (1993) History of Isahaya Bay reclamation. Isahaya Bay Regional Improvement Fund, p 2 (in Japanese)

Kawachi T (1999) Tideland and reclamation. Nagasaki Prefecture Rokin, p 53 (in Japanese)

KRAAO (Kyusyu Regional Agricultural Administration Office) (2007) Outline of state-owned Isahaya Bay land improvement project. KRAAO (in Japanese)

MAFF RPB (2003) Ideas, proposals, etc. towards the opening of the gate. 6th medium/long-term gate opening survey materials delivered in the deliberation committee meeting. Website of MAFF RPB. http://www.maff.go.jp/j/study/other/kaimon/sen06/pdf/data3.pdf (in Japanese)

MAFF RPB (Ministry of Agriculture, Forestry and Fisheries Rural Promotion Bureau) (2001) Study material for investigation on the opening and closing of the tidal embankment drainage gates -Ariake Sea seaweed crop failure third party committee materials-. Website of MAFF RPB. http://www.maff.go.jp/kyusyu/seibibu/isahaya/chousa/pdf/data_23.pdf (in Japanese)

Nagasaki Prefecture (2011) Guidelines for large-scale eco-friendly agriculture and technical measures for Isahaya Bay polder. Nagasaki Prefecture, p 16 (in Japanese)

Nagasaki Prefecture (2016) Outline of farming in Isahaya Bay polder. Nagasaki Prefecture Isahaya Bay Polder Farming Center, Nagasaki Prefecture Isahaya Reclamation Division (in Japanese)

Chapter 10
Soil Dressing with Alluvial Soil Materials: "*Dorotsuke*"

Shokichi Wakabayashi

Abstract *Dorotsuke* was a winter off-season chore of the farmers in the Omiya upland area alongside the Arakawa River from November to May. Farmers transported alluvial soil material onto the uplands by horse, left it to mature around their fields, and then used it a few years later. The application of alluvial soil materials to Andosol fields had the effect of supplying available phosphates, and increasing yields of barley. Periodic long-term application of *Dorotsuke*, together with ploughing, created thick anthropogenic epipedons consisting of a mixture of alluvial soil material and Andosol topsoil. The soil profile exhibits vertical weakening of the andic properties, such as low bulk density, high content of short-range-order minerals, and high phosphate retention. The contents of acid-oxalate-soluble aluminum (Al_{ox}) and iron (Fe_{ox}), derived from short-range-order minerals and organo-mineral complexes, were lower in the upper horizons. Phosphate retention (P ret) also decreased from the Andosol horizons to the present topsoil. The soil profile was rich in exchangeable calcium (Ex_{Ca}) mainly derived from the alluvial soil material receiving the water of the Arakawa River. Base saturation (BS) was higher than 80% and soil acidity was mild in most of the profile, but acidification has progressed in the present topsoil through calcium leaching. In the field where the anthropogenic epipedon is thicker than 50 cm and its base saturation is higher than 50%, the soil can be classified as Terric Anthrosols. When the BS in topsoil dips below 50% through calcium leaching, however, the taxa of the soil may change.

Keywords Soil fertility · Andosols · Anthrosols · Soil dressing

---

S. Wakabayashi (✉)
National Agriculture and Food Research Organization, Tohoku Agricultural Research Center,
Agricultural Radiation Research Center, Fukushima, Japan
e-mail: shokichi@affrc.go.jp

M. Watanabe, M. Kawahigashi (eds.), *Anthropogenic Soils in Japan*,
International Perspectives in Geography 9,
https://doi.org/10.1007/978-981-13-1753-8_10

10.1 Introduction

In pre-modern times, Japanese farmers used many types of natural fertilizers, not only organic materials but also earth-derived materials such as river mud, sea sand, burnt soil, or sod. In the Omiya upland, on the central Kanto plain, farmers gathered alluvial soil from the neighboring dry riverbed of the Arakawa River to apply to their fields up until the early twentieth century. This traditional soil dressing technique is referred to as "*Dorotsuke*." *Dorotsuke* was a winter off-season chore, from November to May. Farmers transported the alluvial soil onto the uplands by horse, left it to mature around their fields, and then used it a few years later (Yoshikawa 1975). The alluvial soil was spread on the fields together with organic materials (human manure, soymeal, or compost) at the time of sowing barley, or it was spread by itself around the base of barley crops during the growth phase. The amount of applied alluvial material was 3.8–5.6 kg m^{-2} annually or biyearly during the 1900s (Shiba and Sasaki 1960). On the basis of ^{14}C dating of soil humic acids and charcoal, however, *Dorotsuke* is estimated to have been practiced for 400–600 years, with an application rate throughout the period estimated at 0.8–1.3 kg m^{-2} $year^{-1}$ (Wakabayashi et al. 2012). Natural soils on the Omiya upland are Andosols (volcanic ash soils), which were regarded as one of the least productive soils in Japan because the short-range-order minerals they contain strongly fix soil phosphates, thus inhibiting plant uptake until the introduction of phosphate fertilizers. The application of alluvial soil materials to Andosol fields had the effect of supplying available phosphates, and increasing yields of barley (Sakai 1949). Through periodic long-term application, the alluvial soil material had gradually accumulated on the Andosol via mixing with the original topsoil, and consequently a thick anthropogenic epipedon was formed. Its thickness is sometimes over 50 cm, and reaches a maximum of 100 cm. This anthropogenic pedogenesis is similar to that in plaggen soils in Europe.

10.2 "*Dorotsuke*" in the Omiya Upland

10.2.1 Geological and Agricultural Setting of the Omiya Upland

The Omiya upland in Saitama Prefecture is a Late Pleistocene terrace located to the north of Tokyo, Japan, and is surrounded by alluvial lowlands of the Arakawa River system (Fig. 10.1). The area where *Dorotsuke* had been practiced is in the western part of the upland, within a 4 km swath to the east of Arakawa River, between Konosu City and Saitama City (Yoshikawa 1975).

Figure 10.2 is the soil map showing the Omiya upland and the surrounding area. This map data is based on a fertility conservation survey (1959–1978) in Japan. In the survey, upland soils containing distinct alluvial soil material were classified as

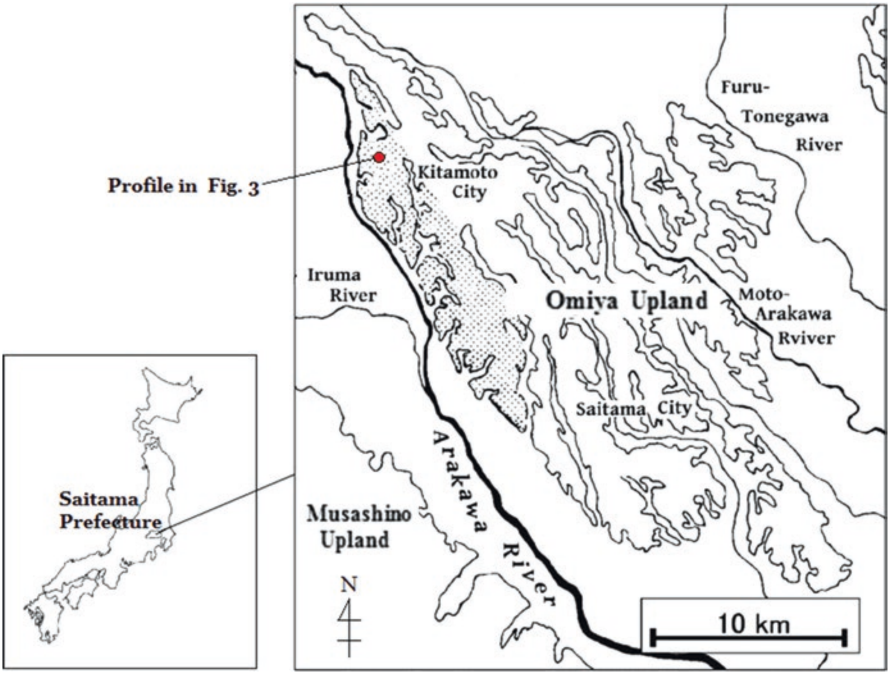

Fig. 10.1 Location of the area where *Dorotsuke* had been practiced. (Dotted area; Yoshikawa 1975)

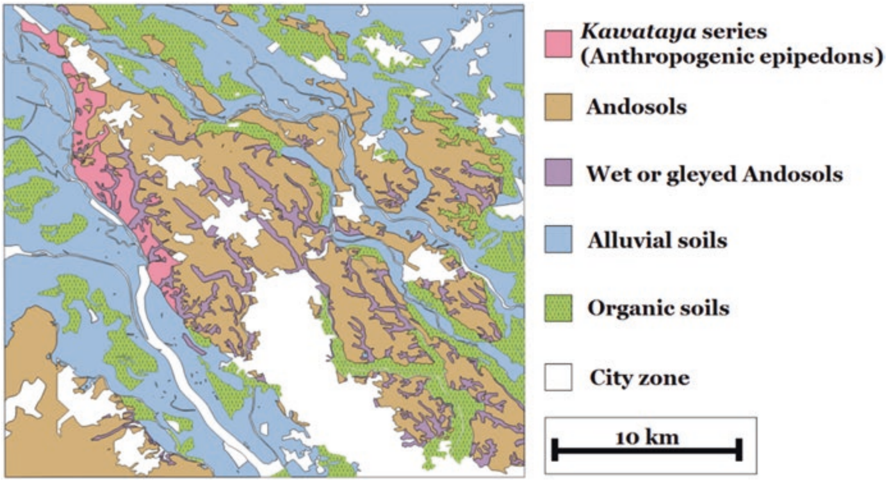

Fig. 10.2 Soil map of Omiya upland and surrounding area

the Kawataya series (Akimoto and Nomura 1975). Its distribution area is illustrated on the western part of the upland in the soil map, though it does not cover the whole area where *Dorotsuke* had been practiced (Fig. 10.1).

Traditional agriculture on the Omiya upland was based on winter harvesting of barley (*Hordeum vulgare*) along with summer harvesting of soybeans (*Glycine max*), upland rice (*Oryza sativa*), foxtail millet (*Setaria italica*), or sweet potatoes (*Ipomoea batatas*) in the nineteenth and early twentieth centuries (Hayama 1980; Saitama Prefecture 1954). Wheat (*Triticum aestivum*) was also harvested in winter but its acreage was smaller than that of barley until 1960 (Ministry of Agriculture and Forestry 1962; Saitama Prefecture 1954). After that time, barley production was phased out as farmers crop new vegetables, orchard trees, or paddy rice in the fields.

10.2.2 Soil Descriptions and Physico-chemical Properties

Ap: 0 to 8 cm, brownish black (10YR2/2), clay loam, moderate medium sub-angular blocky structure and weak fine crumb structure, moderately moist, compactness 11, high organic matter, smooth clear boundary,

A1: 8 to 27 cm, brownish black (10YR2/3), clay loam, weak coarse sub-angular blocky structure, moderately moist, compactness 19, high organic matter, wavy gradual boundary,

A2: 27 to 39 cm, brownish black (10YR/3/2), clay loam, moderate coarse sub-angular blocky structure, moderately moist, compactness 14, high organic matter, very weakly positive NaF reaction, wavy diffuse boundary,

A3: 39 to 51 cm, brownish black (10YR3/2), clay loam, weak medium sub-angular blocky structure, moderately moist, compactness 15, high organic matter, weakly positive NaF reaction, irregular diffuse boundary,

A4: 51 to 64 cm, brownish black (10YR3/1), light clay, moderate coarse sub-angular blocky structure, moderately moist, compactness 16, high organic matter, moderately positive NaF reaction, irregular clear boundary,

2A5: 64 to 84 cm, black (10YR2/1), light clay, moderate medium sub-angular blocky structure, moderately moist, compactness 14, very high organic matter, strongly positive NaF reaction, irregular gradual boundary,

2Bw: 84 to 100+ cm, dark brown (7.5YR3/4), heavy clay, moderate coarse sub-angular blocky structure, moderately moist, compactness 24, medium organic matter, strongly positive NaF reaction.

In the soil profile of Fig. 10.3, the buried black color horizon (2A5) is a remnant of the original Andosol topsoil. The brighter color horizons above are an anthropogenic epipedon consisting of a mixture of the original topsoil and the alluvial soil material. The anthropogenic epipedon, unlike plaggen soils in Europe, generally contains no artifacts.

Fig. 10.3 Soil profile of the *Kawataya* series (in Kitamoto City)

Table 10.1 Physical properties of the Kawataya series

Depth (cm)	Gas (%)	Liquid (%)	Solid (%)	BD (Mg/m^3)	MWHC (%)
0–5	30	30	40	1.08	45
15–20	25	31	44	1.22	46
30–35	29	33	38	1.07	51
50–55	36	36	27	0.79	58
65–70	37	40	23	0.63	64
80–85	30	50	20	0.58	68

BD bulk density, *MWHC* maximum water holding capacity

10.2.2.1 Soil Physico-chemical Properties

As a result of the periodic application of alluvial soil along with ploughing, the soil profile exhibits vertical weakening of andic properties, such as low bulk density, high content of short-range-order minerals, and high phosphate retention.

The physical properties of the soil profile are shown in Table 10.1. In the Andosol horizons (below 64 cm depth), the solid phase was only 20% of total soil volume, and bulk density (BD) was 0.6. In the anthropogenic epipedon, these properties were higher in the upper horizons because the mixing ratio of alluvial soil material increased. Conversely, maximum water holding capacity (MWHC) and water content (liquid phase) were higher in the lower horizons where there was a higher

Table 10.2 Chemical properties of Kawataya series

Horizon (cm)	TC (g/kg)	TN (g/kg)	pH (H_2O)	CEC ($\mathrm{cmol_c/kg}$)	$\mathrm{Ex_{Ca}}$ ($\mathrm{cmol_c/kg}$)	BS (%)	$\mathrm{Al_{ox}}$ (g/kg)	$\mathrm{Fe_{ox}}$ (g/kg)	P ret (%)
Ap (0–8)	15.3	1.4	5.62	13.2	5.0	50	6.3	5.6	33.1
A1 (8–27)	11.2	1.0	5.57	12.5	4.6	51	6.2	5.7	34.8
A2 (27–39)	16.5	1.3	6.32	16.5	11.0	81	14.4	9.1	62.5
A3 (39–51)	23.9	1.7	6.45	18.7	15.8	96	22.1	11.9	78.2
A4 (51–64)	23.0	1.6	6.54	19.5	17.5	100	21.7	11.7	77.7
2A5 (64–84)	44.8	2.9	6.52	26.1	22.2	93	44.5	20.5	97.4
2Bw (84–100+)	19.7	1.7	6.67	18.6	14.6	89	47.5	25.5	98.6

TC total carbon, *TN* total nitrogen, *CEC* cation exchange capacity, Ex_{Ca}, exchangeable calcium, *BS* base saturation, Al_{ox}, Fe_{ox} acid-oxalate-soluble aluminum and iron, *P ret* phosphate retention

incidence of relict Andosol materials. Chemical properties are shown in Table 10.2. The contents of acid-oxalate-soluble aluminum ($\mathrm{Al_{ox}}$) and iron ($\mathrm{Fe_{ox}}$), derived from short-range-order minerals and organo-mineral complexes, were lower in the upper horizons. Phosphate retention (P ret) also decreased from the Andosol horizons to the present topsoil. Total carbon (TC) and nitrogen (TN) contents and cation exchange capacity (CEC) were highest in the remnants of the original Andosol topsoil, and decreased at the upper horizon. The soil profile was rich in exchangeable calcium ($\mathrm{Ex_{Ca}}$) mainly derived from the alluvial soil material receiving the water of Arakawa River. The river water is high in calcium concentration as a result of limestone weathering in the Chichibu Mountains (Kobayashi 1943). The vertical distribution of $\mathrm{Ex_{Ca}}$, however, indicates that a large portion of the calcium contained in the applied soil material has leached down. Base saturation (BS) was higher than 80% and soil acidity was mild in most of the profile, but acidification has progressed in the present topsoil through calcium leaching. In the field where the anthropogenic epipedon is thicker than 50 cm and its BS is higher than 50%, the soil can be classified as Terric Anthrosols using world reference base for soil resources (IUSS Working Group WRB 2014). When the BS in topsoil dips below 50% through calcium leaching, however, the taxa of the soil may change.

10.3 Conclusion

An historical soil dressing technique, "*Dorotsuke*", ameliorated the fertility of the Omiya upland soils along Arakawa River. Exchangeable calcium and available phosphate mainly supplied by soil dressing were a great advantage for crop production. Andosols were covered by thick anthropogenic epipedons consisting of a mixture of the original topsoil and the dressed soil. Soil properties were vertically changed in the anthropogenic epipedon and at the boundary with buried Andosols. Suspension of the soil dressing process decreases base saturation, resulting in a change in soil taxa due to changes in major soil properties.

References

Akimoto T, Nomura S (1975) III. Soil map. In Fundamental land classification survey "Konosu", Saitama, pp 34–41 (in Japanese)

Hayama T (1980) Bibliographical introduction of "Kosaku Shiyo sho". In: Nihon Nosho Zenshu 22. Nobunkyo, Tokyo, pp 295–342 (in Japanese)

IUSS Working Group WRB (2014) World reference base for soil resources 2014. International soil classification system for naming soils and creating legends for soil maps, World soil resources reports no. 106. FAO, Rome

Kobayashi J (1943) Chemical study of the quality of irrigation water -1st report: water quality of the Arakawa and Tamagawa river systems. Jpn J Soil Sci Plant Nutr 17(7):373–375 (in Japanese)

Ministry of Agruculture and Forestry (1962) Japanese agricultural census 1960. Association of Agriculture and Forestry Statistics, Japan (in Japanese)

Saitama Prefecture (1954) Musashi no kuni gunsonshi Vol. 2: pp.323–380, Vol. 3: pp.6–12, pp.27–138, pp.199–202, pp 215–218. Saitama Prefecture Library, Saitama (in Japanese)

Sakai N (1949) Improvement of volcanic ash field soils through soil dressing. Saitama Agricultural Library 6. Saitama Prefectural Agricultural Experiment Station, Saitama (in Japanese)

Shiba H, Sasaki K (1960) Researches on variation of chemical and physical properties of the mixture of two different soils. Bulletin of the Saitama Prefectural Agricultural experiment station 16. Saitama Prefectural Agricultural Experiment Station, Saitama (in Japanese with English summary)

Wakabayashi S, Matsuzaki H, Miyairi Y, Asano M, Tamura K (2012) Chronology of anthropedogenesis in the Omiya tableland, Japan, based on a 14C age profile of humic acid. Soil Sci Plant Nutr 58(6):737–749

Yoshikawa K (1975) "*Dorotsuke*" soil dressing cultivation technique on the Omiya tableland. Saitama Folklore 5: 120–128 (in Japanese)

Chapter 11
Soils Modified by Topsoil Dressing and Deep Tilling in Peaty Farmland

Hitoshi Hashimoto

Abstract In the Ishikari Plain in Hokkaido, where peat soils originally developed in a wetland setting, drainage of ground water and soil dressing were essential processes to develop new agricultural areas. Dressing soils were generally taken from the subsoil strata of adjacent areas, and include soils from plateaus or hills such as grey upland soils, brown forest soils, and occasionally dredged sediments from the bottom of dam lakes. Multiple rounds of soil dressing were required for compensation of ground subsidence and provision of extra nutrients. The thickness of the current surface mineral horizon averages 30 cm, and is often not classified as peat soil according to most soil classification systems. Multiple applications of soil dressings containing clayey soil reaching up to 38 cm thickness have been implemented since 1980s, supporting development of a gleyic horizon with positive dipyridyl soil reaction underlain by thick sapric peat horizons. The soil was classified as Transportic Sapric Histosols. This is one of the typical agricultural soils distributed on the Ishikari Plain, where multiple soil dressing processes are implemented with an effective drainage system to decrease ground water level. Fresh mineral soil dressing is preferable to reduce protein content in grown rice as compared to those grown directly on peat soils.

Keywords N uptake · Rice quality · Water drainage · Ground subsidence

11.1 Introduction

Nanporo is located in the lower reaches of the Ishikari River, which at 268 km is the longest river in Hokkaido with a catchment area of 15,000 km^2. At just 6–10 m above sea level, it is relatively low-lying and consists of 5700 ha of agricultural land, most of which is used for rice paddy fields and with a basically even distribution of peat soils and aquic lowland soils. The peaty areas in the lower reaches of the

---

H. Hashimoto (✉)
Hokkaido Central Agricultural Experiment Station, Hokkaido, Japan
e-mail: hashimoto.hitoshi@ebony.plala.or.jp

M. Watanabe, M. Kawahigashi (eds.), *Anthropogenic Soils in Japan*,
International Perspectives in Geography 9,
https://doi.org/10.1007/978-981-13-1753-8_11

Ishikari River were developed into agricultural land on a small scale when first settled around 1890. The state government then began to develop it into agricultural land on a rather larger scale around 1955, supported in some districts by the World Bank from around 1955 through 1960. Enabling the land to be mainly used as rice paddy fields necessitated major regional drainage and soil dressing (soil addition) projects, which have continued up to the present. The groundwater level was successfully lowered through the main drainage canals and agricultural field drainage, resulting in no overall subsidence, but with undulations occurring in the agricultural fields.

Soil dressing ensures adequate rooting zone for crops, the production of high-quality rice, the movement of agricultural machinery, and reductions in water loss. Soil dressing projects have been carried out by the national government and the Hokkaido Prefectural government as well as other organizations. The targeted land area and subsidy rate for the expenses involved varied by project, with some projects being carried out by individuals. Dressing soils are generally taken from the subsoil strata of adjacent areas. Soil from plateaus or hills such as grey upland soils and brown forest soils are the most common, though alluvial soils dredged from the bottom of dam lakes are used in some cases.

The typical soil used for dressing consists mainly of clay with some gravel. The dressing soil is transported to a farmland by truck or tractor, and a 5–10 cm layer is generally spread over the ground surface. The soil dressing also typically takes place during winter. Soil dressing has generally been implemented at least once or twice or as many as five to six times over the same farmland through various subsidized projects over the past few decades. The reasons for multiple implementation of soil dressing include the need for extra soil due to ground subsidence—one to two implementations having been proven insufficient, the provision of additional nutrients through fresh soil dressing, the need for extra soil dressing material after soil reductions due to mixing with decomposed peat, and finally, enabling easier cultivation when the fields are used. High quality rice cultivation in the rice paddy fields aims to obtain a rice that is low in protein, and hence nitrogen-rich peaty soil is not suitable to achieve this goal without fresh mineral soil dressing.

Agricultural land was originally intended for use as rice paddy fields in Japan, but approximately 40% of the land is presently used as upland fields because of the conversion policy to address the problem of rice overproduction. Spring-sown wheat, autumn-sown wheat, soy beans, and vegetables are grown as replacement crops in the converted fields in Hokkaido. Wheat historically accounted for the majority, but the amount of vegetables grown has increased in recent years, and Nanporo is renowned for growing cabbage. Upland fields need to be tilled deeper than rice paddy fields (15–30 cm, versus 10–15 cm for rice paddy fields). The surface horizon of rice paddy fields formed through soil dressing mixes with peat in the deeper horizons. In some cases, further soil dressing takes place thereby forming a thicker surface horizon in the upland field. This then results in the surface layer usually reaching a thickness as much as 25–40 cm. In the surface layer of upland fields, peat is moderately mixed in to form a layer that has the required physical properties, which include air and water permeability, however, in some cases, clay soil dressing can result in over-thickening, too much of which negatively affects the surface drainage of the agricultural land.

As mentioned above, most of the present peaty farmland has a thick artificial surface horizon (mineral soil horizon) consisting of clay soil dressing or clay soil dressing mixed with peat, resulting from a number of different factors that include the number of times soil dressing is performed, the thickness, the tilling method used, and cultivation history. It is vastly different from natural peat soil, which contains very little mineral soil in the surface horizon, placing it in the category of man-made soil. The thickness of the surface horizon (mineral soil horizon) is currently about 30 cm on average, and is often not classified as peat soil according to most soil classification systems (Hashimoto 1994, 2006).

Soil dressing does have its disadvantages, in that it can be environmentally unfriendly as parts of plateau and hills get leveled when large volumes of soil are removed, and the soil dressing materials may contain potential acid sulfate soils (Ishiwata et al. 1992). The subsidence of farmland and emission of greenhouse gases can also result from soil dressing. Ground subsidence can occur due to the contraction/consolidation or accelerated decomposition of the peat layers, resulting from reduced groundwater levels or increased tilling depth. The subsidence problem is larger in scale for upland fields than rice paddy fields, with some researches and certain case studies corroborating this (Miyaji et al.1995; Kohyama et al. 1995). Preservation of peat farmland is generally thought to require the fields to be used as rice paddy fields (Inoue 2012) but because of the circumstances, use as upland fields is considered unavoidable. The problem of greenhouse gases being emitted as the peat decomposes is also being studied (Nagata et al. 2010).

Results of case studies of two locations in Nanporo are described below. Both were previously rice paddy fields but are currently being used as upland fields. Nanporo-1 consists of low-moor peat soils with a surface horizon (tilled layer) depth of 38 cm, and with gleization of the lower part of the surface layer being quite distinctive. Nanporo-2 consists of high-moor peat soils with a surface horizon (tilled layer) of as much as 40 cm in depth, and with soil dressing having been implemented several times in the past.

11.2 Management by Soil Dressing on Low Moor Peat Land, Nanporo-1

11.2.1 Vegetable Field with Shallow Tillage

The Naporo-1 site (Fig. 11.1) is located at 10 m above sea level, and at 43° 4′ 29.89″ N latitude and 141° 37′ 38.95″ E longitude. It is located 500 m from a canal (major drainage canal). The most recent 15 cm-thick soil dressing at the site was implemented in 1981 using clay soil. Prior soil dressing history is unknown, but it was implemented at least once or twice. The field was tilled to 25 cm during plowing in

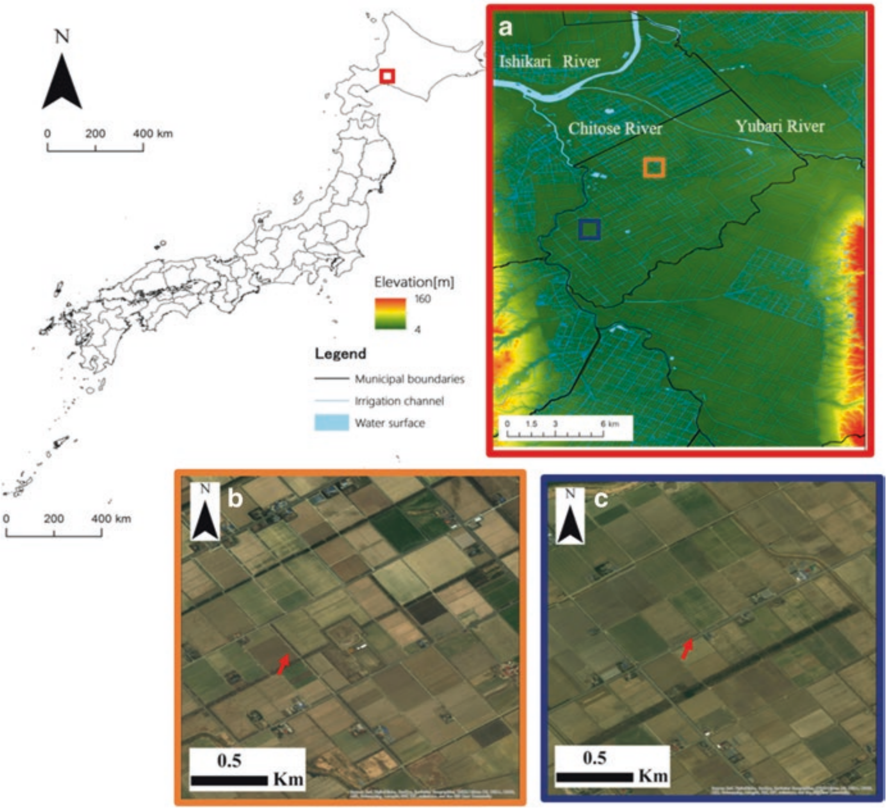

Fig. 11.1 Location of survey sites in Nanporo. (**a**) topographic map of study region, with the orange and blue squares marking the Nanporo-1 and -2 sites, respectively, (**b**) aerial photograph of the Nanporo-1 site, (**c**) aerial photograph of the Nanporo-2 site

1982 and then to 35 cm during large-scale plowing that took place in the spring of 1989. Use of the upland fields first commenced that year and cabbages have been regularly cultivated since then. The profile photograph in Fig. 11.2 was taken in April of 1990.

11.2.2 Soil Description and Physico-chemical Properties

Apg: 0 to 18 cm, dull yellowish brown (10YR4/3), light clay, sub-angular blocky structure, wet, common mottles, hardness of 10, no gravel, abundant humus (including decomposed peat), no NaF reaction, and a relatively clear smooth boundary,

Gp: 18 to 38 cm, greenish gray (5G5/1), light clay, structureless, slightly wet, common mottles, hardness of 18, no gravel, abundant humus (including decomposed peat), dipyridyl+, no NaF reaction, and a clear, smooth boundary,

Fig. 11.2 Soil profile of Nanporo-1, the site of soil dressing on low-moor peat land

He: 38 to 63 cm, brown (7.5YR4/6), decomposed low moor peat (reed), moist, hardness of 10, no gravel, no NaF reaction, and a relatively clear, smooth boundary,
Hi: 63+ cm, bright brown (7.5YR4/6), poorly decomposed low moor peat (reed), moist, hardness of 8, no gravel, and no NaF reaction.

11.2.2.1 Physico-chemical Properties of Soil

The physico-chemical properties of the soil profile at Naporo-1 are listed in Table 11.1. The surface horizon reaches a depth of 38 cm (Apg), and was formed of clay and peat in the lower layers mixed through multiple implementations of clay soil dressing and tilling. It can be considered an artificial surface soil that would never occur naturally. In the Gp horizon, only the clay soil has been compressed in the lower part of the surface horizon via an unidentified process, converted to a low permeable layer, reduced, and then formed into a gleyic element. Deep tilling following soil dressing is contrary to the original purpose of soil dressing, but in upland fields the tilling depth is deep and an artificial surface layer (mineral soil horizon) containing peat consequently forms and a naturally deposited peat layer appears beneath it. The soil is classified as Transportic Sapric Histosols according to the international union of soil science working group (IUSS Working Group WRB 2015) and Typic Low-moor Peat soils (Pedology second classification system). The surface horizon contained 5–6% organic matter with a total carbon (TC) value of 3.1–3.2%, while the peat horizon contained 40% organic matter and 23% TC

Table 11.1 Physico-chemical properties of the Nanporo-1

Horizon	pH	Gas	Liquid	Solid	Bulk density	TC	CEC	Ex_{Ca}	Ex_{Mg}	Ex_K	Base Saturation	Available P
(cm)	(H_2O)	(%)	(%)	(%)	(Mg/m^3)	(g/kg)	($cmol_c/kg$)				(%)	(mg/kg)
Ap (0–18)	6.0	16.4	44.0	39.6	1.06	3.2	30.6	13.2	8.4	0.6	72.5	98
Gp (18–38)	5.9	6.7	53.0	40.3	1.08	3.1	30.2	12.3	8.6	0.8	71.9	87
He (38–63)						23.1						

Ex exchangeable cations, *P* phosphorus

(He horizon). The soil reaction (pH) of the surface horizon was slightly acidic and inorganic carbon was not determined.

11.3 Management by Soil Dressing on High Moor Peat Land, Nanporo-2

11.3.1 Wheat Field with Deep Tillage

The location of the Naporo-2 site is 7.0 m above sea level, and at 43° 2′ 32.73″ N latitude and 141° 35′ 17.28″ E longitude. It is located about 1 km from the Chitose River, a tributary of the Ishikari River (Fig. 11.1). The most recent 15 cm-thick soil dressing was carried out using clay soil in 1981. Similar to the Naporo-1 site, prior soil dressing history is unknown, but is said to have been carried out at least four to five times. The field was tilled to a depth of 40 cm in a deep plow in the autumn of 1985 when the two different types of base materials, namely the conventional surface horizon (a soil dressing and peat mixture) and peat in the lower layer, were mixed to form a new 40 cm deep surface horizon (Ap1 + Ap2). Local drainage is available and the groundwater level (stagnant water level) is at least 1 m deep. It has been used as an upland field since 1986 and constantly used for spring-sown wheat and autumn-sown wheat crops. The profile photograph of Fig. 11.3 was taken in October 1989 after autumn-sown wheat had been harvested.

11.3.2 Soil Description and Physico-chemical Properties

Ap1: 0 to 22 cm, grayish yellow brown (10YR4/2), light clay, sub-angular blocky structure, slightly wet, hardness of 18, no gravel, abundant humus (including decomposed peat), no NaF reaction, and a relatively clear, smooth boundary,

Fig. 11.3 Soil profile of Nanporo-2, the site of soil dressing on high-moor peat land

Ap2: 22 to 40 cm, grayish yellow brown (10YR4/2), light clay, structureless, slightly wet, no mottles, hardness of 24, no gravel, abundant humus (including decomposed peat), no NaF reaction, and a relatively clear, smooth boundary,

Ha: 40 to 55 cm, black (7.5YR2/1), decomposed high moor peat (with no fiber), wet, hardness of 18, no gravel, no NaF reaction, and clear wavy boundary,

Hi: 55+ cm, dark brown (7.5YR3/3), poorly decomposed high moor peat (*Carex middendorffii*), wet, hardness of 13, no gravel, no NaF reaction.

11.3.2.1 Physico-chemical Properties of Soil

The physico-chemical properties of the soil are listed in Table 11.2. The surface horizon (Ap1 + Ap2) to a depth of 40 cm was formed of peat, with the lower horizon having been mixed through multiple implementations of clay soil dressing and tilling. The Ha horizon was a peat horizon containing no decomposed fibers, and the Hi layer consisted of poorly decomposed high-moor peat (*Carex middendorffii*). The soil is classified as Transportic Sapric Histosols according to the international union of soil science working group (IUSS Working Group WRB 2015) and Typic Low-moor Peat soils (Pedology second classification system). The surface horizon organic substances content was 6.9–9.0% with a TC of 4.0–5.2%, while in the peat horizon (Ha horizon) the organic matter content was 69.2% with a TC of 40.1% and a little inorganic carbon. The soil reaction of the surface horizon was slightly acidic (6–6.5) and the bulk density 1.18.

Table 11.2 Physico-chemical properties of the Nanporo-2

Horizon (cm)	pH (H_2O)	Gas (%)	Liquid (%)	Solid (%)	Bulk Density	TC (g/kg)	CEC ($cmol_c$/kg)	Ex_{Ca} ($cmol_c$/kg)	Ex_{Mg} ($cmol_c$/kg)	Ex_K ($cmol_c$/kg)	Base saturation (%)	Available P (mg/kg)
Ap (0–18)	6.0	12.3	42.0	45.7	1.18	4.0	25.2	11.2	6.5	0.4	72.0	69
Gp (18–38)	6.5					5.2	28.0	16.3	4.7	0.6	77.0	98
He (38–63)	5.6					40.1						

Ex exchangeable cations, *P* phosphorus

11.4 Conclusion

Soil dressing is a common technique to improve soil conditions for crop production. Peat distribution in wetlands is remains a potential drawback for use paddy fields for agricultural use from a physical and chemical point of view. In the Ishikari Plain in Hokkaido, peat soils were covered with mineral soils up to 30 cm thickness for use as rice paddy fields. Soil dressing promotes high-quality rice production by controlling N availability through peat decomposition. Land subsidence can also be compensated by mineral soil dressing. As the soil profiles have mineral soil horizons greater than 35 cm thickness, the soil name is changed to Transportic Sapric Histosols, representing the anthropogenic process of soil dressing.

References

Hashimoto H (1994) Soil survey results of peaty paddy-upland rotation field, −subsoil improvement for peaty paddy-upland rotation field spread along the basin of the lower stream of the River Ishikari (1)-. Soil physical conditions and plant growth, Japan (Research Association of Soil Physics, Japan) 70: 37–42 (in Japanese with English abstract)

Hashimoto H (2006) Actual soil conditions of peaty arable land in Hokkaido. J Jpn Soc Soil Phys 103:87–94 (in Japanese)

Inoue T (2012) Landuse of peatland and its conservation. J Jpn Soc Soil Phys 120: 21–22 (in Japanese)

Ishiwata T, Okita Y, Saito M (1992) The kinds, distribution and characteristics of acid sulfate soils in Hokkaido. Jpn J Soil Sci Plant Nutr 63(1):86–90 (in Japanese)

IUSS Working Group WRB (2015) World reference base for soil resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps, World soil resources reports no. 106. FAO, Rome

Kohyama K, Miyaji N, Otsuka H, Kasubuchi T (1995) Sustainability map for arable peatland based on forecasting data of ground subsidence. Jpn J Soil Sci Plant Nutr 66(5):482–489 (in Japanese with English abstract)

Miyaji N, Kohyama K, Otsuka H, Kasubuchi T (1995) Surface subsidence of peatland in Bibai, Central Hokkaido. Jpn J Soil Sci Plant Nutr 66(5):465–473 (in Japanese with English abstract)

Nagata O, Yazaki T, Yanai Y (2010) Nitrous oxide emissions from drained and mineral soil dressed peatland in Central Hokkaido. Jpn J Agric Meteorol 66(1):23–30 (in English with Japanese abstract)

Chapter 12
Soils in Greenhouse Plots in an Urban Area

Shuji Sano and Honami Kongo

Abstract Although Osaka Prefecture has a large population (8.8 million people), agricultural lands occupied about 8% of the total area (13,920 ha) in 2010. Man-made soils are widely distributed in the agricultural fields, especially those with greenhouses. According to the Japanese Soil Classification system, soils over 35 cm thick consisting of materials transported from other sites that were dressed on the surface layer are classified as man-made soils. Here, one survey field, formerly a rice paddy, was located on a flood plain of the Yamato River. Soil dressing was conducted twice. Most soil properties were remarkably different among the horizons. Deeper buried horizons, separated from the upper horizons by an abrupt boundary, can be identified as dredged materials from nearby rivers, since the content of phosphorus (P) and exchangeable calcium (Ca) were relatively high and pH (H_2O_2) was remarkably lower than pH (H_2O). Previous land use for the paddy field was also confirmed at the deeper horizons by an upper wavy boundary, and a lower boundary separating it from a plow pan layer with iron mottles. In another research site located at Sakai City, known as Senboku new-town in the mountainous areas, the field site had been reclaimed 40 years before by clearing sections of old growth forest. Sulphur-containing marine clay makes up the deep layer of soil profiles in this area, necessitating dressing of soils from other sites. There were drastic differences in soil properties among soil horizons, especially the deeper layers characterized by reductive soil reactions, which consisted of marine clay. Relatively high contents of sulfuric compounds probably influence soil acidification by further cultivation of soils in the deeper layer.

Keywords Construction works · Cut and bank · Urban agriculture · Soil dressing

---

S. Sano (✉) · H. Kongo
Research Institute of Environment, Agriculture, and Fisheries,
Osaka, Osaka Prefecture, Japan
e-mail: sano@mbox.kannousuiken-osaka.or.jp; KongoH@mbox.kannousuiken-osaka.or.jp

M. Watanabe, M. Kawahigashi (eds.), *Anthropogenic Soils in Japan*,
International Perspectives in Geography 9,
https://doi.org/10.1007/978-981-13-1753-8_12

12.1 Introduction

At a meeting of the Organization of Economic Co-operation and Development (OECD) in 1998, it was remarked that agriculture has multiple functions. In urban areas, this multifunctional system becomes especially significant (Takatori 2000; Kiminami and Kiminami 2006; JA Osaka Chuokai et al. 2012). Most urban areas of large cities in Japan are still host to agricultural production of some kind. The Osaka Prefecture has a large population (8.8 million people) and is characterized as highly urbanized, yet agricultural lands occupied about 8% of the total area, which amounted to 13,920 ha in 2010. In comparison to agricultural lands in other highly urbanized areas, such as in metropolitan Tokyo (3.4%) and Kanagawa Prefecture (8.3%) (Ministry of Agriculture Forestry and Fisheries (MAFF) 2013), the allocation of land for agriculture and its productivity in Osaka Prefecture is relatively high (Kasama 1980; Osaka Prefectural Government 2009; JA Osaka Chuokai et al. 2012). Although agricultural production amounted to 33 billion Japanese yen (JPY), the economic value of agricultural lands was calculated to be as much as 100 billion JPY, whether the land was used for land conservation, the preservation of biodiversity, or other non-urbanization uses (Osaka Prefectural Government 2009).

In agricultural fields of the Osaka Prefecture, man-made soils are widely distributed (Fig. 12.1), especially in greenhouse areas. According to the Japanese Classification system of Cultivated Soils, soils over 35 cm thick consisting of materials transported from other sites that are dressed on the surface layer are classified as man-made soils (Cultivated Soil Classification Committee 1995). Soils used for

Fig. 12.1 Man-made soils in urban agricultural area in Osaka Prefecture. In the field on the right of the photograph, soils were dressed on a former paddy field, resulting in a surface level that was higher than that of original field

top dressing are mainly derived from lower layer soils that were produced mainly through the construction of buildings, roads, etc., in mountainous areas. Local names for the soils are "Masa-tsuchi" or "Yama-tsuchi", and they are classified as Cambisols, Acrisols, Alisols, and Regosols according to the international union of soil science working group (IUSS Working Group WRB 2015). The former land use of these fields has been variable, and includes not only older agricultural fields such as paddy fields, to prevent the wet condition for vegetable production, but also former non-agricultural fields such as reclaimed land from residential areas and factories.

Man-made soils differ remarkably from ordinary soils, especially in regard to lower content of organic matter and nutrients (Sano et al. 2015). Since man-made agricultural soils were characterized by various conditions in terms of former land use, soil profiles of man-made soils should be surveyed to understand how the physico-chemical properties of these soils can affect productivity. In this chapter, the characteristics of two representative man-made agricultural soils in urban areas are presented (Fig. 12.2).

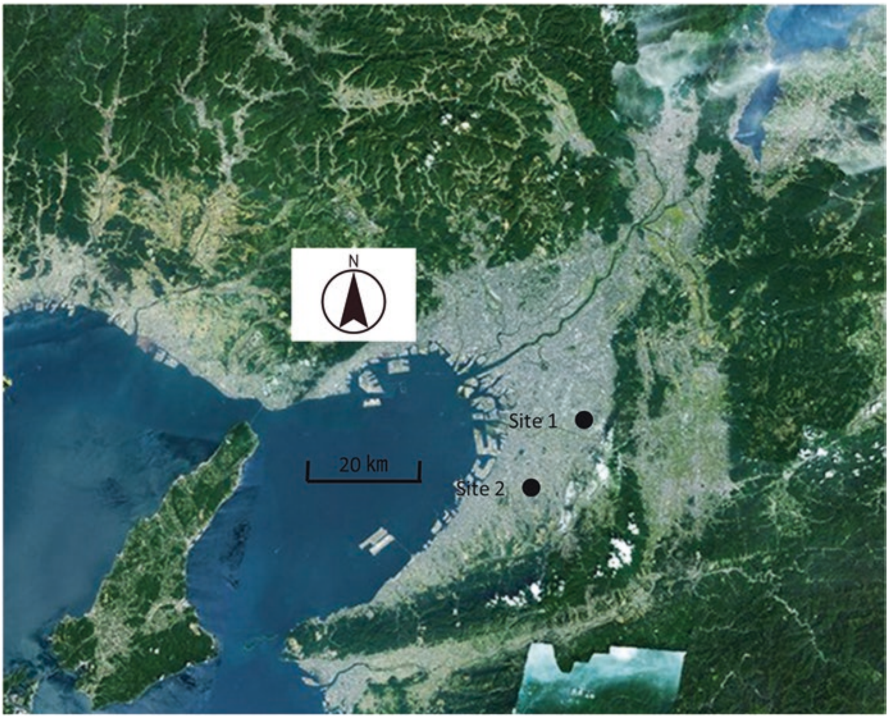

Fig. 12.2 Location of survey sites

12.2 Site 1: Man-made Agricultural Soils Established on Paddy Fields in Urban Areas

12.2.1 Shifting of Agricultural Land Uses from a Former Paddy Field

Site 1was located in Kashiwara City, eastern Osaka Prefecture. In these areas, various kinds of vegetables, fruits and flowers are produced, and agricultural fields are surrounded by residential areas (Fig. 12.3). The survey field was located on the flood plain of the Yamato River, and previously had been used as a rice paddy. Soil dressing was conducted twice. Twenty-five years ago, when the land use of the field had been converted from paddy to upland, soils were top-dressed on the paddy field at 10–15 cm, and some type of vegetable and strawberries were cultivated for a few years. After 5 years, a second soil top-dressing was conducted. The soil was top-dressed on the former upland field at 40–50 cm, and a plastic house was built for vegetable production. A drain pipe was also introduced before soils were top-dressed. The main crops at this location are young soy bean, Komatsuna (*Brassica rapa var. porviridis,* or Japanese mustard spinach), garland chrysanthemum, welsh onion, and leaf burdock.

Fig. 12.3 Local features at Site 1

12.2.2 Soil Description and Physico-chemical Properties

The soil profile for Site 1 is shown in Fig. 12.4, and features nine horizons. Horizons in this soil profile are clearly different in terms of material and color.

Ap1: 0 to 14 cm, dark brown (7.5YR 3/4), no mottles, loam, no gravels, sub-angular blocky weak and crumb weak structure, sticky, slightly plastic, compactness 6, common fine roots, moderately wet, positive reaction of dipyridyl test, smooth clear boundary,

Ap2: 14 to 19 cm, brown (7.5YR 4/6), no mottles, sandy clay loam, no gravels, massive structure, sticky, plastic, compactness 19, no roots, moderately wet, no reaction of dipyridyl test, smooth clear boundary,

C1: 19 to 31 cm, bright brown (7.5YR 5/8), no mottles, sandy loam, no gravels, massive structure, slightly sticky, slightly plastic, compactness 18, no roots, moderately wet, no reaction of dipyridyl test, smooth gradual boundary,

C2: 31 to 42 cm, bright brown (7.5YR 5/6), no mottles, sandy loam, no gravels, massive structure, slightly sticky, slightly plastic, compactness 24, no roots, moderately wet, no reaction of dipyridyl test, irregular boundary,

2C3: 42 to 54 cm, olive gray (10Y 5/2), no mottles, loam sand, no gravels, massive structure, slightly sticky, slightly plastic, compactness 23, no roots, wet, positive reaction of dipyridyl test, irregular boundary,

Fig. 12.4 Soil profile at Site 1

3Cg1: 54 to 69 cm, brownish black (7.5YR 2/2), few root-like mottles (brown 7.5YR 4/3), sandy loam, no gravels, massive structure, slightly sticky, slightly plastic, compactness 23, no roots, wet, strongly positive reaction of dipyridyl test, smooth gradual boundary.

4Bg1: 69 to 76 cm, brown gray (10YR 4/1), many root-like and common tubular mottles (brown 7.5YR 4/4), sandy clay loam, no gravels, massive structure, slightly sticky, slightly plastic, compactness 27, no roots, wet, strongly positive reaction of dipyridyl test, wavy gradual boundary,

4Bg2: 76 to 92 cm, brownish gray (10YR 5/1), abundant tubular mottles (brown 7.5YR 4/6), sandy loam, no gravels, massive structure, slightly sticky, slightly plastic, compactness 23, no roots, wet, positive reaction of dipyridyl test.

12.2.2.1 Soil Physico-chemical Properties

Soil physico-chemical properties are shown in Table 12.1. Most of properties were remarkably different among the horizons.

Ap1 and Ap2 were high in various plant nutrient elements and humus, and cannot be separated by color. Similarities in characteristics can be attributed to relatively high input of fertilizer, lime, and organic materials, and cultivation by rotary tiller. The drastic decrease of pH from (H_2O) to (H_2O_2) is the result of high humus content. Layers C1 and C2 were lower in humus content than Ap1 and Ap2. However, Truog-phosphorus (Truog-P), exchangeable calcium (Ex_{Ca}), and exchangeable magnesium (Ex_{Mg}) contents were relatively high, reflecting leaching from the plow layers. 2C3 is distinguished by its grayish color, which would have been derived from the second volume of dressed materials, because the boundary of C2 and 2C3 is abrupt. If this grayish color is derived from reducing conditions, the boundary then appears smooth. It is likely that the dressed material would have been dredged from near a river, since the content of P and ExCa were relatively high and

Table 12.1 Physico-chemical characteristics of the soil profile for site 1

	Depth	pH (Water)	pH (H_2O_2)	EC	Truog-P	Ex_K	Ex_{Ca}	Ex_{Mg}	Ex_{Mn}	Humus
Horizon	(cm)	Soil: water =1:5	Soil: water =1:10	mS cm^{-1}	(mg kg^{-1})	cmolc kg^{-1}			mg kg^{-1}	g kg^{-1}
Ap1	0–14	6.40	4.54	0.224	819	0.12	13.0	0.64	1.4	18.2
Ap2	14–19	6.85	4.78	0.094	227	0.07	12.4	0.71	0.5	18.5
C1	19–31	7.29	8.61	0.028	46	0.08	8.2	1.02	0.1	1.6
C2	31–42	7.85	9.38	0.029	41	0.09	5.6	1.01	0.0	1.0
2C3	42–54	8.32	6.80	0.059	109	0.25	7.7	1.36	15.7	6.9
3Cg1	54–69	7.72	7.56	0.050	97	0.17	5.4	1.08	10.8	15.9
4Btg1	69–76	7.54	8.33	0.029	10	0.14	3.7	1.00	24.6	4.5
4Btg2	76–92+	8.05	8.32	0.030	14	0.12	4.3	1.20	42.2	3.2

pH (H_2O_2) was remarkably lower than pH (H_2O). Although the 3Cg1 horizon was grayish in color, its components differed from 2C3 in terms of the texture and the difference of pH (H_2O_2) and pH (H_2O). The higher contents of some nutrients and humus indicates that this layer was derived from the plow layer in the former upland use, together with the mixture of first dressed soils and paddy plow layer. The abrupt boundary was derived from the ridges of former upland fields. 4Btg1 and 4Btg2 were derived from ordinary paddy soils. The higher compactness value of 4Btg1 indicates that this horizon was the plow pan layer of former paddy fields. The 4Bg1 and 4Bg2 layers contained many clear brown-orange root-like and tubular mottles, which had been present in the former paddy use days. High Ex_{Mn} content indicates that these layers are characterized by reducing conditions. Indeed, groundwater was percolating from the 4Btg2 horizon.

12.3 Site 2: Man-made Agricultural Soils Established on Reclaimed Residential Land

12.3.1 Vegetable Cultivation on Reclaimed Residential Land

Site 2 is located in Minami Ward, Sakai City, in the southern part of the Osaka Prefecture. This area had been largely developed as a residential area from 1965 to 1981, and was known as Senboku new-town in the nearby mountainous areas. Sakai City also supports relatively large agricultural fields, and supplies fresh vegetables mainly for the Osaka Prefecture. As such, some agricultural fields are distributed among the residential areas (Fig. 12.5). The Site 2 field had been reclaimed from land initially used for agriculture after clearing an old-growth forest, 40 years before. Since marine clay that contains sulfur material was widely distributed at

Fig. 12.5 Local features at Site 2

deeper layers in southern part of Osaka Prefecture, soils moved from other areas were used to top-dress the agricultural areas. In this field, Osaka-shirona (*Brassica pekinensis RUPR,* or Napa cabbage), Komatsuna (*Brassica rapa var. porviridis)* and garland chrysanthemum are cultivated. The survey was conducted when garland chrysanthemum was being harvested.

12.3.2 Soil Description and Physico-chemical Properties

The soil profile for Site 2 is shown in Fig. 12.6, and features five horizons. This soil profile also exhibits clearly different materials and colors.

Ap1: 0 to 10 cm, dull yellowish brown (10YR 4/3), no mottles, loam, no gravels, sub-angular blocky weak structure, sticky, plastic, compactness 10–20, many fine roots, moderately dry, no reaction of dipyridyl test, smooth gradual boundary,

Ap2: 10 to 18 cm, dull yellowish brown (10YR 4/3), no mottles, loam, no gravels, sub-angular blocky weak structure, sticky, plastic, compactness 18, common fine roots, moderately dry, no reaction of dipyridyl test, smooth clear boundary,

2C1: 18 to 44 cm, bright brown (7.5YR 5/6), mottles from lower layer by disturbance through soil dressing process (dark reddish brown 5YR 3/4), heavy clay, no gravels, massive structure, sticky, very plastic, compactness 22, few fine roots, moderately wet, no reaction of dipyridyl test, wavy gradual boundary,

3C2: 44 to 48 cm, grayish olive (5Y 5/2), filmy mottles along cracks (dark reddish brown 5YR 3/4), heavy clay, no gravels, massive structure, sticky, very plastic, compactness 27, no roots, moderately wet, no reaction of dipyridyl test, wavy gradual boundary, a vertical crack from this horizon to a deeper horizon,

Fig. 12.6 Soil profile at Site 2

3C3: 48 to 77 cm, dark greenish gray (5G 4/1), filmy mottles along cracks (dark reddish brown 2.5YR 3/4), heavy clay, no gravels, massive structure, sticky, very plastic, compactness 27, no roots, moderately wet, strongly positive reaction of dipyridyl test, slightly positive reaction of tetra base test along the mottles, ground water appeared from vertical cracks trending below the depth of the profile.

12.3.2.1 Soil Physicochemical Properties

Soil physico-chemical properties are shown in Table 12.2. Most of the properties are remarkably different among the horizons.

Ap1 and Ap2 were high in content of various plant nutrient elements and humus. Indeed, they were separated by color. This would have reflected the relatively high input of fertilizer, lime and organic materials, and cultivation by rotary tiller. The very low pH (H_2O_2) would be reflected in this high humus content.

2C1 contained lower Truog-P and humus than Ap1 and Ap2. However, Ex_{Ca} and Ex_{Mg} contents were relatively high, reflecting the leaching from the plow layers. The materials of this layer were dressed soils similar to Ap1 and Ap2, although the texture differed. The difference of texture between Ap horizons and 2C1 could be the result of the difference in humus content and structure according to cultivation in Ap horizons. The lower layer soils abruptly appeared, reflecting the disturbance of soil dressing operations.

3C2 was a very thick layer and separated by its color, being more grayish than the upper layer and more brownish than the lower layer. This layer may be derived from marine clay. When the fields had been reclaimed, this layer surfaced, suggesting the original reducing characteristics would be changed. Indeed, the Fe(II) test was negative, and pH (H_2O_2) was not lower than pH (H_2O). The reddish filmy mottles along cracks are a notable characteristic of this horizon.

3C3 showed the grayish blue color that would be derived from marine clay. The positive Fe(II) test indicated that this layer was still characterized by reducing conditions. The pH (H_2O_2) was lower than pH (H_2O), suggesting that some reductive

Table 12.2 Physico-chemical characteristics of the soil profile for site 2

	Depth	pH(H_2O)	pH (H_2O_2)	EC	Truog-P	Ex_K	Ex_{Ca}	Ex_{Mg}	Ex_{Mn}	Humus
Horizon	(cm)	Soil: water =1:5	Soil: water =1:10	mS cm^{-1}	(mg kg^{-1})	cmolc kg^{-1}			mg kg^{-1}	g kg^{-1}
Ap1	0–10	6.04	3.80	1.734	793	0.21	22.2	6.71	1.9	32.7
Ap2	10–18	6.16	3.94	1.889	188	0.17	24.8	7.77	0.5	32.9
2C1	18–44	5.73	6.11	0.449	5	0.20	7.9	8.15	1.5	4.2
3C2	44–48	6.68	7.02	0.255	13	0.28	9.0	9.69	0.9	8.3
3C3	48–77+	8.15	7.31	0.223	13	0.32	9.7	9.41	3.2	10.0

sulfur still remained. As with 3C2, reddish filmy mottles along cracks are a remarkable characteristic of this horizon. The relatively high value of Ex_{Ca} and Ex_{Mg} were the result of leaching from upper layers.

At first glance, the soil characteristics seem very similar between two fields. They were both categorized as greenhouse fields in terms of land use. However, the nature of sub-surface and lower soil horizons were significantly different, which will in turn affect the mid- to long-term management of the fields. A detailed man-made soil map is required as basic information for agricultural management as well as land use schemes.

12.4 Conclusion

Agricultural soils distributed in urban cities have been largely modified by banking or dressing soils. Land use change is often accompanied by changing soil classification and properties. Developed soil for agriculture has largely different soil properties and soil horizons. Deeper horizons consisting of marine sediments with reductive soil conditions have a potential to release strong acid by oxidation of marine clay. Understanding soil properties before land use changes are important for management of agricultural fields.

Acknowledgments The authors are grateful to local farmers for their cooperation in the field survey, as well as Mr. Yoshinori Ueda (Chubu Office for Agriculture-Forestry Promotion and Nature Conservation, Osaka Prefectural Government) and Miss Ayaka Yagi (Senshu Office for Agriculture-Forestry Promotion and Nature Conservation, Osaka Prefectural Government) for their assistance in the field survey. We also would like to thank members of the Research Institute of Environment, Agriculture, and Fisheries in Osaka Prefecture for their assistance in the laboratory analysis.

References

Cultivated Soil Classification Committee (1995) Classification of cultivated soils in Japan, third approximation. Misc Publ Natl Agro Environ Sci 17:1–79 (in Japanese)

IUSS Working Group WRB (2015) World reference base for soil resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps, World soil resources reports no. 106. FAO, Rome

Kasama S (1980) Changes in agricultural production in urban areas. A case study of Higashiyodogawa Ward, Osaka City, Japan. Jpn J Hum Geogr 32:79–91 (in Japanese)

Kiminami LY, Kiminami A (2006) Sustainability of agriculture and urban quality of life in Japan: economic efficiency, sociality and environment protection. Stud Reg Sci 36:305–321

Ministry of Agriculture, Forestry and Fisheries (2013) Statistics of agricultural lands in Japan. http://www.maff.go.jp/j/tokei/kouhyou/sakumotu/menseki/ (2015.2) (in Japanese)

OECD (1998) Agriculture in a changing world: which policies for tomorrow? meeting of the committee for agriculture at the ministerial level, press communique, Paris, 5–6 March

JA Osaka Chuokai, Osaka Prefectural Government, Osaka-fu Nougyo Kaigi (2012) Agriculture of Osaka prefecture. Osaka, Japan, 24p (in Japanese)

Osaka Prefectural Government (2009) Agriculture and its circumstances in Osaka Prefecture, Osaka, Japan, 13p (in Japanese)

Sano S, Kongo H, Uchiyama T (2015) Characteristics of man-made soils of greenhouse fields in urban areas, Osaka Prefecture, Japan. Soil Sci Plant Nutr 61:123–134

Takatori Y (2000) The multi-functional system of urban agriculture in the suburbs of Tokyo: a case study in the Nishi-Ooizumi area of Nerima Ward. Tokyo J Geogr 109:401–417 (in Japanese with English abstract)

Chapter 13
Soils Affected by Conversion of Abandoned Paddy Fields to Alternate Uses

Masayuki Kawahigashi

Abstract In Japan, agricultural land use has constantly decreased since 1961, when the cultivated area reached 6 million ha. Here, the research area formerly used as paddy fields has been replaced by sections for buckwheat cultivation, chestnut orchards, and a parking lot. The region located at higher elevation in the valley plains study area was converted to upland fields by drainage and soil dressing in 1975, and was followed by conversion to a chestnut orchard in 1990. Both soils were Skeltic Fulvisols. The middle elevation area was converted to a parking lot by paving with 2 cm thick asphalt, thus the soil is classified as Ekranic Technosol. The lower elevation area has been transformed into a buckwheat field in 2000. Soil texture varies widely depending on distribution of alluvium in the soil profile, indicating diverse intensity of stream flow and alluvial deposition processes. Construction of a hard pan layer was inevitable to manage water in the paddy field. The hard pan layer with finely textured soil was confirmed in the chestnut orchard and in the parking lot. The distribution of oxide mottles in the soil profile under the chestnut orchard and the parking lot was proof of the past use of the field. Values of pH of all surface soils at the three soil profile sites were slightly acidic. Land use conversion from the paddy field has not influenced soil reactions. The difference in bulk density at each site can be indicative of land use conversion. Compaction beneath the asphalt promotes high bulk density, while low bulk densities were brought about by development of chestnut root systems.

Keywords Abandoned agricultural field · Farm population · Policy of reducing acreage · Reduction in rice consumption

---

M. Kawahigashi (✉)
Department of Geography, Graduate School of Urban Environmental Sciences,
Tokyo Metropolitan University, Hachioji, Tokyo, Japan
e-mail: kawahigashi-masayuki@tmu.ac.jp

M. Watanabe, M. Kawahigashi (eds.), *Anthropogenic Soils in Japan*,
International Perspectives in Geography 9,
https://doi.org/10.1007/978-981-13-1753-8_13

13.1 Introduction

In 2015, agricultural land use in Japan occupied 4.5 million ha, corresponding to approximately 12% of the domestic land area. Agricultural land use has constantly decreased since 1961, when the cultivated area reached 6 million ha (Ministry of Agriculture, Forestry and Fisheries (MAFF) 2016). Former agricultural regions have been repurposed for other uses, such as residential areas, roads, recreation areas (golf courses and ski resorts), and greenery lots, or have simply been abandoned (Ministry of Land Infrastructure, Transport and Tourism (MLIT) 2014). Large-scale civil engineering is usually required during land-use conversion to construct new infrastructure. Locations where there are difficulties in managing cultivation because of limited space on hills and valley plains have been abandoned and/or replaced by other land uses. From an economic standpoint, large-scale land management using powerful machines has a number of advantages compared to small-scale agriculture. The decrease in the labor force engaged in agriculture is another reason for reduction of agricultural land use (MAFF 2016). The policy of reducing rice acreage to control rice prices has also promoted an increase in abandoned areas and converted certain areas from rice to upland farming since 1995 (MAFF 2016). These modern transformations around Japanese agriculture have also been influenced by reduction in rice consumption due to changes in our food culture after the period of rapid economic growth in the 1960s. Rice consumption in 2015 is less than half the highest consumption in 1962 (MAFF 2017). Rice for livestock feed, processed foods, and stocks expanded in cultivated areas in Japanese paddy fields. Land use conversion from paddy fields to other crop fields has also occurred during the reduction of rice production. Land-use conversion usually requires soil dressing and soil-surface management using soils from other areas. Polluted soils from alluvial plains have been replaced by mountainous soils from remote places to mitigate the effects of pollution (Ito 2014). Productivity remarkably dropped due to acidification of the dressed soils from the mountains. Evaluation of soil properties after land use conversion is always necessary to maintain the land resources for the future.

This chapter presents soil profiles and the physico-chemical information on soil obtained from a chestnut orchard, a buckwheat field, and a parking lot, areas previously used for rice cultivation.

13.2 Abandoned Paddy Field on a Valley Plain

13.2.1 Conversion of Land Use Since the 1970s

Diversification of land use in practice developed after termination of rice cultivation in the valley plains located at the foot of Itajikiyama Mountain in Yamagata Prefecture, Northeast Japan (Fig. 13.1). The policy of reducing rice acreage has

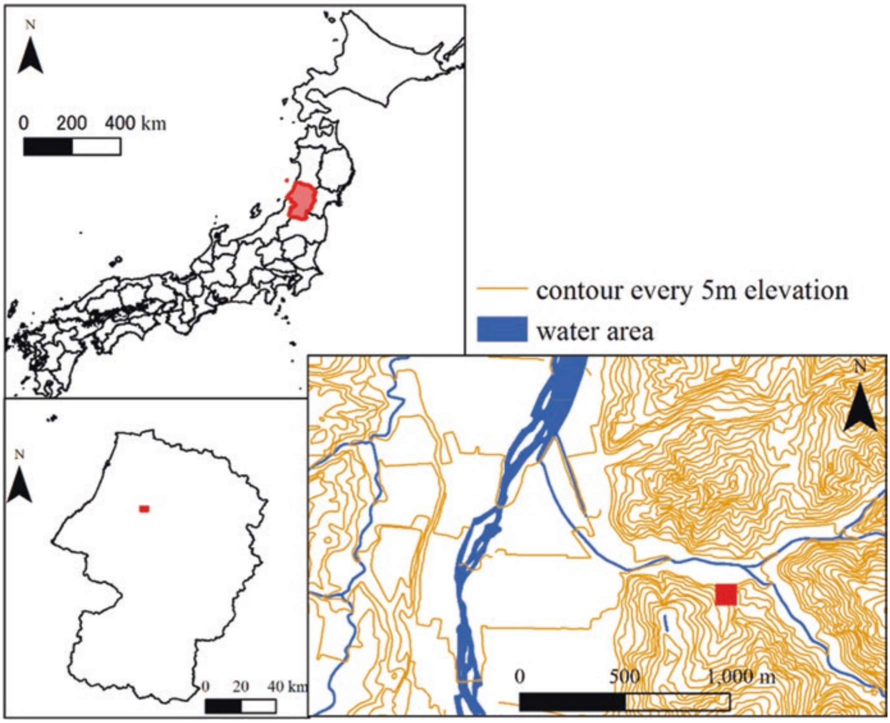

Fig. 13.1 Location of Kumagai shrine (38°43′27.332″ N, 140°01′06.833″ E) This map is made from Digital (Basic Geospatial Information) and Basic map data provided from GSI Japan and National municipality boundary data provided from Environmental Systems Research Institute of Japan

been promoted since the 1970s in the research area. The abandoned area gradually started to be used for other purposes. Here, paddy fields have been replaced by buckwheat cultivation, a chestnut orchard, and a parking lot. The area currently used for buckwheat production lay idle for a period of over 15 years following termination of rice cultivation.

The valley plain was formed by frequent flooding from the Azenami River, a tributary of the Tachiyazawa River system, which itself is a branch of the Mogami River system. Sabo dams (check dams) have been constructed to prevent accumulation of medium-large debris on the river bed. The history of the paddy fields of this area can be traced back 120 years. Improved rice known as "Kame-no-O" has been developed in this region based on the Koshihikari variety known to be tolerant to low temperatures. This variety of rice has been widely cultivated in the region. However, small paddy fields located on slopes have gradually been converted to other ventures because of low yields or difficulties in managing them. Here three sites located at variable elevation from 100 to 110 m a.s.l. on the Azenami River plain were studied. The area located at the highest position on the valley plain was converted to upland fields by drainage and soil dressing in 1975, and was later developed as a chestnut orchard in 1990. The middle elevation area was converted to a parking lot by application of a 2 cm-thick layer of asphalt on 2011. The lowest position was transformed into a buckwheat field in 2000. After some time the area was abandoned and was overrun by Kudzu weeds, but was later used for yam cultivation.

13.2.2 Soil Descriptions at the Chestnut Orchard, Parking Lot, and Buckwheat Field

13.2.2.1 Soil Description at the Chestnut Orchard (Skeltic Fulvisol)

The soil profile at the chestnut orchard is shown in Fig. 13.2. Soil was dressed over the pre-existing alluvium (consisting of boulders) to provide adequate rooting space for planted trees.

Ap: 0 to 15 cm, brown (7.5YR 4/4), no mottling, clay loam, common sub-angular gravels (ϕ 5–10 cm), weak crumb structure (ϕ 2–5 mm), sticky, very plastic, compactness 12, few vesicular porosity (ϕ 0.1–0.5 mm), common very fine and fine roots (ϕ 0–2 mm), moist, slightly positive reaction of dipyridyl test, positive reaction of tetra base test, smooth gradual boundary,

Bg1: 15 to 22 cm, olive gray (10Y 4/2), many root-like mottles (bright brown: 7.5YR 5/6), clay loam, no gravels, weak sub-angular blocky structure (ϕ 2–3 cm), sticky, very plastic, compactness 19, few vesicular porosity (ϕ 0.1–0.5 mm), common fine roots (ϕ 0.5–2 mm) and few medium roots (ϕ 2–5 mm), moist, slightly positive reaction of dipyridyl test, positive reaction of tetra base test, wavy gradual boundary,

Bg2: 22 to 40 cm, grayish yellow brown (10YR 4/2), abundant root-like mottling (bright brown: 7.5YR 5/6), light clay, few weathered angular gravels (ϕ 2–4 cm), weak sub-angular blocky structure (ϕ 2–3 cm) and weak crumb structure (ϕ 2–5 mm), sticky, very plastic, compactness 16, few vesicular porosity (ϕ 0.1–0.5 mm), few fine roots (ϕ 0.5–2 mm) and common medium roots (ϕ 2–5 mm), moist, positive reaction of dipyridyl test, positive reaction of tetra base test, smooth clear boundary,

Cg: 40 to 55 cm, yellow brown (10YR 5/2), abundant root-like mottling (dull reddish brown: 5YR 4/4), sandy clay loam, common slightly weathered sub-angular and sub-round gravels (ϕ 2–5 cm), no structure, slightly sticky, very plastic, compactness 16, no porosity, few medium root (ϕ 2–5 mm), moist, no positive reaction of dipyridyl test, positive reaction of tetra base test, smooth clear boundary,

C1: 55 to 70 cm, brown (7.5YR 4/3), no mottling, sand, common slightly weathered sub-angular and sub-round gravels (ϕ 1–5 cm), no structure, slightly sticky, slightly plastic, compactness 13, no porosity, no roots, moderately moist, no

Fig. 13.2 Overview (**a**) and soil profile (**b**) of Chestnut orchard site

reaction of dipyridyl test, slightly positive reaction of tetra base test, wavy gradual boundary,

C2: 70 to 90 cm, brown (7.5YR 4/3), no mottling, sand, abundant slightly weathered sub-angular and sub-round gravels (ϕ 0.2–5 cm) and many slightly weathered sub-angular and sub-round gravels (ϕ 5–10 cm), no structure, stickiness and plasticity and compactness unavailable, no porosity, few very fine and fine and medium roots (0–5 mm), moderately moist, no reaction of dipyridyl and tetra base tests, wavy gradual boundary,

C3: 90 to 105 cm, brown (7.5YR 4/3), no mottling, sand, dominant slightly weathered sub-round gravels (ϕ 0.2–20 cm), no structure, stickiness and plasticity and compactness unavailable, no porosity, few fine roots (ф 0.5–2 mm), moist, no reaction of dipyridyl and tetra base tests, smooth clear boundary,

C4: 105 to 140+ cm, brown (7.5YR 4/3), no mottling, sand, dominant slightly weathered sub-round gravels (ф 0.2–30 cm), no structure, stickiness and plasticity and compactness unavailable, no porosity, few fine roots (ф 0.5–2 mm), moist, no reaction of dipyridyl and tetra base tests.

13.2.2.2 Soil Description at the Parking Lot (Ekranic Technosol)

The parking lot soil profile is shown in Fig. 13.3. A subbase layer onto which a thin asphalt layer was applied has been identified above the original agricultural surface horizon, Bg.

Subbase: +15 to 0 cm, dark grayish yellow (2.5Y 4/2), no mottling, sand, few slightly weathered sub-angular gravels (ф 10–20 cm), many slightly weathered angular gravels (ф 5–10 cm), and dominant slightly weathered angular and sub-angular gravels (ф 0.2–5 cm), single grain, stickiness and plasticity unavailable, compactness 27–35, porosity unavailable, no roots, moist, no reaction of dipyridyl and tetra base tests, smooth abrupt boundary,

Bg1: 0 to 17 cm, dark brown (10YR 3/3), many root-like mottles (dark reddish brown: 2.5YR 3/4), clay loam, many slightly weathered angular gravels (ф 5–10 cm), massive structure, sticky, very plastic, compactness 19, common tubular porosity (ф 0.1–0.5 mm), no roots, moist, no reaction of dipyridyl test, slightly positive reaction of tetra bases test, wavy gradual boundary,

Bg2: 17 to 32 cm, dark grayish yellow (2.5Y 4/2), many root-like mottles (dark reddish brown: 2.5YR 3/4), light clay, common slightly weathered sub-angular gravels (ф 5–10 cm) and many slightly weathered sub-angular gravels (ф 1–5 cm), massive structure, sticky, very plastic, compactness 14, common tubular porosity (ф 0.1–0.5 mm), no roots, moist, no reaction of dipyridyl test, slightly positive reaction of tetra base test, smooth clear boundary,

C1: 32 to 50 cm, dark reddish brown (5YR 3/6) and dark grayish yellow (2.5Y 4/2) alternation of strata, no mottling, sand, common slightly weathered angular gravels (ф 0.2–5 cm), single grain, slightly sticky (dark reddish brown) and sticky (dark grayish yellow), slightly plastic (dark reddish brown) and plastic (dark grayish yellow), compactness 17, no porosity, no roots, moist, no reaction of dipyridyl test, slightly positive reaction of tetra base test, smooth clear boundary,

C2: 50 to 65 cm, dark reddish brown (2.5YR 3/6), no mottling, sand, abundant slightly weathered sub-round gravels (ф 1–10 cm), single grain, slightly sticky, slightly plastic, compactness 15, no porosity, no roots, moist, no reaction of dipyridyl and tetra base tests, smooth clear boundary,

C3: 65 to 85+ cm, brown (7.5YR 4/6), no mottling, sand, few slightly weathered sub-round gravels (ф 10–20 cm) abundant slightly weathered round gravels (ф

Fig. 13.3 Overview (**a**) and soil profile (**b**) of Parking lot

0.2–10 cm), single grain, slightly sticky, slightly plastic, compactness 9, no porosity, no root, moist, no reaction of dipyridyl and tetra base tests.

13.2.2.3 Soil Description at the Buckwheat Field (Skeletic Fluvisol)

Figure 13.4 shows the soil profile at the buckwheat field, at the lowest elevation of the three survey sites. Dressing of the surface soil occurred in 2000 when the site began its tenure as an upland field.

Fig. 13.4 Overview (**a**) and soil profile (**b**) of Buckwheat field site

Ap: 0 to 8 cm, dark brown (10YR 3/4), no mottling, loam, few sub-round gravels (ϕ 5–10 cm), weak crumb structure (ϕ 2–5 mm) and weak sub-angular blocky structure (ϕ 1–2 cm), sticky, plastic, compactness 8, common vesicular porosity (ϕ 0.1–0.5 mm), few very fine roots (ϕ 0–0.5 mm), moderately moist, no NaF reaction, wavy gradual boundary,

Bw1: 8 to 22 cm, brown (10YR 4/4), no mottling, clay loam, common weathered sub-round gravels (ϕ 5–10 cm), weak crumb structure (ϕ 2–5 mm) and weak sub-angular blocky structure (ϕ 1–2 cm), sticky, very plastic, compactness 17, common vesicular porosity (ϕ 0.1–0.5 mm), common very fine and fine and medium roots (ϕ 0–5 mm), moderately moist, no NaF reaction, smooth clear boundary, C1: 22 to 45 cm, brownish black (10YR 3/2), no mottling, sand, dominant sub-round gravels (ϕ 10–20 cm), no structure, stickiness, plasticity, compactness, and porosity unavailable, common very fine and fine roots (ϕ 0–2 mm), no NaF reaction, smooth clear boundary,

C2: 45 to 60 cm, color unavailable, no mottling, dominant sub-round gravels (ϕ 10–20 cm), no structure, stickiness, plasticity, compactness, and porosity unavailable, few very fine roots (ϕ 0–0.5 mm), no NaF reaction, smooth clear boundary,

C3: 60 to 80 cm, color unavailable, no mottling, dominant sub-round gravels (ϕ 5–10 cm), no structure, stickiness, plasticity, compactness, and porosity unavailable, very few very fine roots (ϕ 0–0.5 mm), no NaF reaction, irregular diffuse boundary,

C4: 80 to 100+ cm, color unavailable, no mottling, dominant sub-round gravels (ϕ 0.2–5, 20–30 cm), no structure, stickiness, plasticity, compactness, and porosity unavailable, no roots, no NaF reaction.

Groundwater appeared at 120 cm depth.

13.3 Soil Properties and Effects of Land Use Changes

Episodic, high-volume runoff in tributaries of the Tachiyazawa River system has resulted in deposition of many boulders on the valley plain, yet alluvial sand has also been deposited through average streamflow. Soil texture varies widely depending on distribution of alluvium in the soil profile, indicating diverse intensity of stream flow and alluvial deposition processes. The coarse soil texture accompanied by boulders has been a disadvantage for paddy field production due to ponding of water on the surface. A hard pan layer constructed by farmers was necessary to manage water in the paddy fields. Existence of the hard pan layer with finely textured soil was confirmed in the chestnut orchard and in the parking lot. These finely textured soils have been dressed on purpose to construct the hard pan layer to promote ponding of water. The distribution of oxide mottles in the soil profile under the chestnut orchard and the parking lot was proof of the past use of the area. Repetition of ponding and discharge water from the paddy fields encourages the formation of mottles, especially above the hard pan layer. Frequent floods promoted abundant alluvium deposition at the buckwheat field at the lower elevation, preventing the formation of the hard pan layer.

Values of pH of all surface soils at all three soil profiles were slightly acidic. Differences in pH between land uses were not confirmed (Table 13.1). The land use conversion from the paddy field has not influenced soil reaction. Asphalt cover in the parking lot has also not affected the soil due to the thin layer of the top coating. Organic matter content was slightly lower under the parking lot due to removal of top soil during the construction. Both the buckwheat field and chestnut orchard contained the same amount of organic carbon, indicating that litter input under the chestnut orchard and buckwheat crop residues have little effect on organic matter accumulation in the soil, probably due to frequent flooding of the stream as well as

Table 13.1 The main soil properties of soils sampling from Kumagai shrine area

Profile name	EC (mS/m)	pH (H_2O)	SOC (g/kg)	TN (g/kg)	C/N	Bulk density (Mg/m^3)
Chestnut	4.67	6.58	17.88	1.80	9.9	0.93
Parking	4.60	6.58	13.68	1.22	11.2	1.05
Yam field	3.19	6.72	17.86	1.73	10.3	1.04

Note: Soil samples taken from 0–30 cm. For the parking area, the 0 cm mark was at the base of the subbase layer
EC electric conductivity, *SOC* soil organic carbon, *TN* total nitrogen

the relatively coarse soil texture. Differences in bulk density can be indicative of land use conversion. Compaction beneath the asphalt promotes high bulk density over 1.0, while low bulk densities were brought about by development of chestnut root systems.

13.4 Conclusion

Abandoned agricultural areas are increasing in Japan. Land use conversion is usually accompanied by drastic changes in soil composition, relative to the original profile. However, original soil properties can still be verified after several tens of years. Common soil properties of paddy fields were identified after conversion to orchard and crop lands. The hard pan layer used to promote water ponding has not deteriorated after 25 or 45 years following land use change. Mottles on subsurface horizons were also detected at the orchard field and a parking lot, indicating that soil properties originated from rice cultivation can persist even after the land use conversion.

Acknowledgments Professor Cheng Weiguo and his students in Yamagata University are gratefully thanked for their introduction to the field site, and for their cooperation with the field survey. Some field information was also provided by Prof. Cheng. Mr. Takayuki Chonan of the Kumagai Shrine in Yamagata Prefecture is thanked for familiarizing us with the history and geography of the area.

References

Ito T (2014) Productivity issue and the solution in salt-excluded paddy fields damaged by tsunami caused by the 2011 off the Pacific coast of Tohoku earthquake. Pédologie 58: pp 51–5 (in Japanese)
MAFF (Ministry of Agriculture, Forestry and Fisheries) (2016) Report using statistical data for rice production in Japan. MAFF, Tokyo (in Japanese)
MAFF (Ministry of Agriculture, Forestry and Fisheries) (2017) Report of situation for rice production in Japan. MAFF, Tokyo (in Japanese)
MLIT (Ministry of Land, Infrastructure, Transport and Tourism of Japan) (2014) White paper on land 2014. MLIT, Tokyo (in Japanese)