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Characterization and classification of agricultural soils in North Savo, Finland

Markku Yli-Halla and Mari Rätty

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Tiivistelmä

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Maatalous- ja ympäristötutkimuksessa tarvitaan tietoja maan ominaisuuksista. Koepaikkojen ja seuranta-alueiden maan ominaisuudet pitää tuntea, jotta ymmärretään, mitkä tekijät ovat vaikuttaneet saatuihin tuloksiin ja osataan arvioida, millaisissa oloissa tulokset ovat soveltamiskelpoisia. Mallintaminen on lisännyt maata koskevan tiedon tarvetta. Monet muokkauskerroksen ominaisuudet ovat saatavilla viljavuusanalyysin tulosten yhteenvetoraporteista, mutta perusteellisempaan maan luonnehtimiseen tarvitaan tietoa myös syvempien maakerrosten ominaisuuksista. Näiden tietojen perusteella maat voidaan luokitella kansainvälisesti ymmärrettävällä tavalla käyttäen esimerkiksi EU:n suosittamaa World Reference Base for Soil Resources (WRB) -järjestelmää.

Tässä hankkeessa tutkittiin 21 maaprofilia Maaningalla ja lisalmessa. Valitut kohteet ovat Luonnonvarakeskuksen (Luke) tärkeitä koekenttiä. Kullakin kohteella kaivettiin näkyviin 1–1.5 m syvä maaprofiili, jonka ominaisuudet määritettiin visuaalisesti kerroksittain, ja jokaisesta kerroksesta otettiin näytteitä analysoitavaksi. Maat luokiteltiin WRB-järjestelmän vuoden 2022 version mukaan.

Lähes kaikissa tutkituissa maissa oli jollain syvyydellä kerros, joka oli savea tai savista hiuetta. On ilmeistä, että tämän alueen maatalousmaissa on pohjamaoreenin päällä lähes kauttaaltaan kerros tällaista melko hienojakoista maata. Useimmilla pelloilla myös muokkauskerros oli hienojakoista tai keskikarkeaa maata. Vaikka suomalainen maalaji oli usein karkeaa hietaa, maassa oli huomattava osuus sitä hienojakoisempia lajitteita. Moreenia tavattiin vain muutamalla pellolla. Joissain kohteissa taas oli pieniä harjumuodostumia, jolloin maan pintakerros oli karkeampaa, ja hienojakoista maata löytyi vasta syvemmältä. Useimpien kivennäismaan näytteiden emäskyllästysaste oli yli 50 %, mikä osoittaa maassa olevan kohtalainen varasto rapautuvia mineraaleja. Tästä syystä podsoloitumista ei havaittu yhdessäkään kohteessa. Kaikissa tutkituissa maissa oli märkyyden aiheuttamia ruostesaostumia, joissain heti muokkauskerroksen alapuolelta lähtien, joissain vasta syvemmällä. Monessa maassa oli nähtävissä maa-aineksen kulkeutumista alaspäin, mikä näkyi makrohuokosiin ja kuivumishalkeamiin kertyneinä pinnoitteina. Alueella havaitut maat kuuluivat kuuteen WRB-järjestelmän 32 pääluokasta: Histosols (2 maata), Gleysols (4), Planosols (6), Stagnosols (4), Arenosols (1) ja Regosols (4). Neljä ensimmäistä luokkaa ilmaisevat ensisijaisesti maan märkyyttä, ja loput kaksi luokkaa edustavat vähemmän märkiä maita, joissa maa-aineksen on edelleen lähes jääkauden aikana ja sen jälkeen paikalle kulkeutuneen lähtöaineksen kaltaista.

Asiasanat: kivennäismaat, maa-analyysi, maannosluokitus, maannostuminen, maaperä, maatalousmaa, morfologia, turvemaat

Abstract

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Information of soil properties is commonly needed in agricultural research. Experimental sites need to be documented in order to understand the factors influencing the results as well as to extrapolate the information to areas of similar soils. Soil data is used in modelling soil and environmental processes. Topsoil properties are usually obtained through agricultural soil testing but for comprehensive soil description deeper soil horizons need also to be analysed. Pedogenic soil classification according to international systems, such as the World Reference Base for Soil Resources (WRB), a system endorsed by the EU, is needed to put the soils into an international context.

In this study, altogether 21 soil profiles were investigated in Maaninka and Iisalmi in North Savo, Finland. The selected sites are used for field experiments carried out in North Savo by the Natural Resources Institute Finland (Luke). The sites were investigated in the field by excavating a soil pit to the depth of 1–1.5 m. The soil profile was morphologically described and photographed. Soil samples were taken by the horizon and analysed for relevant properties. The profiles were classified by the WRB system (IUSS Working Group WRB 2022). On the basis of the morphological and analytical results, the most pronounced pedogenic soil processes of the area were identified and the common soil types in agricultural use were recognized.

Almost all pedons had a horizon consisting of clay or clay loam within the investigated depth. It is obvious that these fine- and medium-textured soil materials are spread out throughout the agricultural soils of the area. Glacial till was rarely found in the fields. The plough layer was loamy in most soils. These clayic and fine loamic layers were at some sites covered with sandy esker material. The base saturation was usually above 50% indicating the abundance of weatherable minerals. All soils exhibited signs of wetness. Some pedons had brown redox concentrations and gray redox depletions only in the subsoil but in some other soils the redoximorphic features were observed right below the plough layer, while wetness and saturation with water has been the prerequisite of the formation of peat soils. Many soils had illuvial material on subsoil aggregate surfaces. In most soils there was a varved appearance in the subsoil below the frost depth, indicating negligible pedogenic development. It is noteworthy that no morphological signs of podzolization were observed. Altogether, six out of the 32 main soil classes of the WRB system were recorded in the area: Histosols (2 pedons), Gleysols (4), Planosols (6), Stagnosols (4), Arenosols (1) and Regosols (4). These soil classes indicate wetness and negligible pedogenic soil development.

Keywords: agricultural soils, mineral soils, peat soils, pedogenesis, soil analysis, soil classification, soil morphology

Foreword

Increasing need of soil information has been experienced by many researchers. Often researchers are required to characterize their experimental sites using international soil names of universal classification systems which are based on pedogenic features of the soil. Many soil profiles of the experiments carried out by the Natural Resources Institute Finland (Luke) Kuopio, Maaninka have been investigated in several projects over the years, but this soil data is mostly dispersed in researchers' own files and has not been comprehensively published. This project was initiated to a) collect all data of soil profiles investigated in Maaninka in 2001–2021 and b) investigate additional soil profiles from important research fields of the research station in 2022–2023.

The earlier projects where altogether 13 soil profiles have been investigated include 1) Suomen Maannostietokanta – Soil Database for Finland in 2003–2006 (5 soils), funded by the Ministry of Agriculture and Forestry and the Ministry of Environment, 2) Buffer strip project (SUOTO) in 2005–2007 (1 soil), funded by the Ministry of Agriculture and Forestry, Maj and Tor Nessling Foundation and Maa- ja Vesitekniikan Tuki ry, 3) Climatic impact of forage production on organic and mineral soils (ORMINURMI) in 2020–2023 (5 soils), funded by the Ministry of Agriculture and Forestry and 4) Biosphere North Savo: Utilization of biomass and biorefining techniques for novel industrial products (BIOSFÄÄRI) in 2020–2023 (2 soils), which received its main funding from the European Regional Development Fund (ERDF) through the Regional Council of Pohjois-Savo.

Compilation of the existing soil profile data and investigation of 8 new soil profiles were conducted in the project of "Peltomaa Pohjois-Savo (grant number 20210907)", which received the funding from the OLVI Foundation. The OLVI Foundation, and all other projects and their funders are gratefully acknowledged. The authors warmly thank the landowner of the study area at the Kirmanjärvi site and the personnel at Luke Maaninka, especially Tuure Houni, Johanna Kanninen, Mika Montonen, Arto Pehkonen and Hannu Raatikainen. Also, the personnel at Luke's Jokioinen laboratory and commercial laboratories are thanked for their laboratory analysis. Even though this report will mostly be used by Finnish scientists, we chose to write it in English for two reasons. First, the Finnish vocabulary for morphological soil description has not been comprehensively established, and second, the information contained in this report will predominantly be used in presentations, reports and scientific papers aimed at international communication and written in English. We hope that this report be well received by those who are in the need of soil information.

Maaninka, June 2024

Markku Yli-Halla and Mari Rätty

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1. Introduction

Soil information is needed in the planning of soil management operations and in the assessment of their impact on the soil itself and in the rest of the environment, e.g., water and the air. Soils characteristics influence the loading of substances into watercourses and the amounts of atmospheric emissions. Simulation models developed for the quantitative estimation of these fluxes usually need data of the properties of the topsoil and commonly also subsoil characteristics are needed. Topsoil properties of the Finnish agricultural soils are well documented and easily available. They can be found in the on-line summaries of soil test data produced by Eurofins Viljavuuspalvelu Oy (<https://tuloslaari.fi>) and in scientific papers of monitoring projects (e.g., Sippola & Tares 1978, Keskinen et al. 2016, Heikkinen et al. 2021). Instead, information of the subsoil properties is more difficult to find.

Proper communication of soil properties is essential in scientific research and in international soil monitoring projects. The audience must know the characteristics of the experimental sites and what kind of soils were analysed in the monitoring. Without this information, it is difficult to interpret the results and evaluate whether the results can be applied to one's own environment. In cross-border work, common terminology of soil qualifications is particularly important because experts from one country do not necessarily know what kind of soils there are in another country.

In the EU, soil issues have returned to the agenda during the last 25 years. The water framework directive 2000/60/EC, accepted in 2000, requires that the soils of the catchments are described. In 2002, the EU Commission gave a communication "Towards a Thematic Strategy for Soil Protection" which, for the first time, listed the threats that endanger proper functioning of soils of Europe (EU 2002). The following threats were identified: 1) loss of soil organic matter, 2) soil compaction, 3) erosion, 4) salinization, 5) soil pollution (diffuse and point loads), 6) loss of soil biodiversity, 7) soil sealing and 8) hydrogeological risks: floods and landslides. On this basis, a directive on soil monitoring was planned but was not eventually passed. In July 2023, a new attempt was made and the Commission published a "Proposal for a Directive on Soil Monitoring and Resilience" ([Proposal for a Directive on Soil Monitoring and Resilience - European Commission \(europa.eu\)](https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32023P0200)). If accepted, the member states need to carry out extensive soil monitoring and report results. Therefore, the need to communicate the properties of the Finnish soils in an internationally understandable manner is increasing.

1.1. Pedogenic soil classification

Name of a soil summarises the essential soil characteristics. Systematic soil classification defines the name for a soil on the basis of its properties. Therefore, soil classification is the key for communication on soils. National soil names, such as "red soils" and "yellow soils" of the Chinese system and clay soils and sandy soils of the Finnish systems, are most often non-compatible and they are relevant and truly understandable only within a country. For example, in Finland it is commonly conceived that clay soils are gray in colour and have a high cation exchange capacity, but this is not the case universally. These presumptions apply only to 2:1 clay minerals, such as illite and vermiculite, but not to 1:1 clay minerals, such as kaolinite, which is the most widespread clay mineral of the world. The local names don't facilitate communication on soils and transfer of soil-related research results internationally. When using different national soil naming systems, it is impossible to tell whether soils in question are

similar or different across national borders of different countries, which makes application of research results difficult outside the area in which they were obtained.

Names which are understandable for the whole Soil Science community can be derived from international soil classification systems, such as World Reference Base for Soil Resources, abbreviated as WRB (IUSS Working Group WRB 1998, 2022). This is the system that is endorsed by EU. Another widely used system is the US Soil Taxonomy (Soil Survey Staff 1999). These systems are based on pedogenic characteristics of soils and are, as much as possible, not affected by man-made changes such as cultivation and fertilization practices. They reflect the basic soil processes and express the most essential soil properties. These systems are universal, and all soils of the world can be classified according to them. Publishing in scientific journals of soil science commonly requires that soils are classified according to these systems. Expressing soil names with these systems allows transfer and application of knowledge from a given area to another with similar or nearly similar soils across national borders.

The WRB system is developed on the basis of the FAO system used as the legend of the Soil Map of the World (FAO 1988). Recently the Soil Geographical Database of Europe at scale 1:1,000,000 has been compiled by the JRC/European Soil Bureau (<http://eusoils.jrc.it>) by correlating the soil types of the national classification systems with the FAO/WRB soil units. This soil database forms a basis for soil protection in EU, and through pedotransfer functions it has facilitated compilation of a map of carbon storage in soils of the EU countries. The previous FAO system has been used even in the calculation of the carbon stock of the World (Batjes 1996). Transfer of knowledge for soil protection throughout the Eurasian continent is much promoted by widening the use of the WRB system to new areas by correlating local soil types with the WRB soil units.

Proper classification requires investigation of the soil profile in the field to the depth of about 1.5–2 m. The different soil horizons are identified, characterized morphologically (colour, structure, consistency) and sampled for analyses made in the laboratory. The analyses are made by the horizon according to internationally agreed methods. They include determinations such as particle size distribution, organic carbon, carbonates, cation exchange capacity, pH, electrical conductivity and bulk density. On the basis of the morphological and analytical information the soil name, summarising the essence of the soil, can be derived in a transparent way using the Key.

1.2. The WRB classification system

The World Reference Base (WRB) is an advanced version of the Legend (FAO-Unesco 1974) and the Revised Legend (FAO 1988) of the Soil Map of the World (FAO-Unesco 1971–1981). Since 1980, the International Society of Soil Science (ISSS, since 2002 the International Union of Soil Sciences, IUSS) worked on a revised form of those legends. The Working Group “World Reference Base for Soil Resources” published the first edition of the WRB classification system in 1998 (FAO 1988). Further editions have been published in 2006 and 2014, and the fourth edition of the WRB, followed in this report, was introduced in 2022 (IUSS Working Group WRB 2022) at the 22nd World Congress of Soil Science in Glasgow.

The classification of a soil is based on a detailed investigation of the soil in the field. The soil is investigated by the horizon usually to the depth of about 150 cm (or to the impermeable layer, such as bedrock, if closer than 150 cm from soil surface). The emphasis is on the

morphological characteristics (colours, texture, structure, consistence, obvious transport of material, depth of occurrence of the various observations). Chemical and physical analyses are used to refine the classification. A proper morphological description is the basis of the classification, and it cannot be substituted by analytical work on soil samples. On the basis of the morphological description amended with analytical data, the diagnostic horizons, diagnostic properties and diagnostic materials, accurately defined in the WRB manual, are identified. Thereafter, the soil can be classified using the Key of the WRB manual. In the actual classification, one has to always start from the top of the Key, which primarily consists of Yes – No questions. If a soil possesses a qualification in question, it falls into that particular category, called Reference Groups. If not, the soil proceeds to the successive questions. Finally, all soils get a classification.

The fourth edition of the WRB system has 32 Reference Groups. They can be divided into groups as follows: Those Reference Groups that have been found in Finland, are bolded.

1. Soils with thick organic layers: **Histosols**
2. Soils with strong human influence
 - With long and intensive agricultural use: Anthrosols
 - Containing significant amounts of artefacts: Technosols
3. Soils with limitations to root growth
 - Permafrost-affected: **Cryosols**
 - Thin or with many coarse fragments: **Leptosols**
 - With a high content of exchangeable Na: Solonetz
 - Alternating wet-dry conditions, shrink-swell clay minerals: Vertisols
 - High concentration of soluble salts: Solonchaks
4. Soils distinguished by Fe/Al chemistry
 - Groundwater-affected, underwater or in tidal areas: **Gleysols**
 - Allophanes and/or Al-humus complexes: Andosols
 - Subsoil accumulation of humus and/or oxides: **Podzols**
 - Accumulation and redistribution of Fe: Plinthosols
 - Stagnant water, abrupt textural difference: **Planosols**
 - Stagnant water, structural difference and/or moderate textural difference: **Stagnosols**
 - Low-activity clays, P fixation, many Fe oxides, strongly structured: Nitisols
 - Dominance of kaolinite and oxides: Ferralsols
5. Pronounced accumulation of organic matter in the mineral topsoil
 - Very dark topsoil, secondary carbonates: Chernozems
 - Dark topsoil, secondary carbonates: Kastanozems
 - Dark topsoil, no secondary carbonates (unless very deep), high base status: Phaeozems
 - Dark topsoil, low base status: **Umbrisols**
6. Accumulation of moderately soluble salts or non-saline substances
 - Accumulation of, and cementation by, secondary silica: Durisols
 - Accumulation of secondary gypsum: Gypsisols
 - Accumulation of secondary carbonates: Calcisols
7. Soils with clay-enriched subsoil
 - Interfingering of coarse-textured, light-coloured material into a finer-textured, stronger coloured layer: Retisols
 - Low-activity clays, low base status: Acrisols

- Low-activity clays, high base status: Lixisols
 - High-activity clays, low base status: Alisols
 - High-activity clays, high base status: **Luvisols**
8. Soils with little or no profile differentiation
- Moderately developed: **Cambisols**
 - Stratified fluviatile, marine or lacustrine sediments: **Fluvisols**
 - Sandy: **Arenosols**
 - No significant profile development: **Regosols**

1.3. Classification of Finnish soils

Soil classification in Finland has traditionally based on 1) the concentration of organic matter and 2) soil texture or particle size distribution (Aaltonen et al. 1949). This classification is simple and useful in this limited area because the soils are young and mostly at an early stage of pedogenesis, still close to the original parent material. Traditional "soil" maps of Finland can be regarded as parent material maps. The WRB system has Reference Groups that accommodate well also soils of these characteristics, and the WRB soil names express their essential characteristics in an internationally understandable manner. In the WRB system, soil texture can be expressed as an attribute of the Reference Group name, thus serving as a link between the Finnish classification and the WRB system.

Researchers from the Institute of Soil Science of the Agricultural Research Centre of Finland (and former and successive organizations) have participated in international projects producing pedogenic soil maps. Professors Benjamin Frosterus and Bernhard Aarnio participated in the compilation of the European soil maps, initiated by the International Society of Soil Science (ISSS). Those maps were published in 1927 and 1937 (Stremme 1997). Thereafter, professors Jouko Vuorinen and Mikko Sillanpää were Finnish representatives in these activities. In 1965, FAO published a soil map of Europe in scale 1:2,500,000 (FAO 1965, Dudal et al. 1966). European Soil Data Centre (formerly European Soil Bureau) is currently the responsible organization for the soil map of Europe, or more accurately Georeferenced Soil Database for Europe at scale 1:1,000,000 (Figure 1). The Finnish input has originally been produced by professor Jouko Sippola and researcher Leila Urvas in the beginning of 1970s. This work where Finland is presented with 1000 map polygons was originally prepared for the FAO Soil Map of the World at scale 1:5,000,000, published in 1974. During this project, an international excursion by eight scientists was made to Finland on 8–9 July, 1971 and the soil classes to be used for Finland were laid out. According to the map by Sippola and Urvas, the proportion of different soil types in Finland is as follows: Orthic/Haplic Podzols (55%, all glacial till soils), Dystric/Eutric Histosol (29%, all organic soils), Dystric/Vertic Cambisols (8%, most farmland), Dystric/Vertic Gleysols (2%, muddy soils, including acid sulfate soils), and Lithic/Haplic Leptosols (5%, exposed bedrock and associated very shallow soils). Later on, this same output was transformed into the Georeferenced Soil Database of Europe at scale 1:1000 000 (European Soil Bureau 1998a). The same presentation has been included also in the Soil Atlas of Europe in 2005 (Jones et al. 2005), where the legend has been revised from the FAO to the WRB system. The same presentation appears also in the Northern Circumpolar Soil Map (Tarnocai et al. 2003). This Finnish participation and appearance in international soil maps has never been advertised and has got no publicity. The probable reason is that the pedogenic soil classification has traditionally been considered useless in Finland.

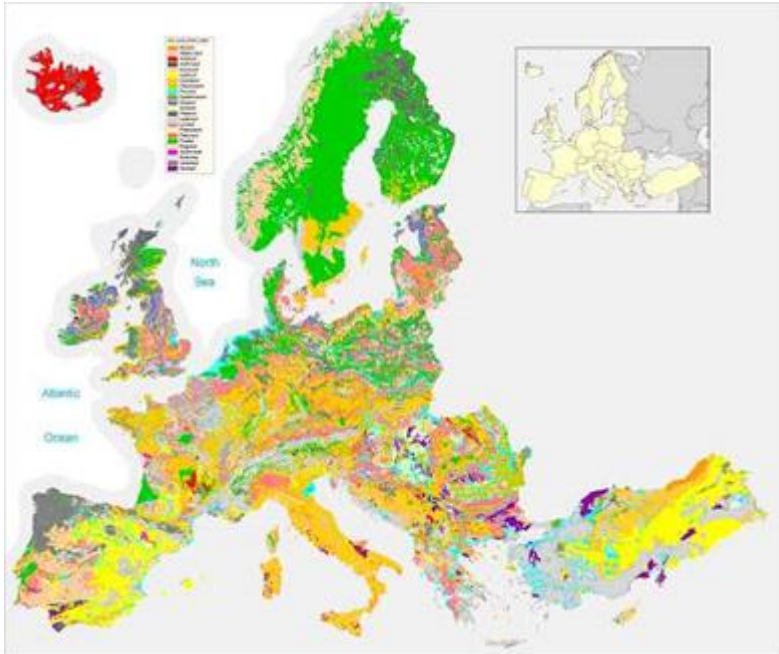


Figure 1. Soil map of Europe. The Finnish output, produced originally at the Institute of Soil Science of the Agricultural Research Centre (MTTK) principally expresses podzols (green) and peatlands (dark gray).

After Finland joined the EU and researchers started to increasingly participate in joint research projects, a need to describe our experimental soils according to the pedogenic classification systems began to grow. Therefore, in the end of the 1990s, a project was started to describe some of the important experimental fields according to the WRB and U.S. Soil Taxonomy systems. Some 30 soil profiles mainly at the various research stations were investigated and documented in detail in a report (Yli-Halla et al. 2000). Some scientific papers were also published on the material (Mokma et al. 2000, Yli-Halla & Mokma 2001, Mokma et al. 2004, Yli-Halla et al. 2006a, 2006b). At the same time, the Geological Survey of Finland launched a project to make a 1:250 000 map of the quaternary deposits of Finland (i.e., a "soil" map, or map of parent materials). As an amendment to this project, soil map according to the WRB system was made following the instructions of the European Soil Bureau (1998b). This project contained very little field work, and the Finnish soil types were converted into the WRB Reference Groups on the basis of the findings made during the investigation of the soil profiles. It was assumed that a certain parent material has developed into a certain WRB Reference Group. It was realized that this approach can be valid only in a limited and climatically rather uniform area. The WRB soil map at scale 1:250 000 was published in 2009 (Figure 2, Lilja et al. 2009) but thus far it has not been integrated into the Geographical Soil Database of Europe where Finland is still presented on the basis of the output originally produced in the 1970s.

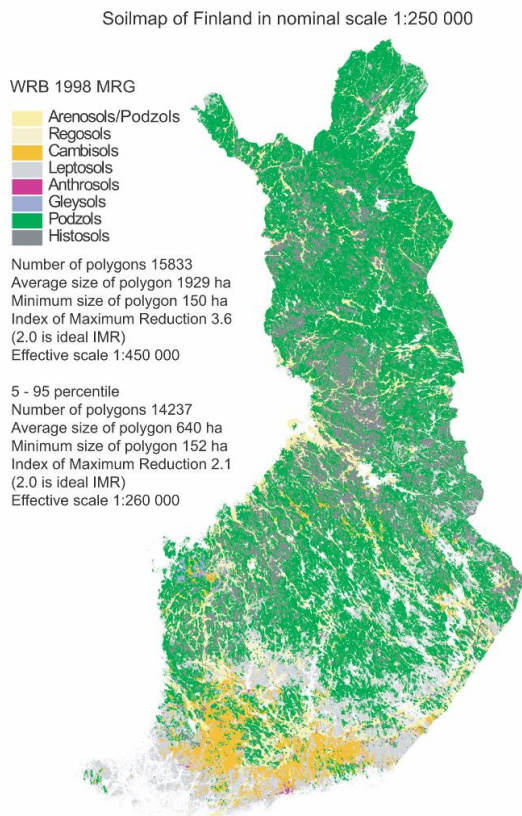


Figure 2. Soil map of Finland according to the WRB system (Lilja et al. 2009).

Soon after publishing the first version of the Soil Map of Finland, it was realized that the wetness of soil was not sufficiently expressed in the WRB names that had been given to Finnish soils. When American and Estonian scientists classified these soils according to Soil Taxonomy, wetness was a predominant element of the soil name. Wetness is such a self-evident and all-embracing characteristic of almost all land area of Finland that it has been neglected when producing names of Finnish soils for international soil maps. For example, most clay soils of Finland have been regarded as Vertic Cambisols according to the FAO/WRB system, not indicating the wetness, while the American and Estonian colleagues, according to Soil Taxonomy, called them Vertic Cryaquepts, where the syllable *-aqu-* indicates the aquic moisture regime. There was thus an obvious need of harmonization. In the unpublished memorandum of the 1971 excursion, the adequacy of the name Gleysols had already been considered but the name Cambisols was eventually adopted in Finland. In 2008–2010, consultations associated with soil excursions were arranged with Norwegian soil scientists who carry out extensive soil classification program according to the WRB system. As a result, it was concluded that the Finnish clay soils should mostly be classified as Stagnosols. A new conversion table (Table 1) was developed and included in the revised user manual of the soil database (Lilja et al. 2017).

Table 1. A rough conversion of the Finnish soil types into typical WRB soil classes (modified from Lilja et al. 2017). Nomenclature follows the 2022 edition of the WRB system.

Finnish soil type	Typical WRB classification
Very shallow soils and rocky areas	
Exposed bedrock and rocky areas	Lithic Leptosols
Very shallow soil (<1 m)	Dystric Leptosols
Glacial till	
Glacial till in dry areas	Haplic Podzols
Glacial till covered with shallow (<40 cm) organic topsoil	Histic Podzols
Sorted coarse-textured soils	
Sand	Haplic Podzols
Sand covered with shallow (<40 cm) organic topsoil	Histic Podzols
Sorted medium-textured soils	
Fine and coarse silt, pH>5.5	Eutric Regosols
Fine and coarse silt, pH<5.5	Dystric Regosols
Fine and coarse silt covered with shallow (<40 cm) organic topsoil	Histic Gleysols
Clay soils, except muddy clay	
Clay soils	Vertic Stagnosols
Clay soils with an organic topsoil	Histic Gleysols
Organic soils	
Peat soils, peat depth >40 cm	Dystric Histosols
Muddy soils, including acid sulfate soils	
Muddy soils	Dystric Gleysols
Muddy soils with a shallow (<40 cm) organic topsoil	Histic Gleysol

The legend of the Geographical Soil Database of Finland consists of six reference groups, i.e., Podzols, Histosols, Stagnosols, Leptosols, Regosols and, Gleysols. This low number of reference groups is due to the limitations of the data which this database is based on. Even though also Arenosols, Cambisols, Cryosols, Fluvisols, Luvisols, Umbrisols and Planosols do occur in Finland, they could not be delimited on the map on the basis of the available data. Moreover, most of these soils cover only small areas and do not meet the minimum area of 150 ha to justify their appearance in the generalized map. Therefore, these Reference Groups are included in the few dominating Reference Groups of the map. However, when classifying individual fields or experimental sites, all Reference Groups are considered, and the soil is classified as it is.

2. General features of the soils of North Savo

2.1. Soil geology of North Savo

The ancient basement of Finland has been formed gradually over a long period of time. It is part of the Precambrian block of northern and eastern Europe, i.e., Fennoscandian craton, being one of the oldest parts in the Eurasian continent. The northern and eastern parts of Finland belong to the 3100–2500 million years old Archaean domain, and the southern and central parts of the country to the 1930–1800 million years old Early Proterozoic domain. Only a small part of the Finnish basement is younger than 1800 million years, of which the most significant area is the 1650–1540 million years old Middle Proterozoic rapakivi granite in southern Finland (Korsman & Koistinen 1998). The oldest Archaean nucleus of the Fennoscandian Shield is mostly located in the Kola Peninsula and Russian Karelia, from where it extends to the

northern and eastern parts of Finland. Of which only about 20% lies in Finland, however, accounting for almost a third of the Finnish basement. The Finnish part consists mostly of large areas of 3100–2650 million years old migmatite-granitoids, containing small greenstone belts of a volcanic origin and mica schist-paragneiss areas of a sedimentogenic origin. For example, in central Finland, the Archaean domain extends as a wide zone from the south of Kemi through Pudasjärvi and Iisalmi to the south side of Kuopio, Siilinjärvi, Vehmersalmi and Kaavi. They can be divided into the complexes of Pudasjärvi, Iisalmi and Rautavaara (Luukkonen & Sorjonen-Ward 1998), covering the significant part of North Savo region. The Karelian formations of the Fennoscandian Shield consist of 2500–1900 million years old metamorphic sedimentary rocks and vulcanites which were deposited on the Archaean domain and subjected to the Svecofennian orogeny 1900 million years ago. Karelian schist zones are found in Kainuu, North Karelia, Savo and Northern Ostrobothnia (Laajoki 1998). The border zone between the Archaean and Svecofennian domains is clear. Most of the present basement in southern and central Finland has been formed in connection with the formation of Svecofennian orogeny (1900 million years ago). The Svecofennian schist of the Savo belt is dominated by mica schists of turbidite origin, gneiss complexes and migmatites (Kähkönen 1998).

In general, the Finnish bedrock is characterized mainly by intrusive (igneous) rocks (52.5%; granites, granodiorites, quartz-diorites) and migmatites (21.8%) and smaller parts by schists (9.1%; phyllites, mica schists, biotite gneiss), igneous rocks (poor in silicic acid) (8.2%; gabbros, diabases, amphiboles), quartzites and sandstones (4.3%), granulites (4.0%) and calcareous rocks (0.1%). Volcanic rocks are more abundant in Lapland than in southern Finland. Only about 3% of the bedrock appears as a bare rock (Korsman & Koistinen 1998, SKGK 2024). Less than one percent of all intrusive (igneous) rocks are alkali rocks, including carbonate rocks, alkaline silicate rocks and lamprophyre hypabyssal rocks. The most significant carbonate complexes are located in Siilinjärvi (North Savo) and Sokli (Lapland) (Vartiainen 1998).

As an opposite to one of the world's oldest bedrock, the Finnish soils are geologically young, and their formation has been influenced by the latest glaciation and the subsequent evolutionary stages of the Baltic Sea and post-glacial land upheaval. Finland and adjacent areas were covered several times by the Scandinavian ice sheet during the Quaternary cold stages. Accordingly, the pre-Quaternary weathered bedrock surface and the sediments deposited during the Weichselian Stage, which ended about 11,700 years ago, commonly lie on the pre-Cambrian bedrock (Johansson et al. 2011). At least 7 meters thick layer of bedrock has been estimated to be eroded by the degradation processes of the last glacial period (Laitakari 1998). The ice sheet has shaped landscapes through the processes of grinding, removal, deposition and sorting. Soil chemical and physical properties are broadly determined by parent materials presented in the previous paragraphs. However, the mineralogy of Finnish bedrock is considered to be relatively monotonous, generating fines largely similar in mineralogy (Lintinen 1995, Keskinen et al. 2022a).

In Finland, the thickness of the surficial sediments can be even up to 100 m, however, averaging 6–7 m in depth (Lintinen 1995). In some areas, bare rock is exposed and/or soil layer, typically till materials, is thinner than one meter above the bedrock. For example, this kind of areas cover on average 3% of the land area in Maaninka region (Saarelainen & Leino 2002a) and about 7% in Iisalmi and Lapinlahti regions (Urvas & Hyvärinen 1992, Saarelainen & Leino 2002b). In Central Finland, these exposed bedrock areas can be so extensive that they are shown as the dominant soil type (Leptosols) in the soil map of Finland (Figure 2). On the other hand, the bedrock can be covered by a thicker till layers, representing various moraine and esker formations. For example, moraine formations, i.e., drumlins, comprise 2.7% of the land area in Iisalmi region, being mainly fine-grained tills. Part of these formations reach up

to nearly 40 m with relatively steep slopes, whereas part of them is flat-topped (Saarelainen & Leino 2002b). Siilinjärvi radial esker branches into two parts, of which one runs via Maaninka and the other via Lapinlahti-lisalmi, being deposited at the margins of retreated ice sheet during deglaciation (Glückert 1974). Esker formations cover about 3.5% of the land area in Maaninka region (Saarelainen & Leino 2002a).

In general, glacial tills consist of a poorly sorted mixture of soil materials with various size and shapes, ranging from clay-size particles to gravel and boulders. Basal till represents the most common surficial sediment, covering the Precambrian crystalline bedrock and about 48% of Finland's land area. The tills are often covered by other deposited sediments. Basal tills are commonly sandy tills, even though some tills are rich in fine soil material ($\geq 30\%$; < 0.06 mm in grain size) and clay fraction ($\geq 5\%$; < 0.002 mm). Tills rich in fine fractions, in combination with high clay content and high specific surface area of till fines, occur especially in the northwestern part of the geochemical Lake Ladoga-Bothnian Bay zone, extending from the coast of Bothnian Bay to Riistavesi in North Savo (Lintinen 1995). In North Savo, the fine-grained tills are reported to be common. In Lapinlahti region, for example, tills constitute on average 61% of land area, and fine-grained tills account for two-thirds of all till types (Urvas & Hyvärinen 1992). In lisalmi region, tills (about 43%) mostly consist of fine-grained tills (c. 42%), in which fine contents vary from 35 to 63% (mean 54%) and the respective clay content 4 to 14% (mean 11%) (Saarelainen & Leino 2002b). Naturally eutrophic boreal lakes have been found in till-dominated inland area in North Savo, belonging to the lisalmi Route and adjacent watercourses. These catchment areas are characterized by organic and fine-grained sediments, including fine-grained tills (Tammelin et al. 2017, Tammelin & Kauppila 2018).

The mineralogy of Finnish agricultural soils has been surveyed locally (e.g. Peltovuori et al. 2002, Yli-Halla et al. 2006b, Yli-Halla et al. 2009) and with more extensive geographical coverage (Sippola 1974, Keskinen et al. 2022a). On a semi-quantitative basis by X-ray diffraction (XRD), Peltovuori et al. (2002) produced information on mineralogical features for the genetic horizons of four pedons, which represented fine- and coarse-textured cultivated soils in the southern (Kirkkonummi, Loppi, Jokioinen) and the western (Toholampi) parts of the country. Furthermore, mineralogical compositions of clay, silt and sand fractions have also been determined for the selected genetic horizons of the agricultural pedons on a sandy soil at Sotkamo in east-central Finland (Yli-Halla et al. 2006b) and on clay soil in Jokioinen in southwestern Finland (Yli-Halla et al. 2009). Using differential thermal and XRD analyses, Sippola (1974) identified qualitatively mineral composition of particle size fractions separated from 56 subsoil samples of cultivated and virgin areas originated mostly from southern and western Finland. More recently, based on mid-infrared (MIR) spectroscopy, Keskinen et al. (2022a) selected 120 sampling sites for XRD mineral analyses from the national agricultural soil monitoring programme in 2009, representing the whole agricultural area. In accordance with the previous studies, Keskinen et al. (2022a) discerned quartz, plagioclase (feldspars) and K-feldspar to be the main components of the mineral phase in agricultural topsoils, with the respective compositional means of 33, 26 and 11% over the soil types. In the study by Keskinen et al. (2022a), all or nearly all samples also contained some amphiboles (5.0%) and micas (5.4%), whereas disordered clays (1.8%; inc. vermiculite, smectite), amorphous inorganic components (1.4%; e.g. ferrihydrite), chlorite (0.9%), epidote (0.6%), goethite (0.5%), kaolinite (0.1%) and trace phases (0.9%; e.g., calcite, dolomite, hematite, magnetite) were commonly detected in smaller quantities. As a general trend in the surveys of Sippola (1974) and Keskinen et al. (2022a), the relative proportions of quartz and plagioclases increased with an increasing particle size, whereas the occurrence of e.g., mica, disordered clays and amorphous inorganics were common in clay soils.

2.2. Climatic conditions

2.2.1. Climatic conditions in North Savo

The area of Finland comprises of the five climatic areas, i.e., nature areas, which include the 1) hemiboreal, 2) southern boreal, 3) middle boreal, 4) northern boreal and 5) hemiarctic zones. Most of the inland province of North Savo belongs to the southern boreal zone, whereas hilly areas in the northeastern and northern parts of the region represent the middle boreal zone (Kersalo & Pirinen 2009). The lake-rich North Savo belongs to the Vuoksi River Basin District, which contains about 36% of lake areas in eight Finnish River Basin Management Areas (Tattari & Väisänen 2011). These freshwater bodies also act as a heat-sink by raising nighttime air temperature during summer and autumn, as well as extending the growing season. In higher watershed areas, continental features of the climate are accentuated (Kersalo & Pirinen 2009).

For general description of the climatic conditions in North Savo, the long-term averages for the normal periods of 1981–2010 and 1991–2020 were obtained from Pirinen et al. (2012) and Jokinen et al. (2021), respectively, using observations from the weather station in Kuopio Maaninka. The weather station of Finnish Meteorological Institute (FMI) is located on the premises of Natural Resources Institute Finland (Luke; Kuopio Maaninka). In Finland, the annual mean temperature in the 1991–2020 normal period was 2.9 °C, which is approximately 0.6 °C higher than in the previous 1981–2010 period and approximately 0.9 °C and 1.3 °C higher as compared to the 1971–2000 and 1961–1990 periods, respectively (Jokinen et al. 2021). According to the latest two normal periods, a similar trend in increased monthly mean temperatures can also be observed in Kuopio Maaninka (Figure 3), with 0.6 °C higher annual mean temperature in the latest period (3.2 °C) compared to the 1981–2010 period (3.8 °C). In the 1981–2010 and 1991–2020 periods, the coldest and warmest months of the year were January–February and July, with the respective average monthly mean temperature of -8.8 and 17.1 °C (Pirinen et al. 2012, Jokinen et al. 2021). During the latest two normal periods, the mean of the growing degree day (GDD) sum (the daily mean temperature > +5 °C) was 1189 °C day in 1981–2010 and 1292 °C day in 1991–2020. In the 2020s, as a comparison, the GDD ranged from 1358 °C day in 2022 to 1466 °C day in 2023 (FMI Ilmanet).

Annual precipitation in the area exceeds annual evapotranspiration. The annual mean precipitation was 612 mm in the 1981–2010 period and 617 mm in 1991–2020. However, the variation between years of precipitation was considerable. There was on average 203, 117 and 12 days of precipitation exceeding 0.1, 1.0 and 10.0 mm, respectively, with the highest daily precipitation of 105 mm. Typically, the lowest precipitation occurs in the early spring (April), whereas the rainiest months is in the middle of summer (July), with the respective average monthly mean precipitation of 30 and 81 mm in the 1981–2010 and 1991–2020 periods (Figure 3; Pirinen et al. 2012, Jokinen et al. 2021).

In Finland, snowfall makes up a substantial proportion of total annual precipitation and soils are typically subjected to an annual winter frost period. A maximum of third of the precipitation falls as snow in the southwestern part of the country, whereas snow constitutes 40–50% of the precipitation elsewhere in Finland, even up to 60% in the northern part of the country (Kersalo & Pirinen 2009). In Kuopio Maaninka, permanent snow cover typically lasts from November to April and the snow cover is deepest in March, with the average monthly mean of 48 cm in the 1981–2010 and 1991–2020 periods (Figure 3; Pirinen et al. 2012, Jokinen et al. 2021). In east-central Finland in 1961–1991, mean annual evaporation and runoff have made

up 300–500 mm and <300–400 mm, respectively (Vakkilainen 2009). Peak discharge events are typically caused by snowmelt in the northern and by autumn rainfall in the southern parts of the country. During the snowmelt period in the spring, the average discharge ranges from 100 to 200 mm, comprising about 80% of the maximum snow water equivalent and 30–50% of total annual discharge (Vakkilainen 2009).

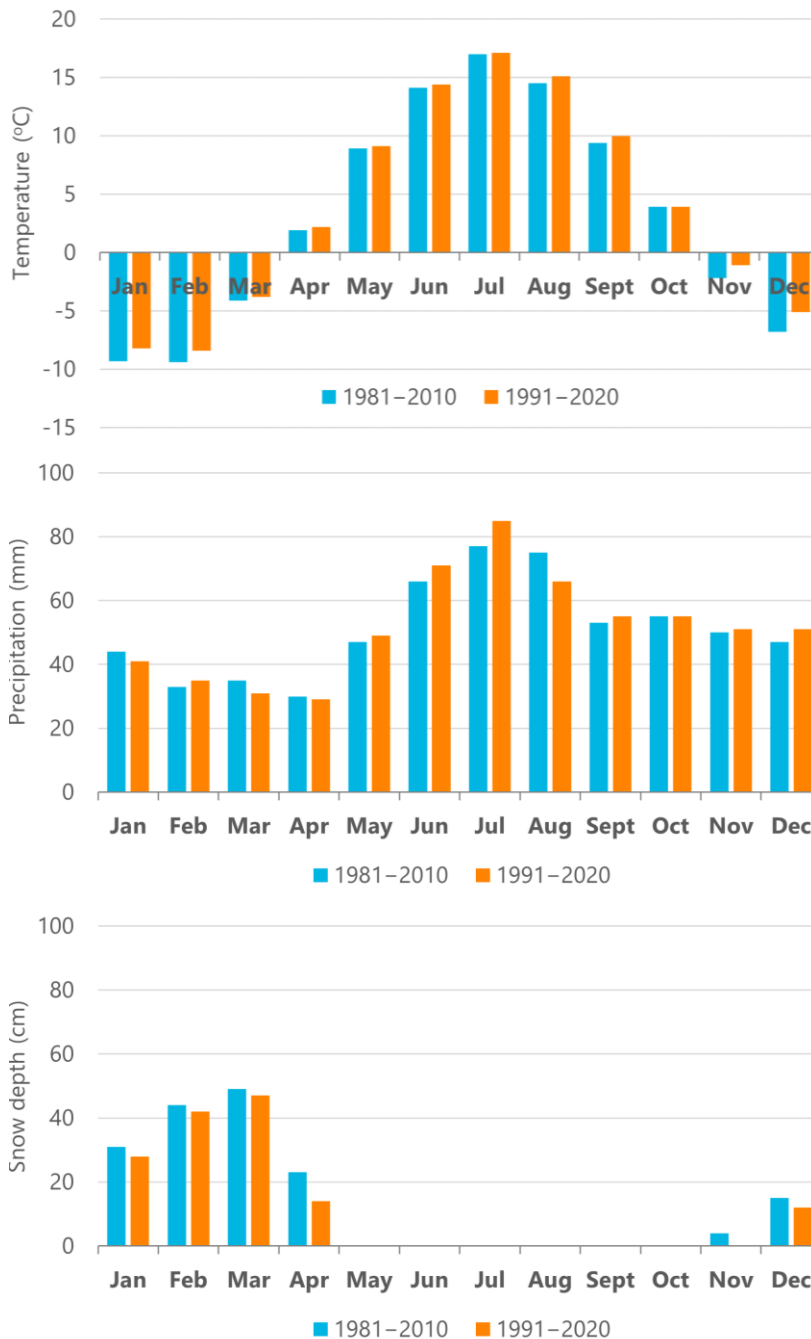


Figure 3. Monthly mean air temperature (°C), precipitation (mm) and snow depth (cm) in the period of 1981–2010 and 1991–2020 in Kuopio Maaninka. Snow depth observations have been made on the 15th day of the month. The long-term averages for the climatological normal periods of 1981–2010 and 1991–2020 were taken from Pirinen et al. (2012) and Jokinen et al. (2021), respectively.

2.2.2. Soil temperature

Soil temperature is dependent on the air temperature, but the fluctuation is much smoother. The mean annual soil temperature in Maaninka is about 6 °C. The mean monthly soil temperature at the depth of 20 cm was below 0 °C from December to April in 1968–1980 indicating the frost duration of about four months. It should be pointed out that the minimum mean monthly temperature was no lower than 1.1 °C (in February). The results demonstrate the cool soil temperatures in the beginning of the growing season, the mean soil temperature in May being only 5.7 °C. The maximum monthly soil temperature of 16.2 °C at this depth was reached in July, and soil temperature remained above 5 °C until late October, i.e., for at least two months after harvesting the cereal crops. The annual amplitude of soil temperature decreased deeper in the soil. While at 20 cm, the difference between the lowest and the highest mean soil temperature was as much as 17.3 °C, the difference was 14.5 °C at 50 cm and only 10.9 °C at 100 cm (Figure 4). Mean monthly temperatures below 0 °C were not reached at 50 cm and 100 cm. On the other hand, the monthly mean soil temperature exceeded 5 °C only in five months at all depths, indicating the cool soil in general.

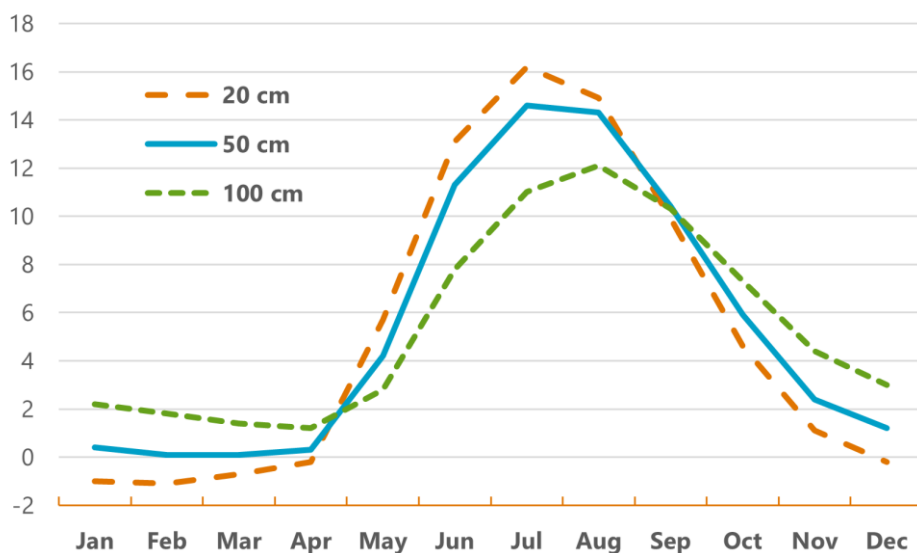


Figure 4. Average monthly soil temperature (°C) in Maaninka measured at different depths in 1971–1990. Data from Heikinheimo and Fougstedt (1992).

In the U.S. Soil Taxonomy system, soil temperature at 50 cm is one of the variables used in soil classification. Soils are divided into different soil temperature regimes (STRs). Particularly the coolest one, the cryic temperature regime, is expressed in soil name, because in those soils low temperature clearly influences soil processes and restricts agricultural land use. In the cryic temperature regime, the mean annual soil temperature (MAST) is between 0 °C and 8 °C and the mean summer soil temperature (MSST) is 15 °C at the maximum. The frigid soil temperature regime has the same criteria for MAST but the MSST is above 15 °C. The basic difference between the cryic and frigid STR is that the summers are cooler in the cryic STR. Whole Finland has represented the cryic STR (Yli-Halla & Mokma 1998), but soils in southern Finland are close to the frigid STR, due to warm summer temperatures.

According to the published results (Heikinheimo & Fougstedt 1992), all the four sites investigated, including Maaninka, were firmly within the cryic STR (Table 2). The unpublished data collected more recently (1996–2015) suggest that the MAST and MSST have increased

slightly compared to the earlier period. In Maaninka, both increases have been almost 1 °C. Even though the average MAST and MSST values fall within the cryic STR, MSST values that meet the criterion of the frigid STR have recently been more common. This trend seems to be consistent throughout the southern and middle Finland, including North Savo area.

Table 2. Mean soil temperature (°C) measured at the depth of 50 cm. The range is presented in the parentheses. The data has been measured by the Finnish Meteorological Institute.

Location	Years ¹	Mean annual soil temperature	Mean summer soil temperature	Years ²	Mean annual soil temperature	Mean summer soil temperature
Anjala	1982–1990	6.4 (5.1–6.8)	13.7 (11.8–14.8)	1996–2014	7.0 (5.9–8.4)	14.6 (12.8–16.0)
Jokioinen	1958–1970	5.9 (5.6–6.4)	12.7 (11.1–13.6)	1996–2013	6.5 (5.3–8.3)	13.2 (12.0–14.5)
Ylistaro	1968–1980	5.5 (4.8–6.4)	13.1 (12.0–15.2)	1996–2015	6.4 (5.1–8.3)	15.0 (13.4–16.4)
Maaninka	1968–1980	5.3 (4.6–6.2)	13.5 (12.3–15.5)	1996–2013	6.2 (5.0–6.9)	14.3 (12.7–16.0)

1) Published by Heikinheimo and Fougstedt (1992).

2) Unpublished. Missing data: Anjala 2005, 2006; Jokioinen 1997, 2005, 2006; Ylistaro 2005, 2006, 2007; Maaninka 2005, 2006.

2.3. Agricultural soils of North Savo

In Finland, the agricultural area (2.3 million ha) in use makes up 7.5% of total land area, of which cereals and grasslands (inc. 10% fallow area) occupy 47% and 45%, respectively. Within the utilized agricultural area (0.15 million ha) in North Savo, the respective proportions are 28% for cereals and 66% for grasslands (inc. 9% fallow area) (OFS 2024a). Agriculture in North Savo is characterized by dairy milk and beef production, the region being the second important milk producer in 2023 (OFS 2024b). In the region in 2023, the average utilized agricultural area was 51 hectares per farm (OFS 2024c). Most of Finnish fields are artificially drained due to excessive wetness (Puustinen et al. 1994), and only about 14% of the agricultural area is cultivated without local drainage (Tike 2014). Fields drained with open ditches and subsurface drainage pipes represented 19% and 67% of the total agricultural area, respectively (Tike 2014). At the national scale, one-third of Finnish fields are located close to inland waterways and around 70% of fields are within 300 m of the shoreline of waterways, including lakes, rivers and main ditches (Peltonen-Sainio et al. 2015).

In North Savo, the plough layers of agricultural soils are generally characterized by relatively coarse texture. Coarse- and medium-textured mineral soils and fine-textured clay soils make up about 50%, 34% and 8% of the soil type groups, respectively (Table 3). Organic soils account for about 8% (range 3–16%), of which mull (inc. mud) and peat soils represent 5% (range 3–10%) and 3% (range 0–7%), respectively. The prevailing soil type is glacial till, representing on average 29–73% (mean 45%) of soil type groups in different municipalities. The proportion of fine sand ranged from 1 to 18% (mean 5%) between municipalities. Of the medium-textured soil types, coarse silt, loam and fine silt soils comprise about 10% (range 2–17%), 15% (range 3–22%) and 9% (0–21%), respectively. In most municipalities, clay soils compose on average from 0 to 9% of the soil type groups. In the norther parts of North Savo

(Iisalmi, Kiuruvesi and Sonkajärvi), however, the proportion of different clay soils is relatively high, being 15–16%. Part of arable soils with the finest texture might be attributable the presence of fine-grained tills, of which clay-size particles have been transported to water bodies to settle. After draining and/or natural drying this kind of areas might be reclaimed, being suitable for agricultural land.

At the European scale, Finnish topsoils are relatively rich in organic carbon (Jones et al. 2004, Aksoy et al. 2016), the nationwide mean organic carbon content being 33 g/kg (3.3%) for cultivated mineral soil at the depth of 0–15 cm (Heikkinen et al. 2022). In agricultural soils of North Savo, mean annual nitrogen and phosphorus balances were 56 kg/ha and 4.3 kg/ha in 2021, respectively (Luke 2023). In North Savo in 2005–2009, the average soil phosphorus test concentration was 10.4 mg/l, compared with that of 13.0 mg/l for the whole country, involving extraction with acid ammonium acetate at pH 4.65. Mean soil phosphorus concentrations ranged from 8.7 to 11.4 mg/l for the plough layer of mineral soils within municipalities of the North Savo region, the respective values being 8.3–9.0 mg/l for organic soils. In a seven-grade classification system, about 71% of the analyzed samples represented soil phosphorus fertility classes of fair-satisfactory (Lemola et al. 2018).

Table 3. Occurrence (%) of different soil types in the agricultural fields of North Savo on the basis of advisory soil testing carried out by Eurofins Viljavuuspalvelu Oy in 2016–2020.

Region	Glacial till	Fine sand	Coarse silt	Loam	Fine silt	Clay	Organic	Peat	Total
	<i>Moreeni</i>	<i>Karkea hieta</i>	<i>Hieno hieta</i>	<i>Hiue</i>	<i>Hiesu</i>	<i>Savi</i>	<i>Multa, lieju</i>	<i>Turve</i>	
Iisalmi	31	6	9	9	21	16	7	1	100
Joroinen	59	14	9	4	1	1	7	5	100
Kaavi	73	4	3	6	3	1	5	5	100
Keitele	61	12	6	5	0	2	10	4	100
Kiuruvesi	46	3	4	14	4	15	8	6	100
Kuopio	41	8	11	19	10	7	3	1	100
Lapinlahti	43	6	14	17	9	5	4	2	100
Leppävirta	66	4	4	10	3	6	6	1	100
Pielavesi	61	7	5	9	1	6	7	4	100
Rautalampi	45	12	12	9	4	2	10	6	100
Rautavaara	51	12	16	5	6	0	3	7	100
Siilinjärvi	32	8	17	22	12	6	3	0	100
Sonkajärvi	37	1	3	19	16	15	7	2	100
Suonenjoki	66	8	12	4	3	1	3	3	100
Tervo	61	10	6	5	0	2	9	7	100
Tuusniemi	56	18	11	3	6	0	4	2	100
Varkaus	73	3	2	7	0	2	8	5	100
Vesanto	55	12	8	10	4	4	5	2	100
Vieremä	29	6	11	19	20	9	4	2	100
Whole Area	45	5	10	15	9	8	5	3	100

3. Materials and methods

3.1. Field work

Soil profiles were investigated to the depth of about 1.5 m in a soil pit made by an excavator. Soil morphology was described according to the FAO guidelines (FAO 2006). In the determination of soil colours, the Munsell Soil Color Chart (Munsell 1992) was used. Each horizon was sampled for chemical and physical analyses. The soils were tentatively classified already in the field according to the World Reference Base for Soil Resources (WRB) system (IUSS Working Group WRB 2006, 2014 and 2022) and refined after receiving the analytical results using the 2022 version of the WRB system. For a few soils, the classification according to the U.S. Soil Taxonomy (Soil Survey Staff 2022) is also presented.

3.2. Analytical methods

Particle size distribution was determined by the pipette and sedimentation method (Elonen 1971). Soil pH and electrical conductivity (EC) were measured in a soil-water suspension (1:2.5 v/v). Total carbon (C) and nitrogen (N) were determined by dry combustion method (Dumas). Total C can in Finland be taken as the measure of organic C because the soils here are acidic and carbonate minerals are almost absent. For potential cation exchange capacity (CEC_{pot}), soil samples were extracted four times with a buffered ammonium acetate (1 M CH_3COONH_4 , pH 7.0) at a soil-to-solution ratio of 1:5 (w/v) and the extracts were pooled. Concentrations of potassium (K), sodium (Na), calcium (Ca) and magnesium (Mg) in centrifuged and filtered extracts were measured with an ICP-OES instrument. Titratable acidity ($H^+ + Al^{3+}$) was determined by back-titration to pH 7.0 with 0.02 M NaOH. Poorly crystalline aluminium (Al) and iron (Fe) oxides were extracted with 0.2 M acid ammonium oxalate at pH 3.0 at a soil-to-solution ratio of 1:50 (w/v), shaken for 4 h in the dark (McKeague & Day 1966). The suspensions were centrifuged and filtered, and concentrations of Al and Fe were measured with an ICP-OES (dilution of samples with 0.1 M HCl). According to agronomic soil test, phosphorus (P), K, sulfur (S), Ca and Mg were extracted with 0.5 M ammonium acetate – 0.5 M acetic acid at pH 4.65 at a soil-to-solution ratio of 1:10 (v/v) (Vuorinen & Mäkitie 1955). Acid-extractable reserves of P, K, Ca and Mg were determined by extraction with 2 M HCl (2 h, boiling water bath) at a soil-to-solution ratio of 1:4 (v/v). For the determination of total P, soil samples were digested with concentrated H_2SO_4 , H_2O_2 and HF (Bowman 1988). Soil dry bulk density (BD) was estimated using the undisturbed soil samples and/or pre-treated bulk soil samples, which are denoted as BD_{UD} and BD_{P-T} in the tables, respectively. The undisturbed soil samples were taken from the middle of (selected) genetic horizons of the pedons by using steel cylinders ($n = 2-4$), and weighed before and after drying at 105 °C for 48 h. For the pre-treated bulk soil samples, a special 25 ml measurement-cup was filled with the dried, ground and sieved soil samples, compacted by knocking and weighed. All these analytical data are not needed for soil classification, but they are presented in this report in order to provide a comprehensive set of soil data.

4. Characteristics of the individual soil profiles

The general locations of the pedons presented in this report are shown in Figure 5. The individual pedons are listed in Table 4. In many locations, more than one pedon was studied, and their accurate locations are presented later together with the soil properties. The site I in Iisalmi is not within the area displayed in Figure 5. These pedons are representative of the experimental fields where the research station currently operates.



Figure 5. Location of the 21 investigated soil profiles in North Savo, which are numbered as in the text. A = pedons 01–04, B = pedons 05–09, C = pedons 10–12, D = pedon 13, E = pedons 14–16, F = pedon 17, G = site 18, H = site 19, I = pedons 20–21; the distance to pedons from the premises of the Natural Resources Institute Finland in Kuopio Maaninka is about 36 km as the crowflies. The map is printed from the e-service of the National Land Survey of Finland NLS/MapSite (Maanmittauslaitos MML/Karttapaikka).

Table 4. The soil profiles and the examples of the experiments recently carried out in the investigated sites.

Area	Ped-on	Field name	Year	Major experiments and publications	WRB Reference Group	Finnish soil type
A	1	Leaching field, central	2001	e.g., Saarijärvi et al. (2007), Saarijärvi (2008), Järvenranta et al. (2014)	Regosols	KHt
	2	Leaching field, coarse	2001		Arenosols	KHt
	3	Leaching field, low part	2001		Planosols	KHt
	4	Pohjoispelto, central	2023	e.g., Termonen et al. (2020), Keskinen et al. (2022), Louhisuo et al. (2024)	Planosols	KHt
B	5	Keskilohko, spruce fence	2021	e.g., Rätty et al. (2023), Keskinen et al. (2024)	Regosols	KHt
	6	Keskilohko, central	2021		Regosols	KHt
	7	Kauraniemi, tip/buffer strip	2005	Rasa et al. (2007), Rätty et al. (2010)	Regosols	KHt
	8	Kauraniemi, shore	2001	Official variety trials	Planosols	HHt
	9	Kauraniemi, upper	2001	Official variety trials	Planosols	HHt
C	10	Hämeensuo 1	2023		Gleysols	HsS
	11	Hämeensuo 3	2022	Virkajärvi et al. (2016), Rätty and Alakukku (2019), Taimisto et al. (2019)	Gleysols	HeS
	12	Hämeensuo 4	2021	Messiga et al. (2015)	Stagnosols	HsS
D	13	Hirsisuo	2023	Kykkänen et al. (2018), Rätty (2020)	Planosols	HeS
E	14	Anttila 1, central	2022	e.g., Shurpali et al. (2016), Lind (2018), Dwivedi et al. (2023), Li et al. (2023)	Stagnosols	sHHt
	15	Anttila 2, low part	2022		Gleysols	sHe
	16	Anttila 3, high part	2022		Stagnosols	HtS
F	17	Anttila 4, Pihapelto	2022	Keskinen et al. (2019), Soinne et al. (2021)	Planosols	KHt
G	18	Särkisuo	2022	Maljanen et al. (2024)	Histosols	Ct
H	19	Pappilansuo	2022	GHG experiments	Histosols	Ct
I	20	lialmi 1, low part	2023	Rätty (2020), Rätty et al. (2020)	Gleysols	HsS
	21	lialmi 2, high part	2023		Stagnosols	sHs

4.1. Pohjoispelto

The Pohjoispelto field (Figure 6) is located on an esker extending from north-west to south-east in close vicinity of the main building of the research station. It covers an area of 8.11 ha and has an elevation of 87–90 m, which is about 3–6 m above the average level of Lake Maaninka next to the field. There is only a 3-m difference in elevation within the parcel. The leaching field (i.e., surface runoff and lysimeter field, which is known as “AgriLeach platform” at present; 0.7 ha) is within this parcel, and it has been presented in scientific papers such as Saarijärvi et al. (2007). Altogether, four soil profiles have been investigated in 2001 and 2023 in this area. The plough layers of three investigated pedons (01, 03, 04) were sandy loam and in one pedon (02) loamy sand. The depth of the sandy deposit varies within the field. On sites 01 and 02 within the leaching field, the whole pedon to the investigated depth (160 or 180 cm) consisted of fine sand but on the lower position of the parcel (03) and in the central non-sloping level area outside the leaching field (04), varved clay was met in the subsoil at about 80 cm from soil surface.

Irrespective of texture, the soil profiles were weakly developed, not deviating much from the assumed parent material. Down to 50 cm, the pedons have experienced cryoturbation by the annual frost but below that depth the fine sand and the clay were varved and the original horizontal sedimentation layers could be clearly distinguished, i.e., below the frost depth, the soils had a rock structure. In the clayey horizons of pedons 03 and 04, the large prismatic aggregates were easily split horizontally according to the sedimentation strata.

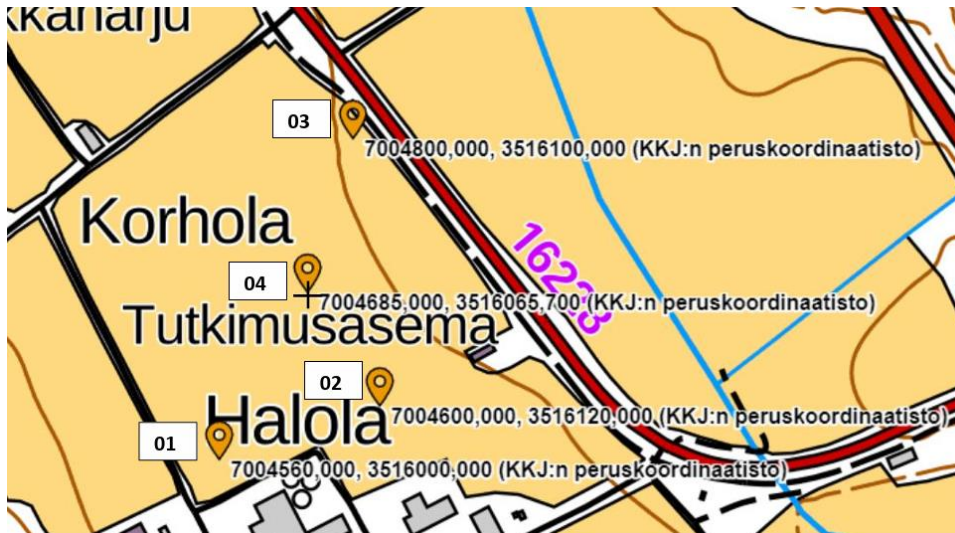


Figure 6. Locations of the four pedons investigated in the Pohjoispelto field.

There were signs of redox reactions in all pedons. In fine sand, these consisted of light-coloured redox depletions that were several centimetres in diameter, and these were surrounded by a brown circle of rusty precipitation. The clayey horizons were mostly gray in colour, indicating the prevalence of wet and reducing conditions in the matrix. The presence of brown precipitation along the desiccation cracks and previous root channels indicates partial oxidation of the soil and translocation of iron within the pedon.

The cation exchange capacity (CEC) of the coarse-textured horizons is low, except the plough layers where it is elevated by soil organic matter. The base saturation of the coarse-textured horizons is mostly 30–50%. The soil obviously contains enough weatherable minerals (mainly in the tiny clay fraction and in the more abundant fine silt fraction) to buffer against the decrease of pH. There were not yet any morphological signs of podzolization in these soils. In clearly podzolized soils, the base saturation is commonly only 10% or below throughout the soil profile (Yli-Halla et al. 2000, 2005).

Maaninka 01: the largest part of the leaching field

- Coordinates $x=3516000$, $y=7004560$, $k=88$
- Day of inspection: 30.5.2001
- No groundwater observed
- Classification: Epidystric **Regosols** (Loamic, Endoarenic, Aric, Drainic, Ochric)
- Short classification: Dystric **Regosols**
- Classification Soil Taxonomy: Aquic Cryothents, coarse-loamy

Maaninka 01 (Table 5) represents the largest part of the leaching field. It has a topsoil colour that is dark enough for a mollic or umbric horizon. Fine sand is the dominant particle size

fraction (Table 6). High base saturation (Table 7), a requirement for a mollic horizon, is caused by agricultural liming and is thus a temporary characteristic and therefore not taken into account in soil classification. The structure is also too weak for a mollic or umbric horizon, and these options are thus waived. The B horizon would texturally qualify as a cambic horizon, being at the coarse borderline, but the soil has too much rock structure (structure of the parent material). The weighted average texture is not quite coarse enough for Arenosols. Therefore, the pedon belongs to Regosols, indicating scant pedogenic development. The Aric qualifier stands for ploughing, Drainic comes from artificial drainage and the Ochric qualifier indicates a rather low organic C content in the topsoil in spite of rather dark colour.

Table 5. Morphological properties of the pedon Maaninka 01 (the leaching field).

Horizon	Depth (cm)	Morphological description
Ap	0–23	Dark grayish brown (10YR 3/2, moist) or brown (10YR 5/3, dry) sandy loam. Weak subangular blocky aggregates. Friable consistence. Many small and medium roots. Abrupt smooth boundary.
Bw1	23–35	Brown (10YR 4/3) sandy loam. Common medium-sized dark yellowish brown (10YR 4/4) mottles. Weak coarse platy aggregates breaking to weak medium angular blocky aggregates. Friable consistence. Few large (diameter 8 mm) worm channels. Common roots. Clear smooth boundary.
Bw2	35–43	Grayish brown (10YR 4/2) silt loam. Few small dark yellowish brown (10YR 4/4) mottles. Weak coarse platy aggregates breaking to weak medium angular blocky aggregates. Friable consistence. Few large (diameter 8 mm) worm channels. Common roots. Clear smooth boundary.
BC	43–58	Brown (10YR 4/3) silt loam. Some of the original stratification still visible. Common circular medium dark yellowish brown (10YR 4/4) mottles (redox concentrations) and within the circle grayish brown (2.5Y 4/2) mottles (redox depletions); few strong brown (7.5YR 4/6) mottles. Weak coarse platy aggregates that part to weak medium angular blocky aggregates. Friable consistence. Few large (diameter 8 mm) worm channels. Common roots. Abrupt smooth boundary,
2C1	58–90	Clear stratification of brown (10YR 4/3), strong brown (7.5YR 4/6) and dark gray (10YR 4/1) medium sand. Very weak medium platy aggregates break along the strata. Very friable consistence. Few large (diameter 8 mm) worm channels. Few roots. Abrupt smooth boundary.
3C2	90–96	Stratification of grayish brown (2.5Y 4/2) and few yellowish brown (10YR 4/4) silt loam. Weak coarse platy aggregates that part to weak medium angular blocky aggregates. Friable consistence. Few large (diameter 8 mm) worm channels. Very few roots. Abrupt smooth boundary.
4C3	96–110	Stratification of brown (10YR 4/3), light brown (10YR 4/6) and dark gray (10YR 4/1) medium sand. Very weak medium platy aggregates along the strata. Very friable consistence. Few large (diameter 8 mm) worm channels. Few roots. Abrupt smooth boundary.
5C4	110–155	Grayish brown (2.5Y 5/2) sandy loam with a few yellowish brown (10YR 5/6) layers of fine sand. Many large discrete strong brown (7.5YR 4/6) mottles. Weak large angular blocky aggregates. Friable consistence. Few large (diameter 8 mm) worm channels. No roots. Gradual boundary. Starting in this horizon, the soil has a grayish colour as opposed to the brownish appearance of the upper horizons.
5C4	155–180	Grayish brown (2.5Y 5/2) sandy loam with few yellowish brown (10YR 5/6) layers of fine sand. No aggregates. No roots. No worm channels.

Table 6. Total organic carbon (Org. C) content and particle size distribution in the soil horizons of the pedon Maaninka 01 (the leaching field).

Horizon	Depth (cm)	Org. C (%)	Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	Total silt	Total sand	Finnish soil type
Ap	0–23	2.0	6	14	21	46	13	35	59	KHt
Bw1	23–35	0.6	4	12	26	46	12	38	48	KHt
Bw2	35–43	0.4	4	18	33	39	6	51	45	KHt
BC-4C3	43–110	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
5C4	110–180	0.1	2	12	25	42	19	37	61	KHt

Particle size limits: Clay = <0.002 mm ("S"); Fine silt = 0.002–0.02 mm ("HHs + KHs"); Coarse silt = 0.02–0.06 mm ("HHt"); Fine sand = 0.06–0.2 mm ("KHt"); Coarse sand = 0.2–2 mm ("HHk + KHk"), representing medium and coarse sand fractions. Words in brackets are the Finnish abbreviations of the size fractions (based on Atterberg's classification system). n.d. = not determined.

Table 7. Soil pH, potential cation exchange capacity (CEC), exchangeable calcium (Ca²⁺), potassium (K⁺), magnesium (Mg²⁺) and sodium (Na⁺), titratable acidity (Al³⁺ + H⁺) and base saturation in the soil horizons of the pedon Maaninka 01 (the leaching field).

Horizon	Depth (cm)	pH (H ₂ O)	Ca	K	Mg	Na	Al+H	CEC (pH 7.0)	Base saturation (%)
Ap	0–23	6.05	5.9	0.24	0.84	0.03	5.7	12.8	55
Bw1	23–35	6.23	3.3	0.16	0.62	0.01	4.4	8.5	48
Bw2	35–43	6.33	3.2	0.17	0.67	0.02	4.3	8.3	48
BC	43–58	n.d.	2.4	0.19	0.55	0.01	3.4	6.6	48
2C1	58–90	n.d.	1.8	0.17	0.53	0.01	2.4	4.9	51
3C2	90–96	n.d.	2.4	0.21	0.72	0.02	3.1	6.4	52
4C3	96–110	n.d.	2.3	0.19	0.70	0.02	2.7	5.9	55
5C4	110–180	6.67	0.65	0.08	0.21	0.00	1.6	2.6	37

n.d. = not determined.

Maaninka 02: the highest and coarsest point of the leaching field

- Coordinates: x=3516120, y=7004600, k=90
- Day of inspection: 30.5.2001.
- No groundwater observed
- Classification: Dystric **Arenosols** (Aric, Oxyaquic, Ochric)
- Short classification: Dystric Arenosols
- Classification Soil Taxonomy: Aquic Cryopsammets

This site is the highest point and the coarsest corner of the leaching field. In spite of the coarse texture, the soil has been wet enough to result in the formation of brown redox concentrations and gray redox depletions starting right below the plough layer (Table 8). The soil is dominated by sand, and the proportion of silt is very low (Table 9). The texture is coarse enough to allow classification as Arenosols. In Soil Taxonomy, this very coarse texture is indicated by the acronym –psamm-. By definition, this coarse texture excludes the presence of a cambic horizon. The Aric qualifier stands for ploughing and Ochric qualifier indicates a rather

low organic C content in the topsoil where the colour is not dark enough to meet the criteria of Mollic or Umbric qualifier.

Table 8. Morphological properties of the pedon Maaninka 02. The highest and coarsest part of the leaching field.

Horizon	Depth (cm)	Morphological description
Ap	0–29	Dark brown (10YR 3/4) loamy sand. Very weak subangular blocky aggregates. Very friable consistence. Common roots. Abrupt smooth boundary.
Bw	29–56	Brown (10YR 4/3) sand. Common large distinct circular dark brown (10YR 4/4) mottles (redox concentrations) and within the circle grayish brown (10YR 4/2) mottles (redox depletions). Very weak angular blocky aggregates. Very friable consistence. Few roots. Clear smooth boundary.
2C1	56–110	Grayish brown (10YR 4/2) medium sand. General appearance is the same as in the redox depletions of the above horizon. Common large strong brown (7.5YR 4/6) and few large yellowish red (5YR 4/6) mottles. Very weak angular blocky aggregates. Very friable. Few roots. Gradual boundary.
2C2	110–160	Brown (10YR 4/3) medium sand. Common large yellowish red (5YR 4/6) mottles. Very weak angular blocky aggregates. Very friable. Few roots.

Table 9. Soil pH, total organic carbon (Org. C) content and particle size distribution in the soil horizons of the pedon Maaninka 02. The highest and coarsest part of the leaching field.

Horizon	Depth (cm)	pH (H ₂ O)	Org. C (%)	Clay (%)	Fine silt (%)	Coarse silt (%)	Fine sand (%)	Coarse sand (%)	Total silt (%)	Total sand (%)	Finnish soil type
Ap	0–29	5.08	2.7	3	5	8	61	23	13	63	KHt
Bw	29–56	5.76	0.2	0	2	3	67	28	5	95	KHt
C1											HHk
C2											HHk

Maaninka 03: the northern edge of the Pohjoispelto field

- Coordinates x=3516100, y=7004800, k=87
- Day of inspection: 30.5.2001
- No groundwater observed
- Classification: Epidystric **Planosols** (Epiloamic, Endoclayic, Aric, Drainic, Raptic)
- Short classification: Dystric Planosols
- Classification Soil Taxonomy: Aquic Cryothent, sandy-over-clayey

This soil, resembling Maaninka 04, at the northern edge of the field was only superficially described (Table 10) and the classification is therefore an approximation. The pedon is characterized by sandy loam and sand in the upper horizons (Table 11) and it has an abrupt textural difference at 80 cm. The horizon below this depth consisted of heavy clay, very likely resulting in stagnic properties. There may be an albic horizon above the abrupt textural difference. The colours were not determined in this pedon, but albic material was found in a close-by pedon Maaninka 04 which is texturally and topographically similar. Therefore, it is assumed that pedon 03 also contains albic material and can be classified as Planosols. The CEC of the heavy clay horizon was only 18 cmol kg⁻¹ (Table 12), which is half of what is measured in Jokioinen,

southern Finland in soils of similar clay content (Yli-Halla et al. 2000). This result suggests that the clay here is coarse clay which resembles fine silt in chemical properties.

Table 10. Morphological properties of the pedon Maaninka 03.

Horizon	Depth (cm)	Partial morphological description
Ap	0–30	Sandy loam
Bw1	30–55	Sandy loam
Bw2	55–80	Very pure fine sand (<i>This wording suggests presence of albic material</i>)
C1	80–110	Varved heavy clay. The varves are 2 mm thick. Brown pore linings around previous root channels.
C2	110–150	Varved silty clay loam. The varves are 2 mm thick.

Table 11. Particle size distribution in the soil horizons of the pedon Maaninka 03. Organic C content was not determined.

Horizon	Depth (cm)	Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	Total silt	Total sand	Finnish soil type
Ap	0–30	11	16	17	48	8	33	56	KHt
Bw1	30–55	4	12	25	58	2	37	59	KHt
Bw2	55–80	4	6	0	85	5	6	90	KHt
C1	80–110	68	26	4	1	1	30	2	AS
C2	110–150	38	55	5	1	1	60	2	HsS

Particle size limits: Clay = <0.002 mm (“S”); Fine silt = 0.002–0.02 mm (“HHs + KHs”); Coarse silt = 0.02–0.06 mm (“HHT”); Fine sand = 0.06–0.2 mm (“KHt”); Coarse sand = 0.2–2 mm (“HHk + KHk”), representing medium and coarse sand fractions. Words in brackets are the Finnish abbreviations of the size fractions (based on Atterberg’s classification system).

Table 12. Potential cation exchange capacity (CEC), exchangeable calcium (Ca²⁺), potassium (K⁺), magnesium (Mg²⁺) and sodium (Na⁺), titratable acidity (Al³⁺ + H⁺) and base saturation in the soil horizons of the pedon Maaninka 03.

Horizon	Depth (cm)	pH (H ₂ O)	Ca	K	Mg	Na	Al+H	CEC (pH 7.0)	Base saturation (%)
Ap	0–30	5.82	5.0	0.21	0.82	0.04	7.3	13.4	45
Bw1	30–55	5.94	2.0	0.22	0.37	0.02	6.1	8.7	30
Bw2	55–80	5.99	1.6	0.20	0.35	0.02	4.4	6.6	33
C1	80–110	6.38	9.0	0.51	4.17	0.12	4.6	18.4	75
C2	110–150	6.51	4.7	0.27	2.60	0.09	3.6	11.3	68

Maaninka 04: middle of the Pohjoispelto field

- Coordinates: x=3516065,700 y=7004685, k=90
- Day of inspection: 22.8.2023
- No groundwater observed
- Crop: barley (Vertti)
- Classification: Endoeutric Albic **Planosols** (Epiloamic, Endoclayic, Aric, Drainic, Humic, Raptic)
- Short classification: Albic Planosols

This soil in the middle of the Pohjoispelto field has a texture of fine sand down to 68 cm while the deeper subsoil is clayic (Table 13, Figure 7), even heavy clay (Table 14). This sharp change in particle size distribution at 68 cm is defined as an abrupt textural difference and lithic discontinuity (attribute Raptic). The horizon at 47–68 cm is coarser than the uppermost horizons and has colours of albic material (Table 13). The varved heavy clay below this depth has probably a very low hydraulic conductivity, resulting in stagnic properties. As a combination, albic material, abrupt textural difference and stagnic properties justify classification as Planosols. The base saturation of the coarsest horizons 35–68 cm is very low (Table 15) and suggests intensive leaching of these horizons. The base saturation of the clayic horizons is higher but the pH of 5.5–5.7 is clearly lower than in clay soils of southern Finland, which commonly have a circumneutral pH (Yli-Halla et al. 2000). Differing from the rest of the Pohjoispelto field, pedon Maaninka 04 has a rather high organic C content. At 0–50 cm (Table 16), the weighted average of organic C is 2.6%, which allows the use of the humic attribute (>1% organic C). In spite of this organic C content, the colour of the topsoil is not dark enough to meet the criteria of the Mollic or Umbric horizon.

Table 13. Morphological properties of the pedon Maaninka 04.

Horizon	Depth (cm)	Morphological description
Ap1	0–20	Dark brown (10YR 3/3 moist), light yellowish brown (2.5Y 6/4 dry) sandy loam. Moderate medium subangular blocky structure. Friable consistency. Common fine roots. Clear smooth boundary.
Ap2	20–35	Horizon created by earlier deep ploughing. Dark brown (10YR 3/3) sandy loam. Very few small prominent dark yellowish brown (10YR 4/4) mottles. Weak coarse prismatic aggregates breaking into moderate medium subangular aggregates. Friable consistency. Few fine roots. Clear smooth boundary.
Bw	35–47	Olive brown (2.5Y 4/3) sandy loam. Few small prominent brown (7.5YR 4/4) mottles. Weak medium angular blocky structure. Friable consistency. Few fine roots. Clear smooth boundary.
E	47–68	Light olive brown (2.5Y 5/3) sandy loam. Many medium prominent yellowish brown (10YR 4/4) mottles. Weak medium angular blocky structure. Friable consistency. Few fine roots. Abrupt smooth boundary.
2Bg	68–95	Brown (10YR 4/3) sandy clay. Common large prominent brown to strong brown (7.5YR 4/3–4/6) mottles. Weak very coarse platy structure breaking into moderate medium angular blocky aggregates. Very firm consistency. Gradual smooth boundary.
2BCg	95–131+	Grayish brown (2.5Y 5/2) sandy clay with thin very dark grayish brown (2.5Y 3/2) varves. Common medium and large prominent strong brown (7.5YR 5/6) to brown (10YR 5/3) pore linings around previous root channels across the varves. Moderate coarse platy structure parting into moderate medium angular aggregates. Very firm consistency.

Table 14. Particle size distribution in the soil horizons of the pedon Maaninka 04.

Horizon	Depth (cm)	Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	Total silt	Total sand	Finnish soil type
		(%)							
Ap1	0–20	11	21	22	43	2	43	45	KHt
Ap2	20–35	11	20	24	43	2	44	45	KHt
Bw	35–47	5	11	28	56	0	39	56	KHt
E	47–68	2	3	13	81	2	16	83	KHt
2Bg	68–95	61	32	3	4	0	35	4	AS
2BCg	95–131+	43	52	4	1	0	56	1	HsS

Particle size limits: Clay = <0.002 mm (“S”); Fine silt = 0.002–0.02 mm (“HHs + KHs”); Coarse silt = 0.02–0.06 mm (“HHt”); Fine sand = 0.06–0.2 mm (“KHt”); Coarse sand = 0.2–2 mm (“HHk + KHk”), representing medium and coarse sand fractions. Words in brackets are the Finnish abbreviations of the size fractions (based on Atterberg’s classification system).

Table 15. Potential cation exchange capacity (CEC), exchangeable calcium (Ca²⁺), potassium (K⁺), magnesium (Mg²⁺) and sodium (Na⁺), titratable acidity (Al³⁺ + H⁺) and base saturation in the soil horizons of the pedon Maaninka 04.

Horizon	Depth (cm)	Ca	K	Mg	Na	Al+H	CEC (pH 7.0)	Base saturation (%)
		(cmol(+)/kg soil)						
Ap1	0–20	7.2	0.11	0.8	0.04	7.0	15.2	54
Ap2	20–35	6.6	0.14	0.8	0.02	7.4	14.9	51
Bw	35–47	2.1	0.13	0.3	0.03	6.9	9.5	27
E	47–68	1.5	0.11	0.3	0.01	3.5	5.4	36
2Bg	68–95	9.6	0.36	5.6	0.14	4.8	20.5	77
2BCg	95–131+	5.3	0.23	3.8	0.11	0.1	9.5	99

Table 16. Bulk density of pre-treated samples (BD_{P-T}), pH, contents of total organic carbon (Org. C) and total nitrogen (Total N), and concentrations of acid ammonium acetate-extractable phosphorus (P_{AAc}), potassium (K_{AAc}), calcium (Ca_{AAc}), magnesium (Mg_{AAc}) and sulfur (S_{AAc}) in the soil horizons of the pedon Maaninka 04.

Horizon	Depth (cm)	BD _{P-T} (kg/l)	pH (H ₂ O)	Org. C	Total N	P _{AAc}	K _{AAc}	Ca _{AAc}	Mg _{AAc}	S _{AAc}
				(%)		(mg/l soil)				
Ap1	0–20	1.56	5.5	3.17	0.20	5.1	31	1 115	80	11
Ap2	20–35	1.50	5.4	2.98	0.18	5.0	36	1 021	75	11
Bw	35–47	1.42	5.5	1.79	<0.08	4.8	36	337	28	7.6
E	47–68	1.41	5.3	0.17	<0.08	1.7	45	305	39	4.7
2Bg	68–95	1.90	5.5	0.39	<0.08	2.0	103	1 435	456	6.4
2BCg	95–131+	1.81	5.7	0.41	<0.08	1.3	73	903	341	5.7

Table 17. Concentrations of acid oxalate-extractable aluminium (Al_{ox}) and iron (Fe_{ox}) oxides, total phosphorus (Total P) and hydrochloric acid-extractable phosphorus (P_{HCl}), potassium (K_{HCl}), calcium (Ca_{HCl}) and magnesium (Mg_{HCl}) in the soil horizons of the pedon Maaninka 04.

Horizon	Depth (cm)	Al_{ox}	Fe_{ox}	Total P	P_{HCl}	K_{HCl}	Ca_{HCl}	Mg_{HCl}
		(mg/kg)		(g/kg)	(mg/l soil)			
Ap1	0–20	2 068	6 227	1.69	1 283	1 808	4 140	4 877
Ap2	20–35	2 061	6 391	1.61	1 173	1 693	3 830	4 411
Bw	35–47	1 966	4 692	1.19	1 360	1 072	3 360	3 359
E	47–68	496	3 583	1.25	1 863	1 175	4 633	3 054
2Bg	68–95	1 668	12 721	0.55	544	2 673	3 601	6 982
2BCg	95–131+	1 018	9 049	0.79	750	3 103	3 211	6 446

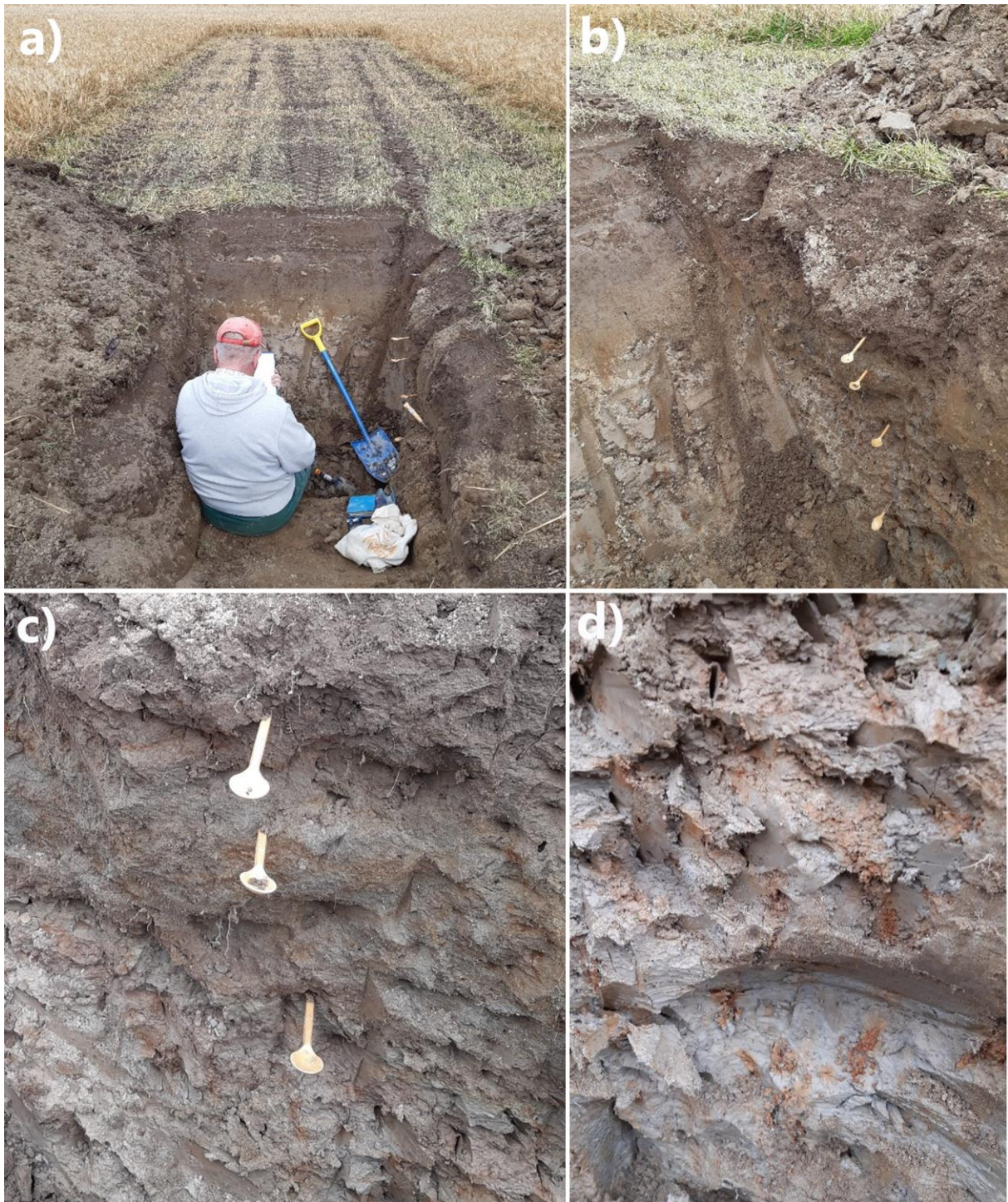


Figure 7. The Maaninka 04 pedon: Pohjoispelto. The pedon is at the highest area of the field (a and b). The light-coloured albic horizon at 47–68 cm can be distinguished (a and b). In the gray clayic subsoil, strong mottling was visible (c and d). Photos by Mari Rätty (Luke).

4.2. Kauraniemi

The Kauraniemi field covers an area of 7.7 ha (inc. Kauraniemi 4.38 ha and Keskilohko 3.31 ha) at the immediate vicinity of the buildings of the station borders to Lake Maaninka. Differing from the flat Pohjoispelto field, it has a saddle-like topography so that the middle areas have the lowest position at 84 m, only two metres above the average level of the Lake Maaninka,

while the edges of the field are up to 6 m higher. Altogether, five pedons were investigated in this field in 2001, 2005 and 2021. Pedons 05, 06 and 07 have high positions while the pedons 08 and 09 in the middle are located in the low position (Figure 8).

The loamy (loam, silt loam, sandy loam) plough layer of the Kauraniemi field is slightly more fine-textured than was measured in the Pohjoispelto. Within the field, there is a difference in texture between the high and low positions. In the upper positions (05, 06 and 07) there was 8–14% clay in the topsoil while in the low positions (08, 09) the clay content was 20%. The higher positions were coarse-textured throughout the investigated depth, and the clay content decreased to very low values while varved heavy clay was met in the subsoil of pedons 08 and 09 at the lower position. The higher positions were rare examples of soils that had horizons formed of glacial till, which is indicated by abundance of coarse fragments (gravel, stones).

A common feature for all pedons was the gray matrix and brownish precipitates along the previous root channels. The soils also contained thin (<1 mm) brownish horizontal sandy layers between layers of more fine textured material, which were gray in colour. On the basis of these features, these soils have stagnic properties. Where they are widespread enough and sufficiently close to soil surface, the soil is classified as a Stagnosol, and in other cases, the Stagnic qualifier applies. The stagnic water regime is easily understood on the basis of soil texture. The texture is commonly coarser in the upper horizons and gets finer upon depth. Water conductivity decreases when the texture gets finer. Therefore, water penetrating into the soil from above is accumulated in the deeper horizons, resulting in alternating reduced and oxidized conditions and the formation of redox concentrations characterized by rust precipitates, and redox depletions, characterized by gray colours.

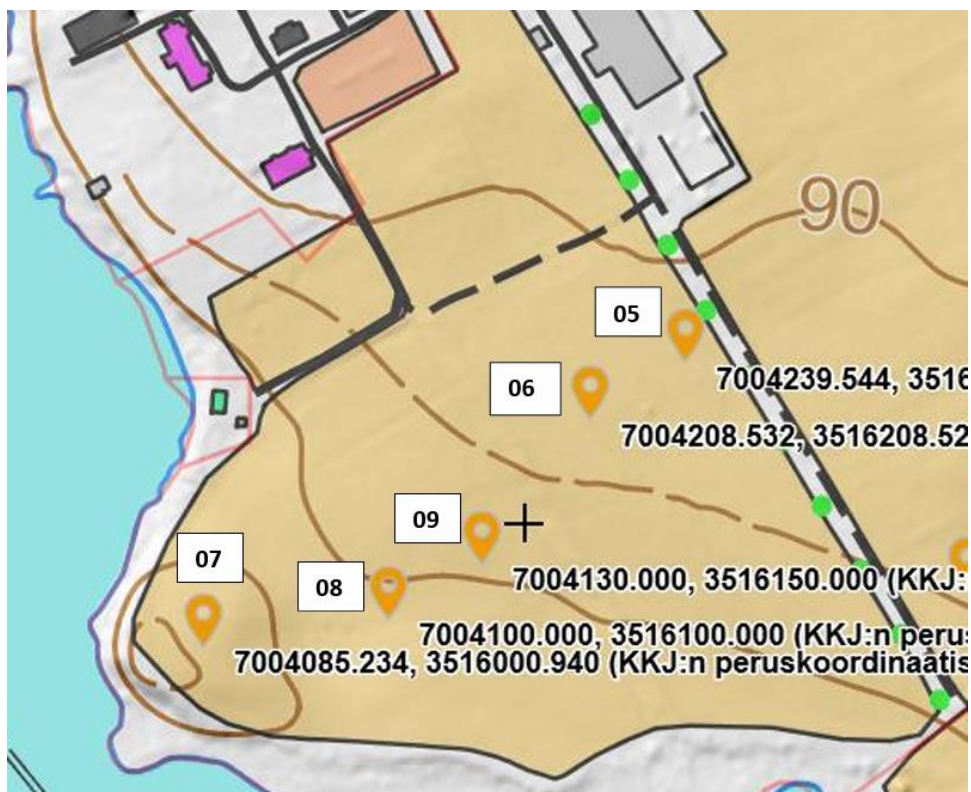


Figure 8. Locations of the five pedons investigated in the Kauraniemi field. The pedons 05 and 06 represent the Keskilohko field plot, and the pedons 07–09 Kauraniemi field plot.

Maaninka 05: Keskilohko 1

- Coordinates x=3516259, y=7004239, k=88
- Day of inspection: 19 August 2021
- Crop: Silage grass (a mixture of timothy and meadow fescue)
- No groundwater
- Classification: Endodystric Bathyglyeyic Stagnic **Regosols** (Loamic, Aric, Drainic, Ochric)
- Short classification: Stagnic Regosols

This pedon (Figure 9) is at the edge of the field close to the tall spruce fence at the far end from the lake. The BIOSFÄÄRI experiment occupied this part of the field. The following diagnostic characteristics were identified on the basis of morphology (Table 18) and analytical results (Tables 19–22):

- Sandy loam texture is not sufficiently coarse (loamy sand or coarser required) to qualify for Arenosols. There is strong structure formation at 30–44 cm but this horizon is too thin to be Cambic. The horizon at 44–66 cm has a weak structure. It is justified to label this pedon as Regosols.
- Stagnic colour pattern (coverage 25–50%) at 62–104 cm -> Stagnic. This colour pattern occurs also at 44–62 cm but it is not widespread enough to be diagnostic for Stagnosol classification.
- Gleyic colour pattern starting at 104 cm -> Not close enough (<75 cm) to soil surface to be diagnostic for the Gleyic qualifier but the Bathyglyeyic qualifier can be used.
- Base saturation >50% in the top horizons (due to liming). Eutric is waived because it is a temporary characteristic caused by human activity. Base saturation <50% in the subsoil -> Endodystric
- Texture dominated by loamic classes -> Loamic
- Ploughed with an abrupt boundary -> Aric
- Artificial drainage -> Drainic
- The Ochric qualifier indicates a rather low organic C content in the topsoil where the colour is not dark enough to meet the criteria of Mollic or Umbric qualifier.

Table 18. Morphological properties of the pedon Maaninka 05.

Horizon	Depth (cm)	Morphological description	Diagnostic features
Ap1	0–25	Dark brown (10YR 3/3 moist) or pale brown (10YR 6/3 dry) loam. Few stones (\varnothing 1 cm). Moderate coarse angular blocky structure parting to moderate fine angular blocky aggregates. Friable consistence. Common fine roots. Common worm channels. Clear smooth boundary.	Dry colour is too light for a mollic/ umbric horizon.
Ap2	25–30	A thin horizon created by deep ploughing. It is a mixture of the plough layer and soil material from the upper part of the subsoil. Brown (7.5YR 4/3) silt loam. Few stones (\varnothing 1 cm). Moderate coarse angular blocky structure parting to moderate fine angular blocky aggregates. Friable consistence. Common fine roots. Common worm channels. Abrupt smooth boundary.	
Bw1	30–44	Grayish brown (2.5Y 5/2) sandy loam. Few stones. Moderate to strong medium angular blocky structure parting to moderate fine platy aggregates. Extremely firm consistence. Few fine roots, common worm channels. Clear smooth boundary.	Too thin to be a Cambic horizon
Bw2	44–62	Brown (10YR 4/3) sandy loam. Common small brown (7.5YR 4/4) redox concentrations. Few to common stones (max \varnothing 5 cm). Shining biotite particles. Weak coarse and medium angular blocky structure. Very friable consistence. Few fine roots. Common worm channels. Clear smooth boundary.	Stagnic colours (<25%) too few to be diagnostic
Bg1	62–87	Olive brown (2.5Y 4/3) sandy loam. Few stones (max \varnothing 20 cm). Shining biotite particles. Few medium brown (7.5YR 4/4) redox concentrations and common medium light olive gray (5Y 6/2) redox depletions along previous root channels. Common large dark yellowish brown (10YR 4/4) redox concentrations. Weak coarse and medium angular blocky structure. Friable consistence. Very few fine roots. Clear wavy boundary, depth varying from 80 to 95 cm.	Common stagnic colours (25–50%) justifying stagnic qualifier
2Bg2	87–104	Olive brown (2.5Y 4/4) sandy loam. Very few stones. Shining biotite particles. Common large dark yellowish brown (10YR 4/4) redox concentrations, and along previous root channels few medium brown (7.5YR 5/4) redox concentrations and few light olive gray (5Y 6/2) redox depletions. Structureless, or very weak medium angular blocky structure. Very friable consistence. No roots. Few worm channels. Clear smooth boundary.	
3BCg	104–124	Gray (2.5Y 5/1) sandy loam. Common medium brown (10YR 4/3) redox concentrations and few light olive gray (5Y 6/2) redox depletions along previous root channels. Common large yellowish brown (10YR 5/4) redox concentrations. Weak fine and medium platy structure, representing original sedimentation layers. Firm consistence. No roots. No root channels. Abrupt smooth boundary marked by a 1-cm thick horizontal strong brown (7.5YR 4/6) sand layer at the bottom of the horizon.	Stagnic colours
4Cg	124–140	Dark grayish brown (2.5Y 4/2) sandy loam. Common large yellowish brown (10YR 5/6) redox concentrations. Very diverse colours, representing original sedimentation layers. Massive, or weak fine to medium platy structure according to the sedimentation layers but the layers don't properly part. Very firm consistence.	Gleyic colours. Too deep to be diagnostic.

Table 19. Particle size distribution in the soil horizons of the pedon Maaninka 05.

Horizon	Depth (cm)	Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	Gravel	Total silt	Total sand	Finnish soil type
		(%)								
Ap1	0–25	14	22	21	33	9	0	43	43	KHt
Ap2	25–30	10	32	19	27	11	2	51	38	KHt
Bw1	30–44	4	12	23	47	9	5	35	56	HtMr
Bg1	44–87	2	11	25	46	9	8	36	55	HtMr
2Bg2	87–104	3	9	21	60	8	0	30	67	KHt
3BC	104–124	4	14	30	47	4	0	44	51	KHt
4Cg	124–140	3	17	31	47	2	0	48	49	KHt

Particle size limits: Clay = <0.002 mm (“S”); Fine silt = 0.002–0.02 mm (“HHs + KHs”); Coarse silt = 0.02–0.06 mm (“HHt”); Fine sand = 0.06–0.2 mm (“KHt”); Coarse sand = 0.2–2 mm (“HHk + KHk”), representing medium and coarse sand fractions; Gravel = >2 mm (“Sr”). Words in brackets are the Finnish abbreviations of the size fractions (based on Atterberg’s classification system).

Table 20. Potential cation exchange capacity (CEC), exchangeable calcium (Ca²⁺), potassium (K⁺), magnesium (Mg²⁺) and sodium (Na⁺), titratable acidity (Al³⁺+H⁺) and base saturation in the soil horizons of the pedon Maaninka 05.

Horizon	Depth (cm)	Ca	K	Mg	Na	Al+H	CEC	Base saturation (%)
		(cmol(+)/kg soil)						
Ap1	0–25	6.6	0.21	0.93	0.01	4.4	12.0	64
Ap2	25–30	3.0	0.11	0.56	0.02	4.6	8.3	45
Bw1	30–44	1.6	0.13	0.36	0.00	1.5	3.5	59
Bg1	44–87	1.7	0.10	0.37	0.00	2.2	4.3	50
2Bg2	87–104	1.2	0.08	0.26	0.00	1.9	3.4	44
3BCg	104–124	1.5	0.10	0.41	0.00	2.9	4.9	41
4Cg	124–140	0.6	0.08	0.16	0.00	1.8	2.6	32

Table 21. Bulk density of undisturbed samples (BD_{UD}), pH, contents of total organic carbon (Org. C) and total nitrogen (Total N), and concentrations of acid ammonium acetate-extractable phosphorus (P_{AAc}), potassium (K_{AAc}), calcium (Ca_{AAc}), magnesium (Mg_{AAc}) and sulfur (S_{AAc}) in the soil horizons of the pedon Maaninka 05.

Horizon	Depth (cm)	BD _{UD} (kg/l)	pH (H ₂ O)	Org. C	Total N	P _{AAc}	K _{AAc}	Ca _{AAc}	Mg _{AAc}	S _{AAc}
				(%)						
Ap1	0–25	1.38	6.0	2.24	0.19	10	148	1268	120	7.7
Ap2	25–30	1.66	6.4	0.28	0.03	2.4	71	616	83	4.2
Bw1	30–44	1.42	6.3	0.21	0.01	4.7	129	416	67	4.1
Bg1	44–87	1.49	6.3	0.17	0.00	1.5	102	393	61	4.1
2Bg2	87–104	1.68	6.5	0.17	0.00	0.8	71	342	52	5.4
3BCg	104–124	1.78	6.4	0.19	0.00	0.8	79	355	63	4.7
4Cg	124–140	1.70	6.5	0.13	0.01	1.0	74	173	31	3.8

Table 22. Concentrations of acid oxalate-extractable aluminium (Al_{ox}) and iron (Fe_{ox}) oxides, total phosphorus (Total P) and hydrochloric acid-extractable phosphorus (P_{HCl}), potassium (K_{HCl}), calcium (Ca_{HCl}) and magnesium (Mg_{HCl}) in the soil horizons of the pedon Maaninka 05.

Horizon	Depth (cm)	Al_{ox}	Fe_{ox}	Total P (g/kg)	P_{HCl}	K_{HCl}	Ca_{HCl}	Mg_{HCl}
		(mg/kg)						
Ap1	0–25	1 513	4 894	1.86	1 358	3 525	3 301	7 022
Ap2	25–30	609	3 000	1.05	1 127	3 148	2 930	5 869
Bw1	30–44	627	2 403	1.30	1 555	3 528	3 404	5 661
Bg1	44–87	380	2 037	1.26	1 733	3 300	4 211	4 427
2Bg2	87–104	392	2 762	0.78	1 136	3 098	2 749	4 157
3BCg	104–124	530	3 734	0.74	1 006	2 833	2 583	3 442
4Cg	124–140	252	1 479	0.81	1 081	2 767	2 656	3 405



Figure 9. The Maaninka 05 pedon (Keskilohko field plot). The sandy loam and silt loam pedon had a grayish colour (a and b) but there was substantial mottling of brown redox concentrations and gray redox depletions (c). Photos by Mari Rätty (Luke).

Maaninka 06: Keskilohko 2

- Coordinates x=3516209, y=7004209, k=90
- Day of inspection: 19 August 2021
- Crop: Silage grass (a mixture of timothy and meadow fescue)
- No groundwater
- Classification: Stagnic **Regosols** (Loamic, Aric, Drainic, Ochric)
- Short classification: Stagnic Regosols

The soil pit was between the third and fourth block of the BIOSFÄÄRI field experiment. This is the highest point of the upper plateau of the field; there seems to be a smooth esker with the thickest deposition around this soil pit. This soil (Figure 10) is pedogenically very poorly developed. The original sedimentation layers are visible below 45 cm. In the topsoil, they have been destroyed by tillage and frost, which commonly extends to 45 cm at the maximum. Owing to the coarse texture, no shrinking and swelling occurs in this soil, and therefore the original sedimentation layers have been preserved.

The following pedogenic properties were considered on the basis of morphology (Table 23) and analytical data (Tables 24–26):

- Even though the clay content is extremely low and the pedon has a coarse appearance, the texture is sandy loam for most of the pedon, which is not coarse enough (loamy sand or coarser) to qualify as Arenosols. The texture would allow a cambic horizon. However, the structure in the relevant horizons is weak, and the original stratification starts already at 45 cm. Regosol is therefore considered the correct reference group.
- Stagnic colour pattern (25–50%) below 50 cm -> Stagnic. This colour pattern occurs also at 32–50 cm but it is not widespread enough to be diagnostic (for a Stagnosol).
- Base saturation (BS) in the topsoil above 50% in > 107 cm, at least partly caused by liming. Eutric attribute is waived because it is a temporary characteristic, and in the subsoil the BS is not much above the threshold. The BS < 50% (Dystric) below 107 cm, but it is too deep to be diagnostic.
- Artificial drainage -> Drainic
- Ploughed with an abrupt boundary -> Aric
- Weighted average SOC content in 0–50 cm < 1%. Dry colour is too light for mollic/umbric -> Ochric

In principle, the digestion of total P is stronger than the HCl extraction. However, there may be some anomalies in the results of the pedons 05 and 06, some of the total P results being smaller than the results of HCl-P (Tables 22 and 27). For the determination of HCl- and AAAC-extractable nutrients, the soil samples are dried, ground and passed through a 2 mm sieve, and the nutrient concentrations are expressed on a volume unit basis. The bulk density (i.e., volume weight) of similarly pre-treated mineral soil samples averages 1.0 kg/l over the soil types (Keskinen et al. 2016), leading to equal values in mass-based conversion.

In the present study, the bulk density was determined from the undisturbed soil sample in its natural state and/or the pre-treated soils sample, which is also referred as the volume weight. Soil bulk density is expressed as the ratio of the mass of solids to the total soil volume, including solids and volume of pores. The well-aggregated fine-textured soils have typically lower bulk densities as compared to the coarse-textured soils. Also, higher organic matter content lowers the bulk density value. Keskinen et al. (2016) reported the mean volume weight of 0.9 kg/l, 1.0 kg/l (range 0.5–1.1) and 1.2 kg/l (range 0.8–1.3) for Finnish clay (n = 106), fine (n = 170) and coarse (n = 173) soils, respectively. For the pedons 05 and 06, the bulk density of pre-treated soil sample was not determined, however, the bulk density of undisturbed soil sample varied from 1.37 to 1.78 kg/l (Tables 21 and 26).

Table 23. Morphological properties of the pedon Maaninka 06.

Horizon	Depth (cm)	Morphological description	Diagnostic features
Ap1	0–22	Dark brown (10YR 3/3 moist) or pale brown (10YR 6/3 dry) silt loam. Moderate coarse to medium angular blocky structure. Firm consistence. Common fine roots. Few worm channels. Clear smooth boundary.	Dry colour is too light for a mollic horizon.
Ap2	22–32	This thin horizon has been created by deep ploughing carried out some decades earlier. It is a mixture of the plough layer and soil material that used to be the upper part of the subsoil. Olive brown (2.5Y 4/3) sandy loam. Few small strong brown (7.5YR 5/6) redox concentrations and few small light olive brown (2.5Y 5/3) mottles that may be redox depletions or pockets of the subsoil underneath. Moderate coarse to medium angular blocky structure. Firm consistence. Few fine roots. Few worm channels. Abrupt smooth boundary.	
BC1	32–50	Dark grayish brown (10YR 4/2) sandy loam. Few small (thin) strong brown (7.5YR 5/6) redox concentrations around old root channels. Common small (thin) light yellowish brown (10YR 6/4) horizontal bands in the lower part of the horizon. Weak fine platy structure parting to weak medium angular blocky aggregates. The original sedimentation layers are faintly visible from 45 cm below. Friable consistence. Few fine roots. Clear smooth boundary.	Stagnic colours but not widespread enough (>50%) to qualify as a Stagnosol.
BC2	50–78	Dark grayish brown (2.5Y 4/2) sandy loam. Few medium light olive brown (2.5Y 5/6) linings in previous root channels. Common medium pale brown (10YR 6/3) horizontal bands. The entire horizon consists of original sedimentation layers. Weak coarse to fine platy structure parting to weak medium angular blocky aggregates. Friable consistence. Few fine roots. Clear smooth boundary.	Stagnic colours widespread enough (>25%) for the Stagnic qualifier.
C1	78–107	Olive gray (5Y 4/2) sandy loam. Few small (thin) dark yellowish brown (10YR 3/4) redox concentrations along previous root channels. Few medium dark yellowish brown (10YR 4/4–4/6) horizontal bands. The entire horizon consists of original sedimentation layers. Weak coarse platy structure parting to coarse and medium angular blocky aggregates. Friable consistence. Very few fine roots. Clear smooth boundary.	
C2	107–136	Grayish brown (2.5Y 5/2) sandy loam. Common strong brown (7.5YR 5/6), common brownish yellow (10YR 6/6) and common light brownish gray (2.5YR 6/2) horizontal bands. The entire horizon consists of original sedimentation layers. Weak coarse platy structure parting to coarse and medium angular blocky aggregates. Friable consistence. No roots. Clear smooth boundary.	
C3	136–156	Grayish brown (2.5Y 5/2) sandy loam. Common medium brown (10YR 4/3) horizontal bands. The entire horizon consists of original sedimentation layers. Weak coarse platy structure parting to coarse and medium angular blocky aggregates. Friable consistence. No roots.	

Table 24. Particle size distribution in the soil horizons of the pedon Maaninka 06.

Horizon	Depth (cm)	Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	Gravel	Total silt	Total sand	Finnish soil type
		(%)								
Ap1	0–22	9	24	28	31	8	1	51	39	KHt
Ap2	22–32	4	11	23	38	18	6	35	56	HtMr
BC1	32–50	2	15	29	50	3	0	44	53	KHt
BC2	50–78	1	13	31	50	3	0	45	54	KHt
C1	78–107	1	9	27	58	5	0	37	62	KHt
C2	107–136	1	8	26	58	7	0	34	65	KHt
C3	136–156	1	6	25	62	6	0	32	68	KHt

Particle size limits: Clay = <0.002 mm (“S”); Fine silt = 0.002–0.02 mm (“HHs + KHs”); Coarse silt = 0.02–0.06 mm (“HHt”); Fine sand = 0.06–0.2 mm (“KHt”); Coarse sand = 0.2–2 mm (“HHk + KHk”), representing medium and coarse sand fractions; Gravel = >2 mm (“Sr”). Words in brackets are the Finnish abbreviations of the size fractions (based on Atterberg’s classification system).

Table 25. Potential cation exchange capacity (CEC), exchangeable calcium (Ca²⁺), potassium (K⁺), magnesium (Mg²⁺) and sodium (Na⁺), titratable acidity (Al³⁺+H⁺) and base saturation in the soil horizons of the pedon Maaninka 06.

Horizon	Depth (cm)	Ca	K	Mg	Na	Al+H	CEC (pH 7.0)	Base saturation (%)
		(cmol(+)/kg soil)						
Ap1	0–22	6.5	0.17	0.74	0.03	2.3	9.8	76
Ap2	22–32	3.3	0.15	0.40	0.02	1.5	5.4	72
BC1	32–50	1.3	0.06	0.22	0.01	1.2	2.8	56
BC2	50–78	0.9	0.05	0.16	0.01	0.6	1.8	65
C1	78–107	0.7	0.05	0.12	0.01	0.8	1.7	52
C2	107–136	0.7	0.06	0.11	0.02	1.3	2.1	41
C3	136–156	0.5	0.04	0.08	0.03	0.7	1.3	47

Table 26. Bulk density of undisturbed samples (BD_{UD}), pH, contents of total organic carbon (Org. C, %) and total nitrogen (Total N), and concentrations of acid ammonium acetate-extractable phosphorus (P_{AAc}), potassium (K_{AAc}), calcium (Ca_{AAc}), magnesium (Mg_{AAc}) and sulfur (S_{AAc}) in the soil horizons of the pedon Maaninka 06.

Horizon	Depth (cm)	BD _{UD} (kg/l)	pH (H ₂ O)	Org. C	Total N	P _{AAc}	K _{AAc}	Ca _{AAc}	Mg _{AAc}	S _{AAc}
				(%)						
Ap1	0–22	1.37	6.6	1.47	0.11	10	124	1391	109	10
Ap2	22–32	1.51	6.7	0.43	0.04	2.9	136	770	74	7.0
BC1	32–50	1.54	6.9	0.18	0.03	1.7	66	369	46	4.6
BC2	50–78	1.59	7.1	0.13	0.02	1.1	58	270	33	3.2
C1	78–107	1.63	7.1	0.12	0.00	0.9	54	191	26	2.7
C2	107–136	1.66	7.0	0.13	0.00	0.9	53	179	22	3.2
C3	136–156	1.68	6.8	0.10	0.00	0.9	42	143	19	2.8

Table 27. Concentrations of acid oxalate-extractable aluminium (Al_{ox}) and iron (Fe_{ox}) oxides, total phosphorus (Total P) and hydrochloric acid-extractable phosphorus (P_{HCl}), potassium (K_{HCl}), calcium (Ca_{HCl}) and magnesium (Mg_{HCl}) in the soil horizons of the pedon Maaninka 06.

Horizon	Depth (cm)	Al_{ox}	Fe_{ox}	Total P (g/kg)	P_{HCl}	K_{HCl}	Ca_{HCl}	Mg_{HCl}
		(mg/kg)						
Ap1	0–22	1 181	4 327	1.71	1 393	3 601	3 949	5 682
Ap2	22–32	779	3 666	1.22	1 328	2 838	3 780	4 318
BC1	32–50	332	1 796	0.77	1 008	2 557	2 823	3 167
BC2	50–78	227	1 092	0.77	1 041	2 571	2 859	3 105
C1	78–107	191	963	0.65	906	2 243	2 524	2 571
C2	107–136	215	1 320	0.70	939	2 086	2 563	2 377
C3	136–156	137	587	0.68	929	2 058	2 545	2 446

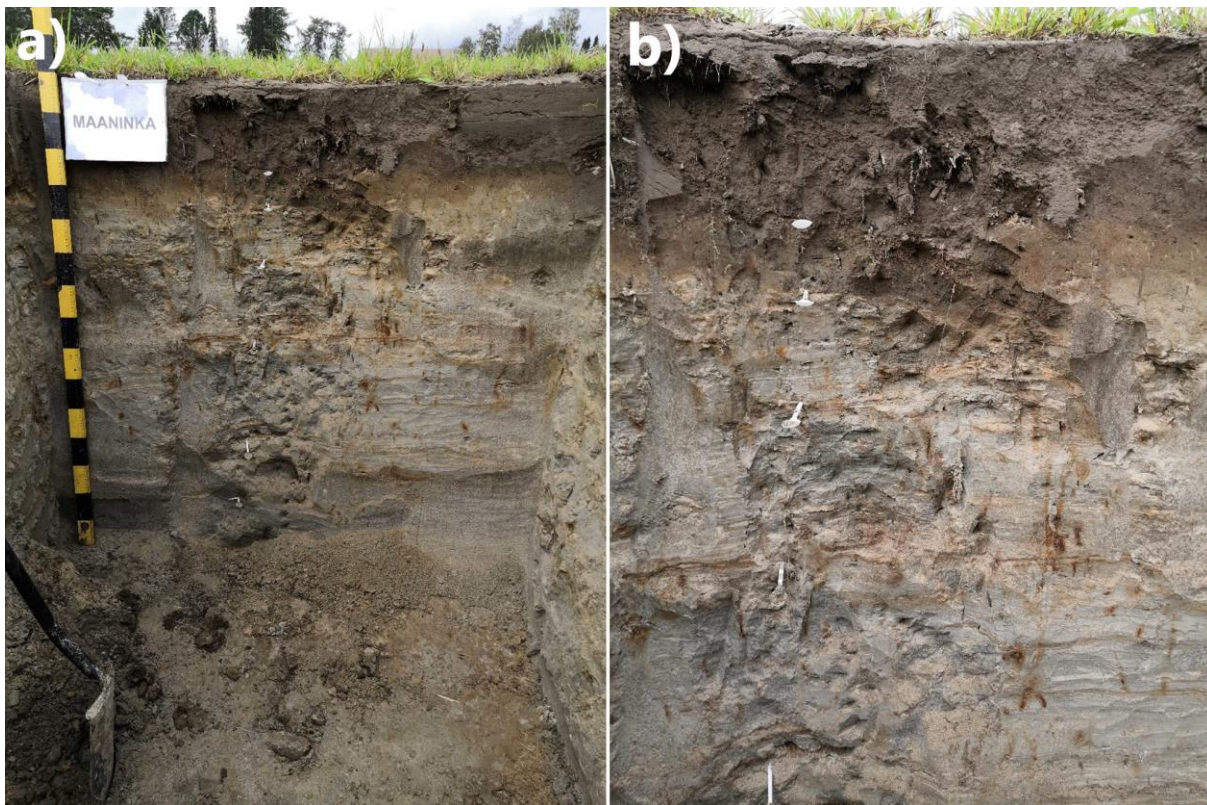


Figure 10. The Maaninka 06 pedon; Keskilohko field plot. The soil dominated by sandy loam texture had a varved appearance (a). Abundant gray colours and brown pore linings suggest poor water conductivity (b). Photos by Mari Rätty (Luke).

Maaninka 07: Kauraniemi buffer strip

- Coordinates: $x=3516000.940$, $y=7004085.234$, $k=87$
- Date of inspection: 14 June, 2005
- Parent material: glacio-fluvial sand
- No ground water observed
- Vegetation: Thick stand of grasses, established a few years earlier
- Classification: Eutric Stagnic **Regosols** (Loamic, Aric, Fluvic, Ochric)
- Short classification: Stagnic Regosols

Pedon Maaninka 07 is at the highest point of an esker formation, sloping (5–10%) to east. About 7 meters west of the soil pit, there is a steep cut (5 m deep) down to the lake. Throughout the pedon, there are thin layers representing coarse silt and various sand fractions, giving the pedon a thinly layered appearance (Table 28, Figure 11). These layers likely represent material deposited in different parts of the year at the end of the latest glaciation. The original stratification is well exhibited and the stratification pattern is unchanged throughout the investigated depth. In spite of clear stratification caused by material sedimented in flowing water, it is questionable if this soil belongs to Fluvisols. It has traditionally been required that fluvic material has been deposited "in recent past", and it is commonly considered that deposition at the end of the Weichselian glaciation is not recent enough. However, the Fluvic attribute is considered appropriate due to the clear retained stratification, even though the age criterion of the fluvic material may not be met.

All subsoil horizons contain redox depletions and concentrations. The changes were considered not sufficient for a Cambic horizon because this soil contains rock structure at all depths below the plough layer, i.e., the original depositional layers are well preserved and not disturbed by pedogenic turbation. However, the stagnic colour pattern is evident, attributable to the prominent pore linings and the alteration of gray and brown colours in the stratified layers. This pedon is dominated by fine sand and coarse silt, all other textural fractions being very low (Table 29), and there are no coarse fragments. The Loamic attribute well describes the texture, which is too fine to allow classification to Arenosols. This pedon belongs to Regosols.

Base saturation is >80% in all horizons (Table 30), probably due to the sufficient amounts of fine particle sizes and weatherable minerals therein, and the pedon is Eutric. It is noteworthy that the high base saturation also occurs in the entire subsoil and is thus not created by agricultural liming. The Aric attribute indicates ploughing and the Ochric attribute indicates a rather low organic C content.

Table 28. Morphological properties of the pedon Maaninka 07.

Horizon	Depth (cm)	Morphological description
Ap	0–30	Dark olive brown (moist 2.5Y 3/3) or light olive brown (dry 2.5Y 5/3) sandy loam. Few fine prominent dark yellowish brown (10YR 4/4) redox concentrations. Moderate medium platy structure, parting to weak medium angular blocky aggregates. Friable (or somewhat firm). Common fine and medium roots. Abrupt smooth boundary.
C1	30–48	Dark grayish brown (2.5Y 4/2) and strong brown (7.5YR 4/6) 0.5 cm strata of silt loam. The strata do not have as abrupt boundaries as in the horizons below. Common medium prominent dark yellowish brown (10YR 4/6) redox concentrations. Weak coarse-to-medium platy structure. Friable (or somewhat firm). Clear smooth boundary.
C2	48–69	Strata of dark grayish brown (2.5Y 4/2) and olive brown (2.5Y 4/4) and dark gray (2.5Y 4/1) silt loam. The strata have very abrupt boundaries. Common medium prominent dark yellowish brown (10YR 4/6) redox concentrations. Weak coarse-to-medium platy structure. Friable. Abrupt smooth boundary.
C3	69–99	Strata of dark grayish brown (2.5Y 4/2) and dark gray (2.5Y 4/1) sandy loam. The strata have very abrupt boundaries. Common coarse prominent reddish brown (5YR 4/3–4) redox concentrations (most abundant in this horizon), particularly around old root channels. Few medium prominent dark reddish brown (5YR 3/2) and common medium prominent yellowish red (5YR 4/6) soft concretions (1 cm in diameter). Weak coarse-to-medium platy structure. Friable. Abrupt smooth boundary.
C4	99–120	Strata of dark gray (2.5Y 4/1) and dark grayish brown (moist, 2.5Y 4/2) silt loam. The strata have very abrupt boundaries. Common medium prominent brown and strong brown (7.5YR 4/4–6) redox concentrations. Weak coarse-to-medium platy structure. Friable. Abrupt smooth boundary.
C5	120–183	Strata of dark grayish brown (2.5Y 4/2), dark gray (2.5Y 4/1) and olive brown (2.5Y 4/3) sandy loam, probably with some textural differences. The strata have very abrupt boundaries. Common coarse prominent strong brown (7.5YR 4/6) redox concentrations around old root channels. Weak coarse-to-medium platy structure. Friable.

Table 29. Particle size distribution in the soil horizons of the pedon Maaninka 07.

Horizon	Depth (cm)	Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	Total silt	Total sand	Finnish soil type
		(%)							
Ap	0–30	8	16	31	34	11	47	45	KHt
C1	30–48	3	12	35	41	9	47	50	KHt
C2	48–69	2	10	34	47	7	44	54	KHt
C3	69–99	2	8	25	50	15	34	65	KHt
C4	99–120	5	16	36	34	9	52	43	KHt
C5	120–183	2	8	29	44	18	37	61	KHt

Particle size limits: Clay = <0.002 mm (“S”); Fine silt = 0.002–0.02 mm (“HHs + KHs”); Coarse silt = 0.02–0.06 mm (“HHt”); Fine sand = 0.06–0.2 mm (“KHt”); Coarse sand = 0.2–2 mm (“HHk + KHk”), representing medium and coarse sand fractions. Words in brackets are the Finnish abbreviations of the size fractions (based on Atterberg’s classification system).

Table 30. Soil total organic carbon (Org. C), bulk density of undisturbed soil samples (BD_{UD}), pH, potential cation exchange capacity (CEC), exchangeable calcium (Ca^{2+}), potassium (K^+), magnesium (Mg^{2+}) and sodium (Na^+), titratable acidity ($Al^{3+}+H^+$) and base saturation (BS) in the soil horizons of the pedon Maaninka 07.

Horizon	Depth (cm)	Org. C (%)	BD_{UD} (kg/l)	pH (H_2O)	Ca	K	Mg	Na	Al+H	CEC	BS (%)
					(cmol(+)/kg soil)						
Ap	0–30	1.43	1.56	6.62	6.2	0.46	1.1	0.13	1.80	9.7	81
C1	30–48	0.28	1.63	6.56	3.8	0.29	0.9	0.07	1.45	6.5	78
C2	32–69	0.09	1.32	6.71	3.1	0.16	0.9	0.10	0.85	5.2	84
C3	69–99	0.06	1.48	6.65	1.8	0.13	2.6	0.09	0.47	5.1	91
C4	99–120	0.08	1.45	6.82	1.7	0.15	3.1	0.08	0.57	5.5	90
C5	120–183	0.06	1.39	6.77	1.4	0.13	2.7	0.09	0.44	4.8	91

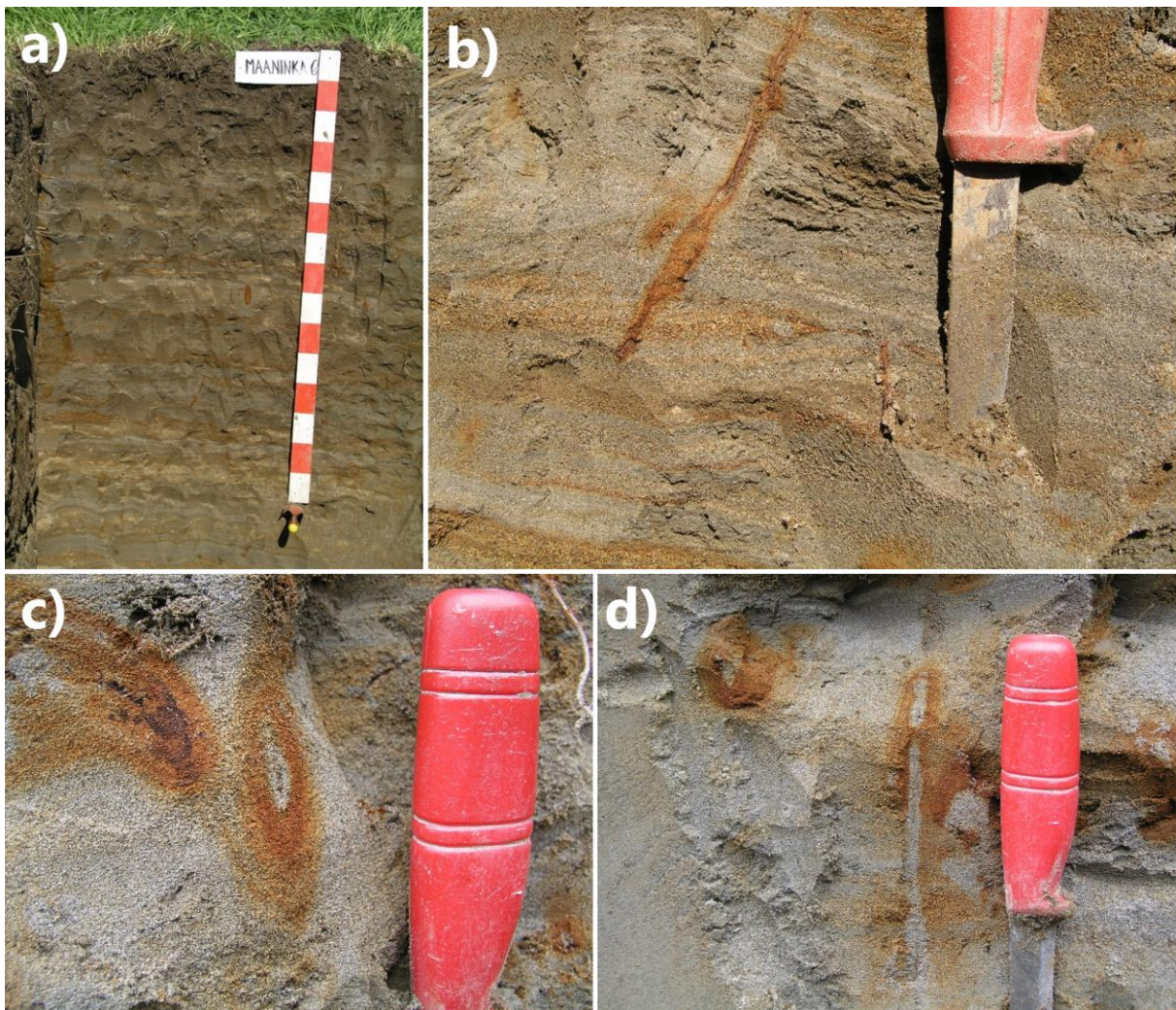


Figure 11. The Maaninka 07 pedon. General view of the soil profile shows the uniform texture and a mixture of brown and gray colours throughout the investigated depth (a). Iron hydroxide precipitates (redox concentrations) start to appear around previous root channels right below the plough layer where the soil matrix is quite oxidized and has predominantly brown colours (b). Deeper in the soil, the redox concentrations around previous root channels are more pronounced, with a sharp contrast to the gray matrix (c and d). Photos by Markku Yli-Halla.

Maaninka 08 and 09: the lowest position of Kauraniemi

Maaninka 08 and 09 are both located at the lowest position of the Kauraniemi field. Both pedons have similar loamy top layers and the subsoil was clayic below the abrupt textural difference at 50 or 65 cm. Maaninka 08 contains varved clay below 91 cm, and also the loam in the Bw1 and Bw2 horizons (28–65 cm) has a platy structure probably inherited from the sedimentary parent material (Table 31). According to a local man operating the excavator, the varved clay extends to the depth of a few metres while still deeper the soil is homogeneous clay without varves. Even though the two pedons were close to each other, clear varving in the clayic subsoil was seen only in pedon 08, not in pedon 09 (Table 34).

Low topographic positions and abrupt textural differences associated with clayic subsoils (clay percentage as high as 73%, Table 32) are conducive to wetness of both pedons 08 and 09. Abundant redox concentrations were described in both pedons (Tables 31 and 34), but redox depletions were not mentioned in these descriptions made as early as 2001. It is likely that the morphological descriptions are inadequate in terms of observing the redox depletions. There are justifications to conclude that both pedons had stagnic properties, and associated with abrupt textural differences, the pedons can be classified as Planosols.

Maaninka 09 is even wetter than Maaninka 08. In Maaninka 08, the horizons below the plough layer were characterized as Bw while in Maaninka 09, they were assigned the label Bg, indicating gleyic properties. In Maaninka 09, the prismatic aggregates were covered by a continuous iron hydroxide precipitate, an undisputed sign of gleyic properties, which, however, occur below 50 cm, too deep (>40 cm from soil surface) to justify the classification as Gleysols but close enough (<75 cm from mineral soil surface) to allow the Gleyic attribute. The wetness of pedon 09 is also proven by the soft, structureless clayic soil material reached at the depth of 115 cm (Table 34).

The CEC of the clayey material was about 20 cmol/kg (Table 33) which is about half of what is measured in soils of similar clay content in Jokioinen, southwestern Finland (Yli-Halla et al. 2000), suggesting that the clay in Maaninka is predominantly coarse clay (0.0002–0.002 mm) which in chemical properties resembles fine silt. Also, the base saturation (64–79%) is rather low compared to the same depth of clay soils in Jokioinen but high enough (>50%) to qualify as an eutric soil. The attribute Aric stands for ploughing and Drainic for artificial drainage. The Raptic qualifier indicates that the loamy soil materials have been deposited in different time from the clayic material underneath.

Maaninka 08.

- Coordinates x=3516100, y=7004100, k=84
- Day of inspection: 30 May 2001
- No groundwater observed
- Classification: Eutric **Planosols** (Epiloamic, Endoclayic, Aric, Drainic, Raptic)
- Short classification: Eutric Planosols
- Soil Taxonomy: Typic Cryaquept, fine-loamy over clayey

Table 31. Morphological properties of the pedon Maaninka 08.

Horizon	Depth (cm)	Morphological description
Ap	0–28	Grayish brown (10YR 3/3) loam. Moderately strong medium subangular blocky aggregates. Firm consistence. Many roots and common worm channels. Abrupt smooth boundary.
Bw1	28–36	Brown (10YR 4/3) loam. Few small dark brown (10YR 4/4) mottles. Weak coarse platy aggregates parting to moderately strong medium angular blocky aggregates. Firm consistence. Few roots and common worm channels. Clear smooth boundary.
Bw2	36–65	Brown (10YR 4/3) loam. Common brown (7.5YR 4/6) mottles. Moderately strong platy aggregates parting to moderately strong fine and medium angular blocky aggregates. Firm consistence. Very few roots. Few worm channels. Clear smooth boundary.
Bw3	65–91	Brown (10YR 4/3) heavy clay. Common rather large dark brown (5YR 4/4) and brown (7.5YR 4/4) mottles. Weak very coarse prismatic aggregates parting to moderate coarse angular blocky aggregates. Firm consistence. Very few roots (65–80 cm). Abrupt smooth boundary.
C1	91–115	Grayish brown (2.5Y 5/2) and dark grayish brown (2.5Y 4.5/2) varved (thickness of strata 2–3 mm) heavy clay. Common large brown (7.5YR 4/6) mottles. Moderate fine platy aggregates that break along the strata, Firm consistence. Abrupt smooth boundary.
C2	115–145	Grayish brown (2.5Y 4/2) and dark grayish brown (2.5Y 4.5/2) varved (thickness of strata 5–10 mm) heavy clay. Between the clayey strata, there is a 0.5 mm sandy layer along which the clayey strata can be easily pulled apart. Many large brown (7.5YR 4/6) mottles. Moderate fine platy aggregates breaking along the strata. Firm consistence. Clear smooth boundary.
C3	145–170+	Dark gray (2.5Y 4/1) and gray (2.5Y 5/1) varved (thickness of strata 5–10 mm) heavy clay. Between the clayey strata, there is a 0.5 mm sandy layer along which the clayey strata can be easily pulled apart. Few strong brown (7.5YR 4/6) mottles. Moderate fine platy aggregates splitting along the strata. Firm consistence.

Table 32. Particle size distribution in the soil horizons of the pedon Maaninka 08.

Horizon	Depth (cm)	Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	Total silt	Total sand	Finnish soil type
Ap	0–28	21	27	23	24	5	40	29	HHt
Bw1	28–36	16	18	29	35	3	47	37	KHt
Bw2	36–65	25	33	25	16	1	58	17	HHt
Bw3	65–91	73	19	5	2	1	24	3	AS
C1	91–115	62	34	3	1	0	37	1	AS
C2	115–145	-	-	-	-	-	-	-	AS?
C3	145–170+	-	-	-	-	-	-	-	AS?

Particle size limits: Clay = <0.002 mm (“S”); Fine silt = 0.002–0.02 mm (“HHs + KHs”); Coarse silt = 0.02–0.06 mm (“HHt”); Fine sand = 0.06–0.2 mm (“KHt”); Coarse sand = 0.2–2 mm (“HHk + KHk”), representing medium and coarse sand fractions. Words in brackets are the Finnish abbreviations of the size fractions (based on Atterberg’s classification system).

Table 33. Soil pH, total organic carbon (Org. C) content, and potential cation exchange capacity (CEC), exchangeable calcium (Ca²⁺), potassium (K⁺), magnesium (Mg²⁺) and sodium (Na⁺), titratable acidity (Al³⁺+H⁺) and base saturation in the soil horizons of the pedon Maaninka 08.

Horizon	Depth (cm)	pH (H ₂ O)	Org. C (%)	Ca	K	Mg	Na	Al+H	CEC (pH 7.0)	Base saturation (%)
				(cmol(+)/kg soil)						
Ap	0–28	6.35	2.7	8.5	0.39	2.0	0.10	7.3	18.3	60
Bw1	28–36	6.13	0.6	3.8	0.26	1.4	0.07	7.3	12.9	43
Bw2	36–65	6.51	0.2	5.1	0.20	3.4	0.08	3.5	12.3	71
Bw3	65–91	6.78	0.3	8.2	0.63	9.4	0.19	5.5	23.9	77
C1	91–115	7.05	0.3	5.3	0.44	6.0	0.14	3.2	15.1	79
C2	115–145	-	0.4	3.3	0.32	3.8	0.10	2.6	10.1	74
C3	145–170+	-	0.4	1.8	0.30	2.2	0.09	2.4	6.8	64

Maaninka 09.

- Coordinates x=3516150, y=7004130, k=84
- Day of inspection: 30 May 2001
- Groundwater at 146 cm
- Classification: Eutric Gleyic **Planosols** (Epiloamic, Endoclayic, Aric, Drainic, Raptic)
- Short classification: Gleyic Planosols
- Soil Taxonomy: Typic Cryaquept, fine-loamy over clayey

This pedon at the lowest position of the Kauraniemi field was not comprehensively described. The colours were the same as in Maaninka 08. This pedon was not sampled, so the texture is based on finger assessment.

Table 34. Morphological properties of the pedon Maaninka 09.

Horizon	Depth (cm)	Finnish soil type	Morphological description. No colour determination.
Ap	0–30	HHt?	Loam. Firm blocky aggregates. Strong consistence. Few roots. Abrupt smooth boundary.
Bg1	30–50	HHt?	Loam. Rather weak coarse prismatic aggregates parting to moderate coarse angular blocky aggregates. Very few roots. Clear smooth boundary.
Bg2	50–85	HsS?	Silty clay. Moderate coarse prismatic aggregates parting to moderate coarse platy aggregates obviously along the original stratification. The prisms had almost continuous coating of iron hydroxide, resulting in the strong structure. Strong pipestems along the previous root channels. Thick worms. Very few roots. Clear smooth boundary.
BC	85–115	HsS?	Silty clay. Strong coarse prismatic aggregates breaking to moderate medium angular blocky aggregates. The prisms had continuous coating of iron hydroxide, resulting in the strong structure. Strong pipestems around the previous root channels. Thick worms. Clear smooth boundary.
C	115–150+	AS?	Gray heavy clay. Structureless, massive. Soft consistence. Wet.

4.3. Hämeensuo and Hirsisuo

Hämeensuo and Hirsisuo are located to north-east and north of the buildings of the research station at the distance of 1.2–1.5 km (Figure 12). The three pedons of Hämeensuo are within 0.5 km from each other. The Hämeensuo area has likely been a wetland reclaimed for agriculture. All the four pedons are dominated by rather fine-textured soil material (mostly silty clay loam to clay). Here, these fine-textured materials are not covered by coarse-textured esker material like pedons 01–09 in the vicinity of the buildings of the research station, where similar fine-textured material was found only in one site (04) in Pohjoispelto and in the lowermost positions (08 and 09) in Kauraniemi.

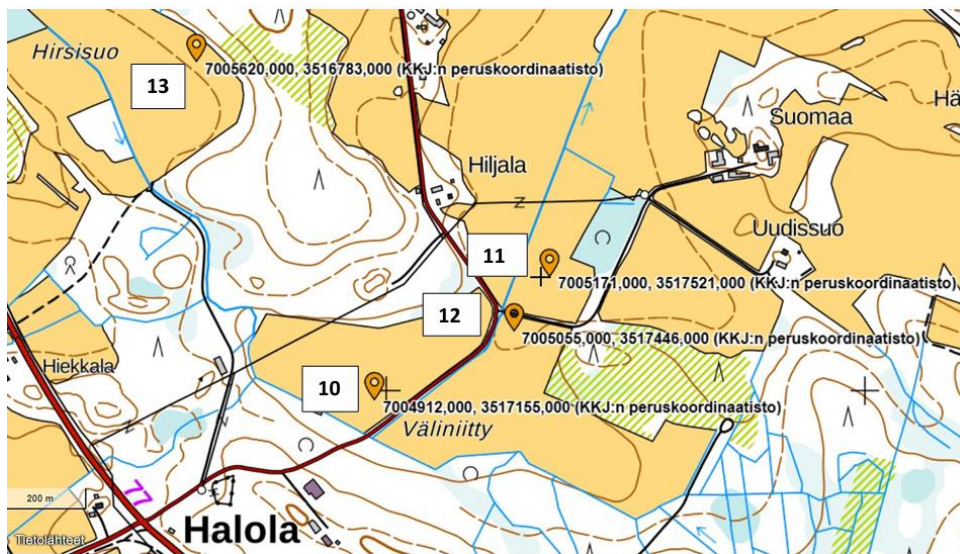


Figure 12. Locations of the pedons investigated in the Hämeensuo - Hirsisuo area. The pedon 10 represents the Hämeensuo 1 field plot (8.12 ha), the pedon 11 the Hämeensuo 4 field plot (1.69 ha) and the pedon 12 Hämeensuo 3 field plot (6.24 ha). One pedon (13) was investigated in the Hirsisuo field plot (9.79 ha).

Maaninka 10: Hämeensuo 1

- Coordinates $x=3517155$, $y=7004912$, $k=87$
- Day of inspection: 29 August, 2023
- Crop: Ley (timothy)
- Groundwater at 120 cm
- Classification: Eutric Mollic **Gleysols** (Loamic, Aric, Drainic, Hyperhumic, Mulmic)
- Short classification: Mollic Gleysols

Hämeensuo 1 is the wettest pedon among the investigated pedons. The gleyic colour pattern with pore linings and gray interiors of aggregates was observed already at 28 cm (Table 35, Figure 13), and the soil belongs to Gleysols. The C_g horizon has never dried out because it was massive and soft with no sign of desiccation cracks. The soil is silty clay loam, and the particle size distribution is practically the same in all horizons (Table 36). High content of silt (>58%), particularly fine silt, throughout the pedon is conducive to poor conductivity to water. Base saturation (57–71%) is rather low in such a fine-textured soil (Table 37) and differs from soils of similar textures in southern Finland where the base saturation is commonly around 90%. Even though the soil has a rather high organic C content in the topsoil (Table

38), it belongs to mineral soils. It has a Mollic horizon on the top (more detailed reasoning presented in Hämeensuo 4). The soil is Hyperhumic, having a weighted average C content of 7.5% in the top 50 cm. The Ap horizon also meets the criteria of Mulmic material, introduced in the WRB system in 2022, because its organic C content at 0–28 cm is within the range of 8–20%, associated with dark colour.

Owing to rising groundwater, the deepest horizon that was morphologically described, could not be sampled for analyses.

Table 35. Morphological properties of the pedon Maaninka 10.

Horizon	Depth (cm)	Morphological description	Diagnostic features
Ap1	0–14	Dark brown (7.5YR 3/2 moist) or brown (10YR 5/3 dry) silty clay loam. Moderate and coarse granular structure. Friable consistence. Common fine and medium roots. Clear smooth boundary.	Mulmic
Ap2	14–28	Horizon affected by ploughing that has been deeper than currently applied. Dark brown (7.5YR 3/2) silty clay loam. Common large distinct brown (10YR 4/3) spots, possibly subsoil material lifted by deep ploughing. Weak coarse prismatic structure parting to moderate medium subangular blocky aggregates. Friable consistence. Common fine roots. Clear smooth boundary.	Mollic (together with Ap2)
Bg1	28–39	Dark grayish brown (2.5Y 4/2) silty clay loam. Common medium distinct brown (10YR 4/3) mottles as prominent pore linings and separately from previous root channels and few small prominent gray (5Y 5/1) interiors of previous root channels. Weak coarse angular blocky structure. Firm consistence. Few fine roots. Clear smooth boundary.	Gleyic properties
Bg2	39–68	Dark grayish brown (2.5Y 4/2) silty clay loam. Common medium (dark yellowish) brown (10YR 4/3–4/4) mottles as pore linings and common medium prominent gray (5Y 5/1) interiors of previous root channels (more pronounced than above). Weak coarse angular blocky structure. Somewhat plastic consistence. Few fine roots. Gradual smooth boundary.	Gleyic properties
Bg3	68–84	Dark grayish brown (2.5Y 4/2) silty clay loam. Common medium prominent dark yellowish brown (10YR 4/4) pore linings and common medium prominent gray (5Y 5/1) interiors of previous root channels (more pronounced than above). Weak coarse angular blocky structure. Somewhat plastic consistence. Very few fine roots. Gradual smooth boundary.	Luvic Gleyic properties
Bg4	84–107	Olive gray (5Y 4/2) silty clay loam. Common large prominent dark yellowish brown (10YR 4/4) pore linings and common medium prominent gray (5Y 5/1) interiors of previous root channels (more pronounced than above). Massive. Somewhat plastic consistence. Clear smooth boundary.	
Cg	107–124+	Dark gray (5Y 4/1) silty clay loam. Shiny small pieces of mica. Common medium (dark) olive brown (2.5Y 3/3–4/3) pore linings, partly some cementation. In the previous root channels, black plant material (horsetail?) was very commonly seen. Massive structure. Plastic consistence. No roots.	Gleyic properties

Table 36. Particle size distribution in the soil horizons of the pedon Maaninka 10 (Cg-horizon was not sampled).

Horizon	Depth (cm)	Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	Total silt	Total sand	Finnish soil type
		(%)							
Ap1	0–14	31	49	12	6	1	61	8	HsS
Ap2	14–28	33	50	10	5	2	60	7	HsS
Bg1	28–39	39	43	15	3	0	58	3	HsS
Bg2	39–68	38	45	17	1	0	62	1	HsS
Bg3	68–84	33	49	16	2	0	65	2	HsS
Bg4	84–107	32	46	19	3	0	65	3	HeS

Particle size limits: Clay = <0.002 mm (“S”); Fine silt = 0.002–0.02 mm (“HHs + KHs”); Coarse silt = 0.02–0.06 mm (“HHT”); Fine sand = 0.06–0.2 mm (“KHt”); Coarse sand = 0.2–2 mm (“HHk + KHk”), representing medium and coarse sand fractions. Words in brackets are the Finnish abbreviations of the size fractions (based on Atterberg’s classification system).

Table 37. Potential cation exchange capacity (CEC), exchangeable calcium (Ca²⁺), potassium (K⁺), magnesium (Mg²⁺) and sodium (Na⁺), titratable acidity (Al³⁺ + H⁺) and base saturation in the soil horizons of the pedon Maaninka 10.

Horizon	Depth (cm)	Ca	K	Mg	Na	Al+H	CEC (pH 7.0)	Base saturation (%)
		(cmol(+)/kg soil)						
Ap1	0–14	16.5	0.15	2.0	0.12	13.1	31.9	59
Ap2	14–28	15.8	0.10	1.9	0.08	13.2	31.1	58
Bg1	28–39	9.5	0.13	1.9	0.11	8.9	20.6	57
Bg2	39–68	7.4	0.28	2.5	0.10	5.3	15.7	66
Bg3	68–84	5.9	0.35	2.9	0.10	3.8	13.0	71
Bg4	84–107	4.9	0.38	2.9	0.10	3.6	11.9	70

Table 38. Bulk density measured from pre-treated samples (BD_{P-T}), pH, contents of total organic carbon (Org. C) and total nitrogen (Total N), and concentrations of acid ammonium acetate-extractable phosphorus (P_{AAC}), potassium (K_{AAC}), calcium (Ca_{AAC}), magnesium (Mg_{AAC}) and sulfur (S_{AAC}) in the soil horizons of the pedon Maaninka 10.

Horizon	Depth (cm)	BD _{P-T} (kg/l)	pH (H ₂ O)	Org. C	Total N	P _{AAC}	K _{AAC}	Ca _{AAC}	Mg _{AAC}	S _{AAC}
				(%)		(mg/l soil)				
Ap1	0–14	1.14	5.4	10.5	0.65	4.4	43	1 919	153	20
Ap2	14–28	1.15	5.4	12.0	0.75	10	44	2 062	171	27
Bg1	28–39	1.33	5.3	3.33	0.29	2.6	29	1 010	118	15
Bg2	39–68	1.51	5.6	2.38	0.18	2.5	52	831	148	8.6
Bg3	68–84	1.50	5.6	1.79	0.13	4.9	68	758	188	8.2
Bg4	84–107	1.44	5.5	1.60	0.11	3.3	72	674	202	10

Table 39. Concentrations of acid oxalate-extractable aluminium (Al_{ox}) and iron (Fe_{ox}) oxides, total phosphorus (Total P) and hydrochloric acid-extractable phosphorus (P_{HCl}), potassium (K_{HCl}), calcium (Ca_{HCl}) and magnesium (Mg_{HCl}) in the soil horizons of the pedon Maaninka 10.

Horizon	Depth (cm)	Al_{ox}	Fe_{ox}	Total P (g/kg)	P_{HCl}	K_{HCl}	Ca_{HCl}	Mg_{HCl}
		(mg/kg)						
Ap1	0–14	3 463	13 553	2.19	1 165	1 312	5 437	4 171
Ap2	14–28	3 475	14 444	2.27	1 101	1 146	5 419	3 764
Bg1	28–39	1 323	6 757	0.74	429	1 260	2 776	3 839
Bg2	39–68	1 142	6 945	0.74	500	2 236	2 769	4 401
Bg3	68–84	988	6 122	0.94	829	2 616	2 906	4 789
Bg4	84–107	1 046	6 258	0.99	758	2 593	2 818	4 791

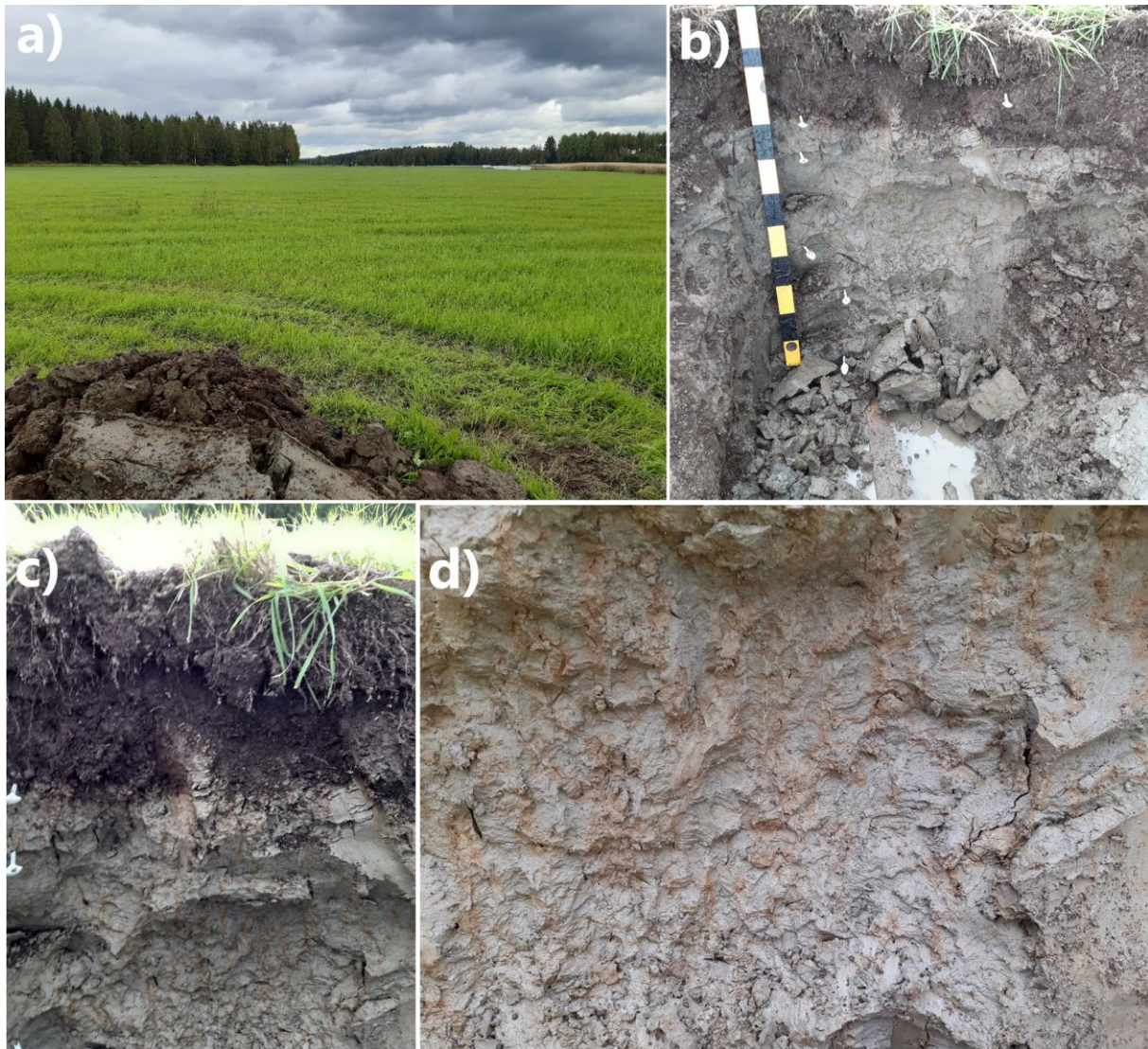


Figure 13. The Maaninka 10 pedon: Hämeensuo 1. Hämeensuo is a flat field (a) and has a very dark plough layer rich in organic matter and generally gray subsoil (b and c). At closer look, plenty of brown redox concentrations can be distinguished, indicating alternating reduced and oxidized conditions (d). Photos by Mari Rätty (Luke).

Maaninka 11: Hämeensuo 4

- Coordinates x=3517521 E, y= 7005171 N, k= 88
- Day of inspection: 15 September, 2022
- Crop: Ley (timothy)
- Groundwater at 117 cm
- Classification: Eutric Mollic **Gleysols** (Loamic, Endoclayic, Luvic, Aric, Drainic, Hyperhumic)
- Short classification: Mollic Gleysols

In Hämeensuo 4 (1.7 ha) the gleyic properties are very prominent (Table 40, Figure 14), justifying the classification as a Gleysol. This soil is characterized by substantial illuvial material (more than in Hämeensuo 1) throughout much of the investigated depth. At 27–71 cm, Hämeensuo 4 has a clay content high enough to qualify as silty clay instead of silty clay loam (Table 41). Also, here the Cg horizon has a massive structure and plastic consistence, and owing to rising groundwater, the deepest horizon that was morphologically described, could not be sampled for analyses. The diagnostic properties are as follows:

- Ap1+Ap2 are dark and jointly meet the colour criteria of the Mollic horizon. Even if the pH of the uppermost horizons is <6 (Table 42), the base saturation is >50% (Table 43). Often the high base saturation in Finnish soils has been elevated by agricultural liming, and the base saturation is substantially lower in the subsoil. But in this case, the base saturation is equally high throughout the investigated depth, and therefore the soil was considered to truly contain a Mollic horizon and get the Mollic qualifier.
- Gleyic properties starting at 26 cm -> Gleysoil
- Plenty of illuvial clay at 47–102 cm -> Luvic
- Base saturation in the mineral subsoil >50% -> Eutric
- Silty clay loam at 0–35 cm and at 71–117 cm. Silty clay at 35–71 cm. -> Loamic, Endoclayic
- Ploughed soil -> Aric
- Artificial drainage -> Drainic
- Weighted average of organic C content at 0–50 cm is 6.9% > 5% -> Hyperhumic. This soil does not contain Mulmic material because the organic C content in the Ap1 horizon is <8%.

Table 40. Morphological properties of the pedon Maaninka 11.

Horizon	Depth (cm)	Morphological description	Diagnostic features
Ap1	0–16	Dark brown (10YR 4/2 moist) or pink (2.5Y 6/2 dry) silty clay loam. Moderate coarse subangular blocky structure parting to moderate fine subangular blocky and granular aggregates. Friable consistence. Common fine and medium roots. Gradual smooth boundary.	Mollic (together with Ap2)
Ap2	16–27	Horizon affected by ploughing that has been deeper than currently applied. Dark brown (7.5YR 2/2) silty clay loam. Few pockets of grayish brown (2.5Y 5/2) loam that are lighter in colour (mineral material transported to the field that was organic soil to start with?). Moderate medium prismatic structure parting to moderate medium (sub)angular blocky aggregates. Firm or friable consistence. Common fine roots. Clear smooth boundary.	
Bg1	27–35	Very dark brown (7.5YR 2.5/2) silty clay rich in organic matter representing the deepest organic layer of the former peatland that was reclaimed for agriculture. Moderate medium subangular blocky structure parting to moderate medium granular aggregates. Friable consistence. Common fine roots. Abrupt smooth boundary.	
Bg2	35–47	Dark olive brown (2.5Y 3/3) silty clay. Common medium brown (10YR 4/4) mottles as prominent pore linings and common dark brown (7.5YR 3/2) fillings of the pores, originating from the above horizon. Weak coarse prismatic structure. Plastic consistence. Few fine roots. Clear smooth boundary.	Gleyic properties
Btg1	47–71	Dark grayish brown (2.5Y 4/2) silty clay. Common medium olive brown (2.5Y 4/4) mottles and diffuse pore linings. Very dark grayish brown (2.5Y 3/2) illuvial material as continuous coatings on desiccation crack surfaces. At the bottom of the horizon, there is a 0.5-cm layer of dusky red (2,5YR 3/2) fine sand. Weak very coarse incomplete prismatic structure; prisms extend throughout the horizon. Plastic consistence. Extremely few fine roots. Abrupt smooth boundary.	Luvic Gleyic properties
Btg2	71–102	Dark grayish brown (2.5Y 4/2) silty clay loam. Common medium olive brown (2.5Y 4/4) pore linings. Olive brown (2.5Y 4/3) illuvial material as continuous coatings on desiccation crack surfaces. Weak very coarse incomplete prismatic structure; prisms extend throughout the horizon. Plastic consistence. Very few fine roots. Gradual smooth boundary.	Luvic Gleyic properties
Cg	102–117+	Dark gray (5Y 4/1) silty clay loam. Common medium olive brown (2.5Y 4/3) and few medium dark reddish brown (5YR 3/3) slightly cemented pore linings (former root channels). Few medium yellowish brown (10YR 5/6) mottles. At 102–105 cm, the clay loam has a homogeneous brown (7.5YR 4/4) colour. Massive structure. Plastic consistence. No roots.	Gleyic properties

Table 41. Particle size distribution in the soil horizons of the pedon Maaninka 11 (Cg-horizon was not sampled).

Horizon	Depth (cm)	Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	Gravel	Total silt	Total sand	Finnish soil type
		(%)								
Ap1	0–16	33	46	11	7	3	0	57	10	HeS
Ap2	16–27	34	46	10	7	2	0	56	9	HsS
Bg1	27–35	40	42	11	6	1	0	53	7	HsS
Bg2	35–47	42	47	8	1	0	2	55	1	HsS
Btg1	47–71	41	51	7	1	0	0	58	1	HsS
Btg2	71–102	37	48	13	2	0	0	61	2	HsS

Particle size limits: Clay = <0.002 mm (“S”); Fine silt = 0.002-0.02 mm (“HHs + KHs”); Coarse silt = 0.02-0.06 mm (“HHt”); Fine sand = 0.06-0.2 mm (“KHT”); Coarse sand = 0.2-2 mm (“HHk + KHk”), representing medium and coarse sand fractions; Gravel = >2 mm (“Sr”). Words in brackets are the Finnish abbreviations of the size fractions (based on Atterberg’s classification system).

Table 42. Bulk density of undisturbed samples (BD_{UD}) and measured from pre-treated samples (BD_{p-T}), pH and contents of total organic carbon (Org. C) and total nitrogen (Total N) in the soil horizons of the pedon Maaninka 11.

Horizon	Depth (cm)	BD _{UD} (kg/l)	BD _{p-T} (kg/l)	pH (H ₂ O)	Org. C	Total N
					(%)	
Ap1	0–16	0.99	0.78	5.9	6.94	0.45
Ap2	16–27	1.01	0.73	5.9	8.27	0.56
Bg1	27–35	-	0.58	5.8	12.95	0.95
Bg2	35–47		0.58	6.0	2.92	0.29
Btg1	47–71	0.80	0.67	6.2	1.90	0.19
3Btg2	71–102	-	0.76	6.1	1.48	0.14

Table 43. Potential cation exchange capacity (CEC), exchangeable calcium (Ca²⁺), potassium (K⁺), magnesium (Mg²⁺) and sodium (Na⁺), titratable acidity (Al³⁺+H⁺) and base saturation in the soil horizons of the pedon Maaninka 11.

Horizon	Depth (cm)	Ca	K	Mg	Na	Al+H	CEC (pH 7.0)	Base saturation (%)
		cmol(+)/kg soil						
Ap1	0–16	15.3	0.15	3.1	0.09	8.6	27.2	68
Ap2	16–27	16.6	0.12	3.2	0.08	9.0	28.9	69
Bg1	27–35	23.7	0.09	4.6	0.16	13.9	42.5	67
Bg2	35–47	10.1	0.15	4.2	0.14	5.4	20.0	73
Btg1	47–71	7.9	0.21	4.2	0.15	4.3	16.8	75
Btg2	71–102	5.0	0.26	3.2	0.15	3.8	12.5	69

Table 44. Concentrations of acid ammonium acetate-extractable phosphorus (P_{AAc}), potassium (K_{AAc}), calcium (Ca_{AAc}), magnesium (Mg_{AAc}) and sulfur (S_{AAc}) in the soil horizons of the pedon Maaninka 11.

Horizon	Depth (cm)	P_{AAc}	K_{AAc}	Ca_{AAc}	Mg_{AAc}	S_{AAc}
		(mg/l soil)				
Ap1	0–16	6.3	50	2 555	282	17
Ap2	16–27	4.1	42	2 666	303	18
Bg1	27–35	2.5	28	2 736	355	28
Bg2	35–47	2.2	41	1 251	287	14
Btg1	47–71	5.6	67	1 097	317	8
Btg2	71–102	3.9	88	940	332	15

Table 45. Concentrations of acid oxalate-extractable aluminium (Al_{ox}) and iron (Fe_{ox}) oxides, total phosphorus (Total P) and hydrochloric acid-extractable phosphorus (P_{HCl}), potassium (K_{HCl}), calcium (Ca_{HCl}) and magnesium (Mg_{HCl}) in the soil horizons of the pedon Maaninka 11.

Horizon	Depth (cm)	Al_{ox}	Fe_{ox}	Total P	P_{HCl}	K_{HCl}	Ca_{HCl}	Mg_{HCl}
		(mg/kg)		(g/kg)	(mg/l soil)			
Ap1	0–16	3 696	8 714	2.37	1 104	2 139	4 572	5 105
Ap2	16–27	4 167	9 319	2.71	1 093	2 054	4 641	5 000
2Bg1	27–35	5 443	9 872	2.09	701	1 093	4 112	3 748
3Bg2	35–47	1 715	5 521	1.33	448	2 236	2 705	5 097
3Btg1	47–71	1 295	5 141	1.12	464	2 903	2 476	5 176
3Btg2	71–102	1 191	6 799	1.44	703	3 111	2 324	5 170



Figure 14. The Maaninka 11 pedon: Hämeensuo 4. General view of the field (a). The pedon has brownish and darker colours in the top horizons while the colours get lighter and turn gray when going deeper (b and c). Attributed to the clay content, the subsoil has desiccation cracks and a coarse prismatic structure, where the prism surfaces are covered with illuvial clay (c and d). Photos by Mari Rätty (Luke).

Maaninka 12: Hämeensuo 3

- Coordinates x= 3517446 E, y= 7005054 N, k= 87
- Day of inspection: 20 August, 2021
- Crop: Italian ryegrass
- No groundwater observed
- Classification: Eutric Luvic **Stagnosols** (Epiclayic, Endoloamic, Aric, Drainic, Humic)
- Short classification: Luvic Stagnosols

This site is located at the edge of the previous soil compaction field experiment. The pedon has stagnic colours starting right below the plough layer (Table 46, Figure 15). The horizon at 33–66 cm has a texture of almost heavy clay (Table 47), certainly a horizon with a high compaction tendency and low permeability to water. This pedon has an uncommon feature that the clay content substantially decreases downwards and turns into silt loam below 82 cm. The original sedimentation layers are visible in these silty horizons, contrary to the upper horizons. The following diagnostic properties were identified or considered:

- Stagnic colour pattern (>50%) closer than 50 cm from soil surface -> Stagnosol
- Gleyic colour pattern starting at 112 cm -> Not close enough (<75 cm) to soil surface to be diagnostic (for the Gleyic qualifier)
- Abundant illuvial clay at 33–66 cm -> Luvic
- Base saturation >50% -> Eutric
- Textural qualifiers Epiclayic and Endoloamic
- Artificial drainage -> Drainic
- The weighted average of the organic C content at 0–50 cm is 4.0% which is not sufficient for the Hyperhumic qualifier (>5%) but sufficient for the Humic qualifier (>1%).

Table 46. Morphological properties of the pedon Maaninka 12.

Horizon	Depth (cm)	Morphological description	Diagnostic features
Ap1	0–23	Dark grayish brown (10YR 4/2 moist) or light yellowish brown (10YR 6/4 dry) silty clay loam. Strong coarse angular blocky structure parting to strong fine angular blocky aggregates. Very firm consistence. Common fine roots. Clear smooth boundary.	Moist and dry colours are too light for a mollic horizon.
Ap2	23–33	This horizon has been created by deep ploughing carried out some decades earlier. It is a mixture of the plough layer and soil material that used to be the upper part of the subsoil. Very dark grayish brown (10YR 3/2) silty clay. Few small light olive brown (2.5Y 5/3) mottles (redox depletions or pockets of the subsoil material). Moderate coarse subangular blocky structure parting to strong fine subangular blocky aggregates. Very firm consistence. Common fine roots. Abrupt smooth boundary.	
Btg	33–66	Dark grayish brown (2.5Y 4/2) (silty) clay. Common to many medium brown (7.5YR 4/4) and dark yellowish brown (10YR 4/4) redox concentrations. Few small dark reddish brown (5YR 2.5/2) and yellowish brown (10YR 5/6) redox concentrations and gray (2.5Y 5/1) redox depletions along previous root channels. Moderate very coarse prismatic structure (incomplete prisms, i.e., desiccation cracks), parting to weak coarse angular blocky aggregates. Abundant illuvial clay on prism faces. Very firm consistence. Few fine roots. Clear smooth boundary.	Stagnic colours (100%) Luvic
Bg1	66–82	Grayish brown (2.5Y 5/2) silty clay loam. Common to many dark yellowish brown (10YR 4/4) redox concentrations and gray (2.5Y 5/1) redox depletions along previous root channels. Massive structure. Original sedimentation layers are visible, but the soil does not break, or breaks only barely, along these lines, due to the lack of sandy layers. Very firm consistence. No roots. Gradual smooth boundary.	Stagnic colours (100%)
Bg2	82–112	Grayish brown (2.5Y 5/2) silt loam. Common to many dark yellowish brown (10YR 4/4) redox concentrations and gray (2.5Y 5/1) redox depletions along previous root channels. Weak coarse platy structure. Original sedimentation layers are visible and the soil breaks along these lines, due to the sandy interlayers, characterized by shining biotite particles. The previous root channels show some cementation (formation of rust pipes that penetrate through the platy aggregates). Some of the root channels are thick (ø 1.5 cm) and some cortex material is remaining. Very firm consistence. No roots. Clear smooth boundary.	Stagnic colours (100%)
Cg	112–138+	Dark olive brown (2.5Y 3/3) and light olive brown (2.5Y 5/3) silt loam. Common small (thin) dark yellowish brown (10YR 4/4) redox concentrations along previous root channels. Original sedimentation layers are visible. Thin yellowish brown (10YR 5/6–5/8) sandy layers along which the soil breaks to moderate very coarse platy aggregates. Firm consistence. No roots.	Gleyic colours but too deep to be diagnostic.

Table 47. Particle size distribution in the soil horizons of the pedon Maaninka 12.

Horizon	Depth (cm)	Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	Gravel	Total silt	Total sand	Finnish soil type
		(%)								
Ap1	0–23	33	44	11	8	5	0	54	13	HeS
Ap2	23–33	43	37	8	9	3	0	44	13	HeS
Btg	33–66	58	28	6	6	2	0	34	8	HsS
Bg1	66–82	37	60	2	0	0	0	62	1	HsS
Bg2	82–112	29	63	4	2	1	1	67	3	HHs
Cg	112–138	20	64	12	2	1	1	76	3	KHs

Particle size limits: Clay = <0.002 mm (“S”); Fine silt = 0.002–0.02 mm (“HHs + KHs”); Coarse silt = 0.02–0.06 mm (“HHt”); Fine sand = 0.06–0.2 mm (“KHt”); Coarse sand = 0.2–2 mm (“HHk + KHk”), representing medium and coarse sand fractions; Gravel = >2 mm (“Sr”). Words in brackets are the Finnish abbreviations of the size fractions (based on Atterberg’s classification system).

Table 48. Potential cation exchange capacity (CEC), exchangeable calcium (Ca²⁺), potassium (K⁺), magnesium (Mg²⁺) and sodium (Na⁺), titratable acidity (Al³⁺+H⁺) and base saturation in the soil horizons of the pedon Maaninka 12.

Horizon	Depth (cm)	Ca	K	Mg	Na	Al+H	CEC (pH 7.0)	Base saturation (%)
		cmol(+)/kg soil						
Ap1	0–23	13.6	0.25	2.5	0.04	6.7	23.1	71
Ap2	23–33	12.0	0.27	2.9	0.06	9.1	24.3	63
Btg	33–66	7.6	0.35	4.3	0.05	2.6	14.9	82
Bg1	66–82	4.6	0.24	3.2	0.04	2.0	10.1	80
Bg2	82–112	3.5	0.21	2.5	0.04	1.1	7.4	85
Cg	112–138	2.5	0.18	1.9	0.02	0.7	5.3	86

Table 49. Bulk density of undisturbed samples (BD_{UD}), pH, contents of total organic carbon (Org. C) and total nitrogen (Total N), and concentrations of acid ammonium acetate-extractable phosphorus (P_{AAC}), potassium (K_{AAC}), calcium (Ca_{AAC}), magnesium (Mg_{AAC}) and sulfur (S_{AAC}) in the soil horizons of the pedon Maaninka 12.

Horizon	Depth (cm)	BD _{UD} (kg/l)	pH (H ₂ O)	Org. C	Total N	P _{AAC}	K _{AAC}	Ca _{AAC}	Mg _{AAC}	S _{AAC}
				(%)						
Ap1	0–23	1.20	6.1	5.61	0.36	6.8	96	2 004	246	13
Ap2	23–33	1.03	6.0	6.20	0.38	2.9	96	1 819	279	13
Btg	33–66	1.55	6.3	0.58	0.04	1.2	122	1 386	453	8.5
Bg1	66–82	1.38	6.5	0.53	0.03	2.1	107	859	375	7.4
Bg2	82–112	1.41	6.8	0.45	0.02	3.5	101	663	307	6.4
Cg	112–138	1.44	7.0	0.36	0.02	2.0	100	461	232	8.9

Table 50. Concentrations of acid oxalate-extractable aluminium (Al_{ox}) and iron (Fe_{ox}) oxides, total phosphorus (Total P) and hydrochloric acid-extractable phosphorus (P_{HCl}), potassium (K_{HCl}), calcium (Ca_{HCl}) and magnesium (Mg_{HCl}) in the soil horizons of the pedon Maaninka 12.

Horizon	Depth (cm)	Al_{ox}	Fe_{ox}	Total P (g/kg)	P_{HCl}	K_{HCl}	Ca_{HCl}	Mg_{HCl}
		(mg/kg)			(mg/l soil)			
Ap1	0–23	3 121	7 994	2.12	980	2 842	3 986	6 476
Ap2	23–33	4 122	10 411	1.92	755	3 152	3 227	6 553
Btg	33–66	1 332	7 852	0.73	535	5 075	2 518	8 206
Bg1	66–82	931	5 766	0.89	694	6 110	2 200	7 849
Bg2	82–112	650	4 885	1.05	801	5 476	2 133	7 047
Cg	112–138	597	3 322	1.01	786	4 925	2 019	6 360

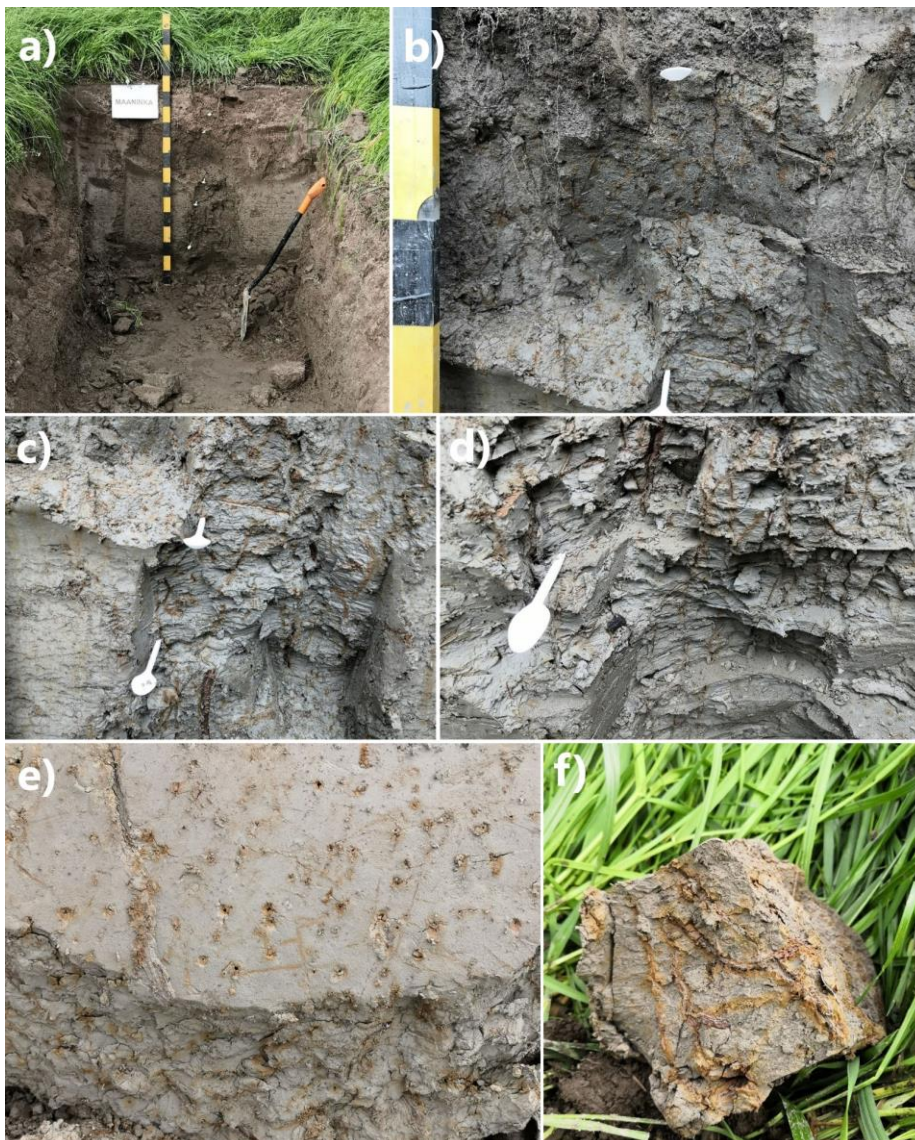


Figure 15. The Maaninka 12 pedon: Hämeensuo 3. General view of the soil profile (a). High clay content results in poor water permeability and predominantly gray colours in the soil matrix (b). The subsoil has a coarse prismatic structure (c). In the deeper subsoil (82– cm), the original sedimentation layers are visible (d). In the deepest horizon, there are plenty of previous root channels originating from the wetland plants before agricultural land use (e and f). Photos by Mari Rätty (Luke).

Maaninka 13: Hirsisuo

- Coordinates x=3516783, y=7005620 , k=93
- Day of inspection: 29 August, 2023
- Crop: grass (a mixture of timothy, meadow fescue, red clover, alsike clover)
- No groundwater observed
- Classification: Eutric Luvic **Planosols** (Epiclayic, Endoloamic, Aric, Drainic, Raptic)
- Short classification: Luvic Planosols

Even though the Finnish name of this field suggests that the area has originally been peatland, at least the investigated pedon at the edge of the field was clearly a mineral soil. The pedon is located about 5 m higher than the Hämeensuo pedons and no groundwater entered the soil pit even though the pedon was investigated on the same day as Hämeensuo 1 characterized by high groundwater level. Lower yields have been typical of this field, which may at least partly be attributed to the very or extremely firm consistence (Table 51).

This pedon is mostly characterized by clayic and loamic horizons but at 30–50 cm there is a layer of fine sand (Table 52, Figure 16), implying abrupt textural difference (-> Raptic qualifier). As usual, stagnic colour pattern is associated with the abrupt textural difference, justifying Planosols classification. Permeability to water is certainly very poor, associated to the very high silt concentration in the subsoil. Varving in the subsoil below 50 cm (sign of rock structure) indicates lack of pedoturbation and poor pedogenesis, which is typical of silty soils. Transport of soil material downwards was easily observed, indicated by the Luvic qualifier in the soil name.

The base saturation is quite high even in this fine sand horizon (84%, Table 53), bringing in the Eutric qualifier. In most fine sand materials of the Maaninka area, the base saturation has been much lower, which may suggest that the present pedon has not been intensively leached. The pedon had somewhat elevated organic C content in the topsoil and a low organic C content in the subsoil (Table 54), further contributing to the extremely hard consistence creating a barrier to root growth. The humic qualifier, requiring that the weighted average of organic C content at 0–50 cm is more than 1%, may formally be met but because the 20–30 cm horizon was not sampled and the 30–50 cm layer was very low in organic C, this qualifier is not mentioned in the soil name. Drainic stands for artificial drainage and Aric indicates ploughing.

Table 51. Morphological properties of the pedon Maaninka 13.

Horizon	Depth (cm)	Morphological description	Diagnostic features
Ap1	0–20	Dark grayish brown (10YR 4/2 moist) or light brownish gray (10YR 6/2 dry) (silty) clay. Moderate fine-to-coarse subangular blocky structure. Very firm consistence. Many roots. Clear smooth boundary.	Too light colours to be a mollic or umbric horizon
Ap2	20–30	Dark grayish brown (10YR 4/2 moist) (silty) clay. Moderate coarse prismatic structure parting to moderate coarse subangular blocky aggregates. Very firm consistence. Many roots. Abrupt smooth boundary.	Abrupt textural difference at the bottom
Bg	30–50	Brown (10YR 5/3) fine sand. No varving. Many medium prominent strong brown (7.5YR 5/6) pore linings. Faces of prismatic aggregates had a uniform grayish brown (2.5Y 5/2) colour with no mottles (illuvial material). Weak very coarse and incomplete prismatic structure parting to strong coarse angular blocky aggregates. Extremely firm consistence. Common roots on prism faces. Clear smooth boundary.	Abrupt textural difference at the bottom Stagnic colour pattern
BCg	50–75	Light brownish gray (2.5Y 6/2) silty clay loam. Thin light gray (5Y 7/1–2) layers between the varved matrix; the varving is somewhat diffuse. Common medium strong brown (7.5YR 5/6) pore linings and common medium prominent mottles ranging from dark reddish brown (5YR 4/4) to yellowish red (5YR 5/6). Faces of prismatic aggregates had a uniform grayish brown (2.5Y 5/2) colour with no mottles (illuvial material). Weak very coarse prismatic structure parting to moderate coarse platy aggregates (varves) and further to moderate medium to coarse angular blocky aggregates. Extremely firm consistence. Common roots on prism faces. Clear smooth boundary.	Luvic Stagnic colour pattern indicated by pore linings
Cg	75–110+	Gray (2.5Y 5/1) silt loam as 1–2 cm varves. Strong brown (7.5YR 4/6) sand layers (1–3 mm) between the varves. Moderate very coarse platy structure parting to weak medium angular blocky aggregates. Very firm consistence. No roots.	

Table 52. Particle size distribution in the soil horizons of the pedon Maaninka 13. The lower part of the plough layer (20–30 cm) was not sampled.

Horizon	Depth (cm)	Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	Total silt	Total sand	Finnish soil type
		(%)							
Ap1	0–20	45	20	14	19	3	34	21	HeS/HtS
Bg	30–50	0	0	0	99	0	1	99	KHt
BCg	50–75	30	67	2	1	0	68	2	HsS
Cg	75–110+	19	62	13	5	1	75	6	KHs

Particle size limits: Clay = <0.002 mm (“S”); Fine silt = 0.002–0.02 mm (“HHs + KHs”); Coarse silt = 0.02–0.06 mm (“HHt”); Fine sand = 0.06–0.2 mm (“KHt”); Coarse sand = 0.2–2 mm (“HHk + KHk”), representing medium and coarse sand fractions. Words in brackets are the Finnish abbreviations of the size fractions (based on Atterberg’s classification system).

Table 53. Potential cation exchange capacity (CEC), exchangeable calcium (Ca²⁺), potassium (K⁺), magnesium (Mg²⁺) and sodium (Na⁺), titratable acidity (Al³⁺+H⁺) and base saturation in the soil horizons of the pedon Maaninka 13. The lower part of the plough layer (20–30 cm) was not sampled.

Horizon	Depth (cm)	Ca	K	Mg	Na	Al+H	CEC (pH 7.0)	Base saturation (%)
		(cmol(+)/kg soil)						
Ap1	0–20	8.5	0.17	1.8	0.07	8.7	19.3	55
Bg	30–50	4.5	0.19	2.9	0.10	1.5	9.1	84
BCg	50–75	3.7	0.24	3.1	0.10	1.6	8.6	82
Cg	75–110+	2.5	0.22	2.1	0.09	1.0	6.0	83

Table 54. Bulk density of pre-treated samples (BD_{P-T}), pH, contents of total organic carbon (Org. C) and total nitrogen (Total N), and concentrations of acid ammonium acetate-extractable phosphorus (P_{AAc}), potassium (K_{AAc}), calcium (Ca_{AAc}), magnesium (Mg_{AAc}) and sulfur (S_{AAc}) in the soil horizons of the pedon Maaninka 13. The lower part of the plough layer (20–30 cm) was not sampled.

Horizon	Depth (cm)	BD _{P-T} (kg/l)	pH (H ₂ O)	Org. C	Total N	P _{AAc}	K _{AAc}	Ca _{AAc}	Mg _{AAc}	S _{AAc}
				(%)						
Ap1	0–20	1.29	5.3	4.46	0.27	4.2	50	1 326	172	12
Bg	30–50	1.48	5.7	0.33	<0.08	2.1	64	811	298	4.7
BCg	50–75	1.50	5.8	0.25	<0.08	2.0	63	544	249	5.3
Cg	75–110+	1.93	5.8	0.15	<0.08	2.4	66	551	215	8.4

Table 55. Concentrations of acid oxalate-extractable aluminium (Al_{ox}) and iron (Fe_{ox}) oxides, total phosphorus (Total P) and hydrochloric acid-extractable phosphorus (P_{HCl}), potassium (K_{HCl}), calcium (Ca_{HCl}) and magnesium (Mg_{HCl}) for the pedon Maaninka 13. The lower part of the plough layer (20–30 cm) was not sampled.

Horizon	Depth (cm)	Al _{ox}	Fe _{ox}	Total P (g/kg)	P _{HCl}	K _{HCl}	Ca _{HCl}	Mg _{HCl}
		(mg/kg)						
Ap1	0–20	2 346	6 630	1.36	905	1 902	3 797	5 499
Bg	30–50	797	5 973	0.71	774	2 825	3 116	5 891
BCg	50–75	731	6 136	0.82	825	3 216	2 964	5 725
Cg	75–110+	491	4 104	0.96	1 128	2 699	3 301	4 140

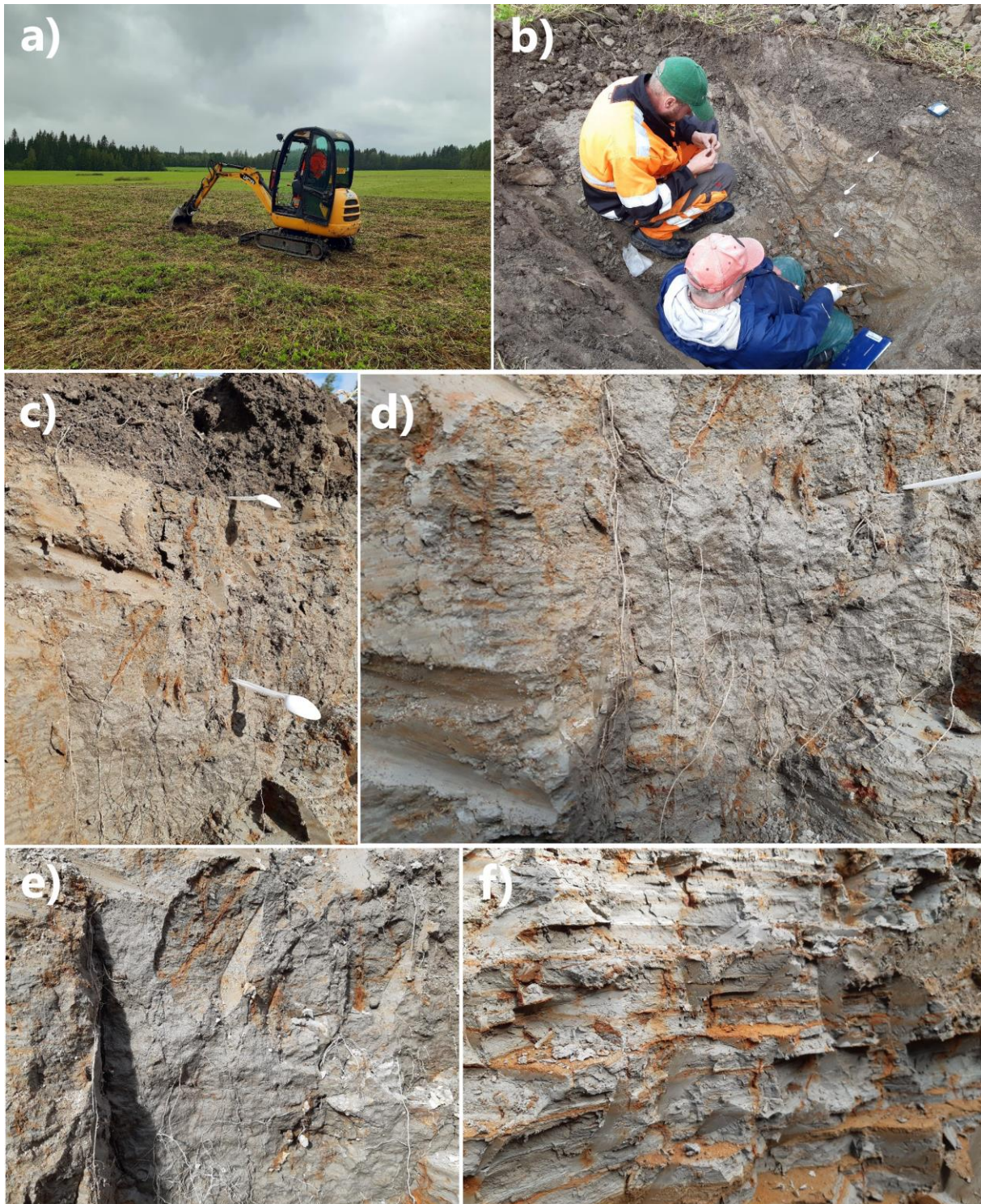


Figure 16. The Maaninka 13 pedon: Hirsisuo. General view of the field (a). From a distance, only the dark plough layer and the light-coloured subsoil can be distinguished (b). Right below the plough layer, there is a brownish layer of pure fine sand (c). Deeper in the soil, there are desiccation cracks that have a coating of illuvial material (d). The subsoil below 75 cm is clearly varved composed of gray clayic and brown very thin sandy layers (e and f). Photos by Mari Rätty (Luke).

4.4. Anttila field

The Anttila field is located across the Lake Maaninka from the research station. It has recently been occupied by GHG studies (OrmiNurmi project). Three soil profiles were studied in the very same field (Figure 17 and 18) because the topography is undulating and the field is known to be heterogeneous. One more pedon on top of a drumlin next to the GHG field was also investigated.



Figure 17. Locations of the four pedons investigated in the Anttila field. The pedons 14–16 represent the Anttila Välipelto field plot (6.1 ha) and the pedon 17 the Pihapelto field plot (7.06 ha).

All three soil profiles of the GHG field had a 26-cm brown plough layer (Tables 56, 62, 68). The field has obviously never been ploughed deeper because the next horizon did not show any sign of topsoil and subsoil material mixed together by deep ploughing.

The textures of all three pedons were dominated by silt, the clay fraction being the largest only in two out of the 18 horizons in the three soils. Even though all soils contained appreciable amounts of fine sand, coarser fractions were practically absent (Tables 57, 63, 69). The textures can generally be characterized as rather fine, likely associated with poor downward water conductivity. Even though groundwater was observed only in the lowermost soil pit (Anttila 2), it is obvious that rain and snowmelt water from above keep the subsoil matrix saturated with water for a considerable time of the year. This stagnation of water results in alternating reduced and oxidized conditions and the formation of redox concentrations characterized by rust precipitates, and associated redox depletions, characterized by gray colours. Oxygen enters the subsoil through previous root channels which are often stabilized by cemented iron hydroxide precipitates. The oxic soil is limited to the vicinity of the root channel while the pores in the soil matrix are so small that they are full of water for most parts of the year.

A common feature in the subsoil of all three profiles was the gray matrix and brownish precipitates. The horizon right below the plough layer has been subjected to frost which has caused soil disturbance and homogenization. The old root channels in this horizon were not characterized by rusty pore linings but the redox concentrations were distributed throughout

the soil matrix. Instead, in the deeper horizons the previous root channels had pronounced rusty pore linings, while the surrounding soil matrix was gray, indicating reduced conditions. The soils also contained thin (<1 mm) brownish horizontal sandy layers between the layers of more fine textured material, which were gray in colour. The brown colours indicate oxic conditions and the gray colours indicate long-term reducing conditions, resulting in the dissolution of iron hydroxides, or preventing their formation to start with. It is obvious that in these soils lateral water movement may be easier than the vertical one.

Another interesting feature of all three pedons is that all of them had abundant accumulation of illuvial material that had attached to the surfaces of desiccation cracks as continuous coatings. Illuvial soil material, most often clay, has been detached from the plough layer and moved downwards in the cracks and other pores. Part of this illuvial material is leached out of the soil through subsurface drainage pipes. When water movement has stopped, owing to dryness, poor permeability or saturation of the lower horizons, the soil material in the pore water has attached to the crack surfaces. In morphological descriptions, this feature is indicated with the suffix "t" in the horizon abbreviations of the morphological descriptions.

None of the plough layers were dark enough to qualify as a mollic or an umbric horizon, even though the plough layers were rather high in organic C. It is typical that in soils dominated by clay and silt fractions the dry colour is commonly too light for an umbric or mollic horizon.

The three soils of the GHG field were divided into two different major categories of the WRB system: Stagnosols and Gleysols, which may sound confusing. However, both classes indicate the wetness of the soil. In the Gleysol, which in this field occurred at the lowermost corner (Anttila 2), wetness is caused by the high groundwater. The high groundwater can be replenished by the lateral water flow from the upslope, augmented by the thin sandy layers and platy structure in the subsoil. In Stagnosols (Anttila 1 and 3), excess water originates from above and stagnates in the soil profile because of the low water permeability. Moreover, both Stagnosols got the Bathyglyeyic attribute indicating that they had gleyic characteristics below 100 cm.

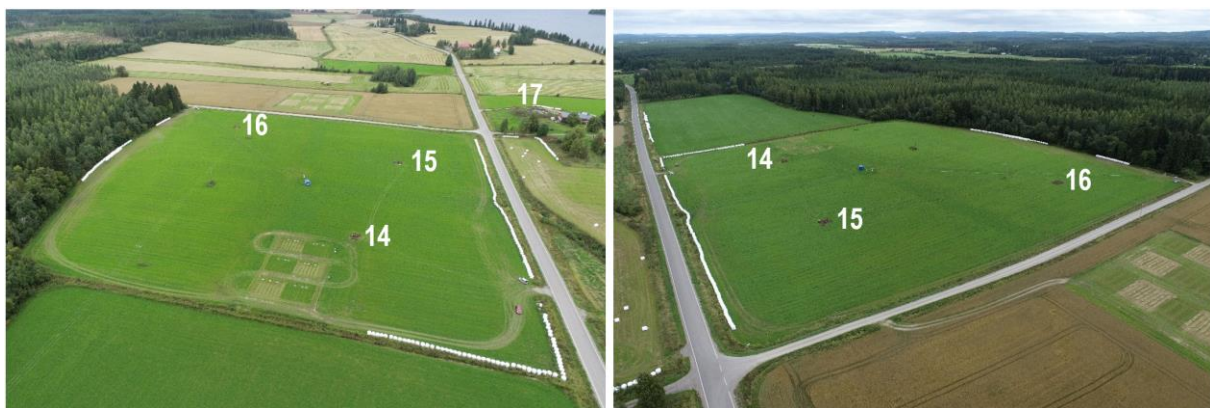


Figure 18. Locations of the pedons 14, 15 and 16 investigated in the Anttila Välipelto field plot, and the pedon 17 in the Pihapelto field plot. Photos by Panu Korhonen (Luke).

Maaninka 14: Anttila 1

- Coordinates: x=3516120, y=7004600, k= 90
- Day of inspection: 6 September, 2022
- Crop: Timothy – red clover
- No groundwater observed
- Classification: Epidystric Endoeutric Luvic Bathyglyeyic **Stagnosols** (Siltic, Endoclayic, Aric, Drainic, Humic, Raptic)
- Short classification: Gleyic Stagnosols

The Anttila 1 pedon was in the central part of the field and it may be the most representative for the largest part of the field. Even though no groundwater was observed, the wetness of the pedon is reflected as the abundance of redox concentrations throughout the pedon starting right below the plough layer (Table 56, Figure 19). The heavy clay horizon below 111 cm (Table 57) has contributed to low conductivity and formation of the stagnic colour pattern.

Table 56. Morphological properties of the pedon Anttila 14.

Horizon	Depth (cm)	Morphological description	Diagnostic features
Ap	0–26	Dark brown (7.5YR 3/3 moist) or light yellowish brown (10YR 6/4 dry) silt loam. Moderate coarse subangular blocky structure parting to moderate fine (sub)angular blocky aggregates. Friable consistence. Common fine and medium roots. Common worm channels. Clear smooth boundary.	The dry colour is too light for a mollic horizon.
Bw	26–36	This horizon has not been subjected to deep ploughing. Dark yellowish brown (10YR 4/4) and light olive brown (2.5Y 5/3) silt loam. Common fine brown (7.5Y 4/3) mottles (redox concentrations). Moderate coarse angular blocky structure parting to moderate very fine angular blocky aggregates. Friable consistence. Common fine roots. Common worm channels. Clear smooth boundary.	
Bt	36–56	Brown (10YR 4/3) and light olive brown (2.5Y 5/3) silt loam. Common large grayish brown (2.5Y 5/2) redox depletions and few medium brown (7.5YR 4/4) redox concentrations. Few illuvial clay coatings on desiccation crack surfaces in the lower part of the horizon. Moderate medium angular blocky structure parting to moderate fine angular blocky aggregates. Friable or firm consistence. Few fine roots. Common worm channels. Clear smooth boundary.	Stagnic properties Luvic?
2Bw2	56–81	Brown (10YR 4/3) and yellowish brown (10YR 5/4) loam. Common large light olive brown (2.5Y 5/3) redox depletions. Plenty of shiny mica particles. Moderate medium platy structure parting to weak large angular blocky aggregates. Friable consistence. No roots. Common worm channels. Abrupt smooth boundary.	Abrupt textural difference at the bottom
3BCtg	81–111	Grayish brown (2.5Y 5/2) silty clay loam. Common to many dark yellowish brown (10YR 4/4) redox concentrations. Light yellowish brown (2.5Y 6/3) coatings of illuvial clay on incomplete prism faces (desiccation cracks) throughout the horizon. Moderate or strong medium (incomplete) prismatic aggregates parting to strong medium angular blocky aggregates. Firm (or sticky) consistence. No roots. Gradual smooth boundary.	Luvic Stagnic properties
3BCg	111–144+	Grayish brown (2.5Y 5/2), brown (10YR 4/3) and reddish gray (5YR 5/2; strange colour, occurring as a ca. 5 cm broad band in the upper part of the horizon) (silty) clay. Many medium brown (7.5YR 4/4) redox concentrations. Massive structure. Sticky consistence. No roots.	Gleyic properties

The following diagnostic features were identified or considered in the Anttila 1 pedon:

- Abrupt textural difference/ lithic discontinuity at 81 cm. This is not close enough (<75 cm) from mineral soil surface to allow Planosols classification.
- Stagnic colour pattern below 36 cm -> Stagnosols.
- Gleyic colour pattern starting at 111 cm -> Not close enough (<75 cm) to soil surface to be diagnostic for the Gleyic qualifier but Bathyglyeyic can be used (indicates the depth of 100–200 cm).
- Textural qualifiers Siltic and Endoclayic
- Abundant illuvial clay at 81–111 cm (within 100 cm of soil surface) -> Luvic
- Weighted average of organic C content at 0–50 cm = 1.9% (Table 58) -> Humic (>1%)
- Base saturation at 20–100 cm as a weighted average 51% (Table 59). In principle, this outcome yields the Eutric qualifier. However, the topmost horizons are clearly dystric and only the horizons below 81 cm are clearly eutric. This discrepancy is expressed by two qualifiers: Epidystric, Endoeutric
- Lithic discontinuity at 81 cm -> Raptic
- Ploughed -> Aric
- Artificial drainage -> Drainic

Table 57. Particle size distribution in the soil horizons of the pedon Maaninka 14.

Horizon	Depth (cm)	Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	Total silt	Total sand	Finnish soil type
		(%)							
Ap	0–26	20	28	25	21	6	53	27	HHT
Bw	26–36	16	25	26	26	7	51	33	HHT/KHT
Bt	36–56	16	23	29	30	2	52	32	KHT
2Bw2	56–81	13	16	33	37	1	49	38	KHT
3BCtg	81–111	35	33	20	11	1	53	12	HeS
3BCg	111–144	63	26	7	3	1	33	4	AS

Particle-size limits: Clay = <0.002 mm (“S”); Fine silt = 0.002–0.02 mm (“HHs + KHs”); Coarse silt = 0.02–0.06 mm (“HHT”); Fine sand = 0.06–0.2 mm (“KHT”); Coarse sand = 0.2–2 mm (“HHk + KHk”), representing medium and coarse sand fractions. Words in brackets are the Finnish abbreviations of the size fractions (based on Atterberg’s classification system).

Table 58. Bulk density of undisturbed samples (BD_{UD}) and measured from pre-treated samples (BD_{P-T}) samples, pH and contents of total organic carbon (Org. C) and total nitrogen (Total N) in the soil horizons of the pedon Maaninka 14.

Horizon	Depth (cm)	BD _{UD} (kg/l)	BD _{P-T} (kg/l)	pH (H ₂ O)	Org. C	Total N
					(%)	
Ap	0–26	1.33	1.00	5.8	3.11	0.17
Bw	26–36	1.37	1.14	5.7	1.00	<0.08
Bt	36–56	1.48	1.17	5.7	0.40	<0.08
2Bw2	56–81	1.80	0.94	5.9	0.17	<0.08
3BCtg	81–111	1.29	0.98	5.6	0.46	<0.08
3BCg	111–144	1.48	0.90	6.3	0.42	<0.08

Table 59. Potential cation exchange capacity (CEC), exchangeable calcium (Ca²⁺), potassium (K⁺), magnesium (Mg²⁺) and sodium (Na⁺), titratable acidity (Al³⁺+H⁺) and base saturation in the soil horizons of the pedon Maaninka 14.

Horizon	Depth (cm)	Ca	K	Mg	Na	Al+H	CEC (pH 7.0)	Base saturation (%)
		(cmol(+)/kg soil)						
Ap	0–26	5.3	0.07	0.76	0.03	7.7	13.9	45
Bw	26–36	3.0	0.06	0.55	0.05	5.9	9.5	38
Bt	36–56	1.9	0.07	0.51	0.05	4.3	6.8	37
2Bw2	56–81	2.6	0.07	0.93	0.04	3.0	6.6	54
3BCtg	81–111	5.6	0.21	3.7	0.11	3.7	13.3	72
3BCg	111–144	8.0	0.38	5.7	0.19	4.0	18.3	78

Table 60. Concentrations of acid ammonium acetate-extractable phosphorus (P_{AAc}), potassium (K_{AAc}), calcium (Ca_{AAc}), magnesium (Mg_{AAc}) and sulfur (S_{AAc}) in the soil horizons of the pedon Maaninka 14.

Horizon	Depth (cm)	P _{AAc}	K _{AAc}	Ca _{AAc}	Mg _{AAc}	S _{AAc}
		(mg/l soil)				
Ap	0–26	3.0	42	1 100	110	8.3
Bw	26–36	2.9	45	700	84	10
Bt	36–56	2.0	44	490	87	8.3
2Bw2	56–81	2.2	77	1 000	370	5.7
3BCtg	81–111	4.2	77	990	350	4.5
3BCg	111–144	2.4	140	1 600	660	2.9

Table 61. Concentrations of acid oxalate-extractable aluminium (Al_{ox}) and iron (Fe_{ox}) oxides, total phosphorus (Total P) and hydrochloric acid-extractable phosphorus (P_{HCl}), potassium (K_{HCl}), calcium (Ca_{HCl}) and magnesium (Mg_{HCl}) in the soil horizons of the pedon Maaninka 14.

Horizon	Depth (cm)	Al _{ox}	Fe _{ox}	Total P (g/kg)	P _{HCl}	K _{HCl}	Ca _{HCl}	Mg _{HCl}
		(mg/kg)			(mg/l soil)			
Ap	0–26	1 821	9 393	1.26	520	1 600	3 100	4 600
Bw	26–36	1 848	13 897	1.18	590	1 700	2 300	4 500
Bt	36–56	1 115	5 228	1.14	530	1 500	3 200	4 700
2Bw2	56–81	620	3 928	1.20	570	2 300	2 500	5 700
3BCtg	81–111	1 220	9 913	1.17	500	1 800	2 300	5 000
3BCg	111–144	1 491	9 130	1.09	370	2 500	1 700	5 200



Figure 19. The Maaninka 14 pedon; Anttila 1. As usual, the soil had brownish colours in the upper horizons and grayish colours deeper in the soil profile (a). The desiccation cracks in the subsoil were covered with a continuous gray layer of illuvial material transported from above (b). Photos by Mari Rätty (Luke).

Maaninka 15: Anttila 2

- Coordinates: x=3512018, y=7006861, k= 88
- Day of inspection: 6 September, 2022
- Crop: Timothy – red clover
- Groundwater at 143 cm
- Classification: Dystric **Gleysols** (Loamic, Bathyclayic, Luvic, Aric, Drainic, Humic)
- Short classification: Dystric Gleysols

The Anttila 2 pedon is in the lowermost corner of the GHG monitoring field, a few meters lower than Anttila 1. The clayey horizons and the position in lowest corner of the field explain the gleyic colour pattern (Table 62, Figure 20). The soil has a loamy texture in the uppermost horizons that turns first to clay loam and at 125 cm to clay (Table 63). This pedon has the highest organic C content in the topsoil within the Anttila field. The lowest horizons (95–155 cm) have a surprisingly high organic C content (1.8%, Table 64), which together with pore linings in ancient root channels suggest that the horizons currently deep in the subsoil have at some stage hosted plenty of biological activity. The plastic consistence below 95 cm suggests that this site has been a wetland, and those horizons have never dried out, confirmed by the massive structure below 125 cm (Table 62). Taken into the account the relatively fine texture, the base saturation (Table 65) is surprisingly low, particularly so in the horizons that had the highest clay contents (95–155 cm), which is against the common observations.

Table 62. Morphological properties of the pedon Maaninka 15.

Horizon	Depth (cm)	Morphological description	Diagnostic features
Ap	0–26	Dark brown (7.5YR 3/3 moist) or light brown (7.5YR 6/3 dry) loam. Moderate coarse subangular blocky structure parting to moderate fine and medium (sub)angular blocky aggregates. Friable consistence. Many fine roots. Abrupt smooth boundary.	Dry colour is too light for a mollic horizon.
Bg1	26–46	Grayish brown (2.5Y 5/2) silt loam. Common medium dark yellowish brown (10YR 4/6) horizontal mottles redox concentrations. No pore linings in previous root channels. Moderate coarse or medium prismatic structure. Friable consistence. Common fine roots. Clear smooth boundary.	Gleyic properties
Btg1	46–63	Grayish brown (2.5Y 5/2) silt loam. Common large dark yellowish brown (10YR 4/6) redox concentrations as pore linings at distances of 3-5 cm while there are no redox concentrations in the soil matrix between the previous root channels. Few small gray (5Y 5/1) redox depletions. Illuvial clay coatings on prism faces. Very coarse structure consisting of incomplete prismatic aggregates. Friable or firm consistence. Few fine roots. Clear smooth boundary.	Gleyic properties Luvic?
Bg2	63–95	Grayish brown (2.5Y 5/2) silt loam. Common medium brown (7.5YR 4/4) redox concentrations as pore linings; many partly cemented pipe stems. Few small gray (5Y 5/1) redox depletions within the root channels. Common shiny mica particles. Massive structure, or weak structure consisting of incomplete prismatic aggregates. Friable consistence. Few fine roots. Clear smooth boundary.	Gleyic properties Abrupt textural difference at the bottom
2Btg2	95–125	Dark grayish brown (2.5Y 4/2) and light olive brown (2.5Y 5/3) silty clay loam. Common medium brown (7.5YR 4/4) redox concentrations and common large gray (5Y 5/1) redox depletions in previous root channels; no cementation. Illuvial clay on prism faces. Weak very coarse structure consisting of (incomplete) prismatic aggregates. Plastic consistence. Very few fine roots. Gradual smooth boundary.	Luvic Gleyic properties
2Cg	125–155+	Dark gray (5Y 4/1) (silty) clay. Few medium brown (7.5YR 4/4) redox concentrations as cemented pipe stems. Few black stripes. Massive structure. Plastic consistence. No roots.	Gleyic properties

The following diagnostic features were identified or considered in the Anttila 2 pedon:

- Gleyic properties starting at 26 cm -> Gleysols
- Illuvial clay at 95–125 cm (within 100 cm of soil surface) -> Luvic
- Base saturation at 20–100 cm = 48% --> Dystric
- Textural qualifier: Loamic, Bathyclayic
- Ploughing -> Aric
- Artificial drainage -> Drainic
- Organic C content at 0–50 cm = 3.9% (>1%) -> Humic

Table 63. Particle size distribution in the soil horizons of the pedon Maaninka 15.

Horizon	Depth (cm)	Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	Total silt	Total sand	Finnish soil type
Ap	0–26	29	24	22	18	7	46	25	He
Bg1	26–46	25	30	26	18	1	56	19	He
Btg1	46–63	24	29	33	14	0	62	14	He
Bg2	63–95	22	24	34	20	0	58	20	HHT
2Btg2	95–125	37	37	18	7	1	55	8	HeS
2Cg	125–155	42	38	15	4	1	53	5	HsS

Particle-size limits: Clay = <0.002 mm ("S"); Fine silt = 0.002–0.02 mm ("HHs + KHs"); Coarse silt = 0.02–0.06 mm ("HHT"); Fine sand = 0.06–0.2 mm ("KHT"); Coarse sand = 0.2–2 mm ("HHk + KHk"), representing medium and coarse sand fractions. Words in brackets are the Finnish abbreviations of the size fractions (based on Atterberg's classification system).

Table 64. Bulk density of undisturbed samples (BD_{UD}) and measured from pre-treated samples (BD_{P-T}), pH and contents of total organic carbon (Org. C) and total nitrogen (Total N) in the soil horizons of the pedon Maaninka 15.

Horizon	Depth (cm)	BD_{UD} (kg/l)	BD_{P-T} (kg/l)	pH (H ₂ O)	Org. C	Total N
					(%)	
Ap	0–26	1.03	0.85	5.4	6.28	0.41
Bg1	26–46	1.29	0.91	5.6	1.52	0.10
Btg1	46–63	1.37	0.95	5.6	0.76	<0.08
Bg2	63–95	1.32	0.95	5.4	0.62	<0.08
2Btg2	95–125	0.71	0.63	5.3	2.16	0.19
2Cg	125–155	-	0.63	5.0	1.51	0.14

Table 65. Potential cation exchange capacity (CEC), exchangeable calcium (Ca^{2+}), potassium (K^+), magnesium (Mg^{2+}) and sodium (Na^+), titratable acidity ($Al^{3+} + H^+$) and base saturation in the soil horizons of the pedon Maaninka 15.

Horizon	Depth (cm)	Ca	K	Mg	Na	Al+H	CEC (pH 7.0)	Base saturation
							(cmol(+)/kg soil)	
Ap	0–26	5.0	0.18	0.73	0.06	13.2	19.1	31
Bg1	26–46	3.6	0.15	0.82	0.05	6.1	10.7	43
Btg1	46–63	3.8	0.11	1.32	0.04	4.5	9.8	54
Bg2	63–95	2.9	0.11	1.58	0.04	4.1	8.7	53
2Btg2	95–125	3.2	0.26	1.82	0.14	9.4	14.8	36
2Cg	125–155	2.3	0.26	1.42	0.13	8.1	12.2	33

Table 66. Concentrations of acid ammonium acetate-extractable phosphorus (P_{AAC}), potassium (K_{AAC}), calcium (Ca_{AAC}), magnesium (Mg_{AAC}) and sulfur (S_{AAC}) in the soil horizons of the pedon Maaninka 15.

Horizon	Depth (cm)	P_{AAC}	K_{AAC}	Ca_{AAC}	Mg_{AAC}	S_{AAC}
		(mg/l soil)				
Ap	0–26	6.6	69	920	110	20
Bg1	26–46	2.7	69	670	100	10
Btg1	46–63	1.8	52	740	150	6.9
Bg2	63–95	1.9	54	590	170	9.7
2Btg2	95–125	5.1	67	440	130	17
2Cg	125–155	4.8	75	340	110	23

Table 67. Concentrations of acid oxalate-extractable aluminium (Al_{ox}) and iron (Fe_{ox}) oxides, total phosphorus (Total P) and hydrochloric acid-extractable phosphorus (P_{HCl}), potassium (K_{HCl}), calcium (Ca_{HCl}) and magnesium (Mg_{HCl}) in the soil horizons of the pedon Maaninka 15.

Horizon	Depth (cm)	Al_{ox}	Fe_{ox}	Total P (g/kg)	P_{HCl}	K_{HCl}	Ca_{HCl}	Mg_{HCl}
		(mg/kg)			(mg/l soil)			
Ap	0–26	3 923	5 092	1.99	630	1 600	2 700	4 300
Bg1	26–46	1 256	3 294	0.94	450	2 400	2 600	5 500
Btg1	46–63	1 010	4 388	1.03	430	2 400	2 600	5 400
Bg2	63–95	961	4 182	1.15	420	2 500	2 400	5 100
2Btg2	95–125	1 540	11 002	1.51	700	1 700	3 400	4 700
2Cg	125–155	1 346	6 639	1.11	460	2 100	1 600	4 400

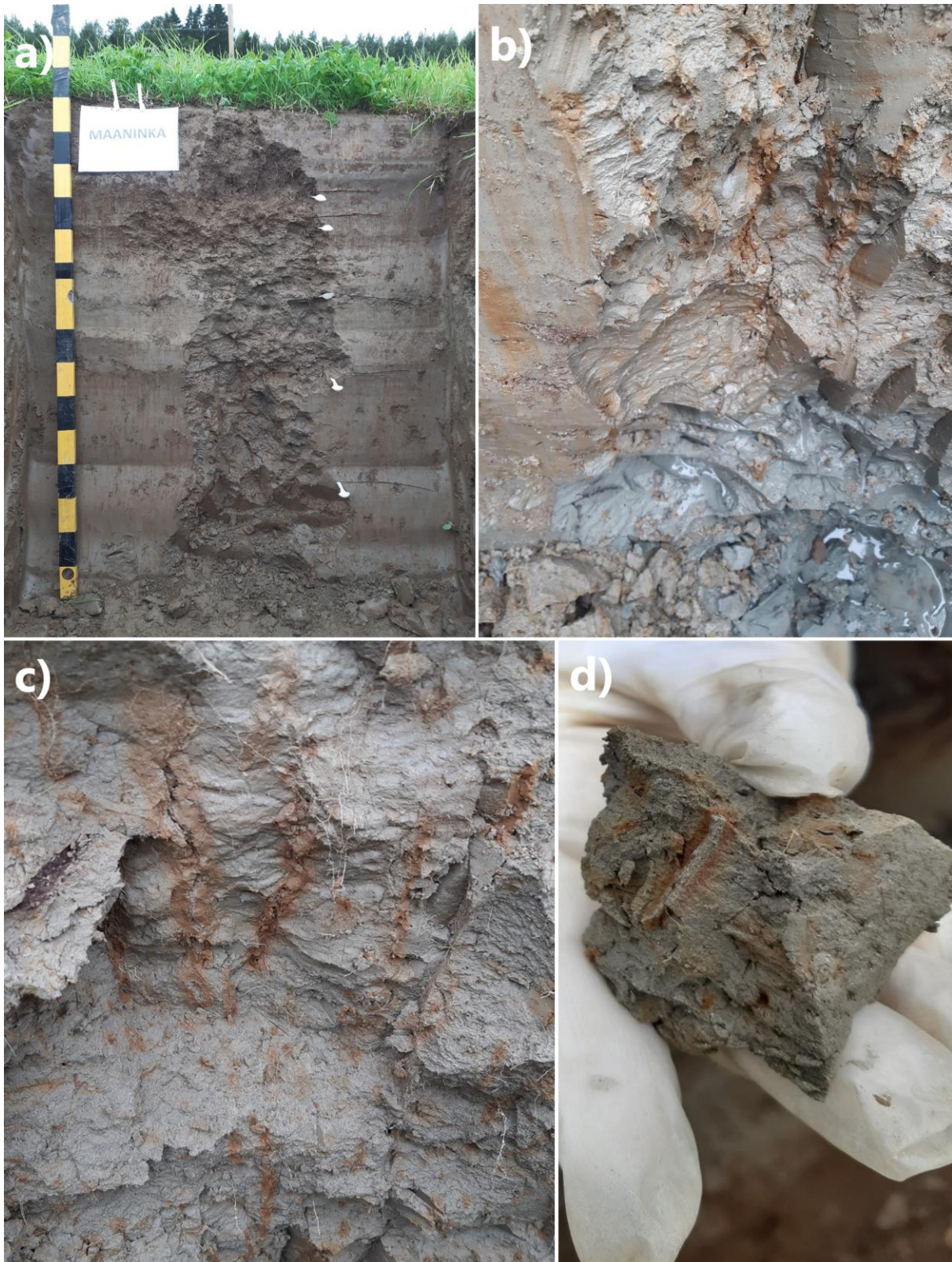


Figure 20. The Maaninka 15 pedon; Anttila 2. A general view of the soil profile (a), where the colours change from predominantly brown to uniform bluish-gray (b). The brown pore linings are prominent in the subsoil (c). A detailed view of the previous root channel with brown pore linings and gray interior (d). Photos by Mari Rätty (Luke).

Maaninka 16: Anttila 3

- Coordinates: x=3511894, y=7006771, k= 92
- Day of inspection: 7 September, 2022
- No groundwater observed
- Crop: Timothy – red clover
- Classification: Eutric Luvic Bathyglyeyic **Stagnosols** (Epiclayic, Endoloamic, Aric, Drainic, Raptic)
- Short classification: Gleyic Stagnosols

The Anttila 3 pedon is in the uppermost corner of the GHG monitoring field. It is about 2 m higher than Anttila 1 and 4 m higher than Anttila 4. The stagnic colour pattern prevails in the soil right below the plough layer (Table 68, Figure 21) and is indicative of the poor pore system. The soil has an extremely firm consistence below the plough layer, which may explain the observation that recent roots were almost lacking in the subsoil below 37 cm. Silt and clay are the dominant particle size classes (Table 69) but the textural sequence of this soil is rarely met. Here, the texture becomes coarser with depth, the clay percentage dropping from 30–53% to 13–16%, and the soil is clay loam at 0–123 cm and silt loam underneath. Very low (<0.5%) content of organic C starting right below the plough layer certainly contributes to the low conductivity and poor root growth. Even though this pedon has the highest position within the GHG field, it receives water from the adjacent forested areas still higher in the landscape. This pedon has a pronounced varved rock structure below 62 cm where the thin brown sandy layers between the gray fine-textured layers certainly contribute to the lateral water movement towards the lower positions in the landscape. Contrary to the other two pedons in the same field, Anttila 3 had a substantially higher base saturation, clearly justifying the Eutric attribute.

Table 68. Morphological properties of the pedon Maaninka 16.

Horizon	Depth (cm)	Morphological description	Diagnostic features
Ap	0–26	Brown (7.5YR 4/3 moist) or light brown (7.5YR 6/3–4 dry) clay loam. Moderate medium subangular blocky structure parting to moderate medium and fine subangular blocky and granular aggregates. Firm consistence. Common fine roots. Abrupt smooth boundary.	The colours are too light for a mollic horizon.
Bw1	26–37	Yellowish brown (10YR 5/4) clay loam. Common medium strong brown (7.5YR 4/6) redox concentrations and common large light olive brown (2.5Y 5/3) redox depletions. No pore linings. Moderate coarse prismatic structure parting to moderate coarse platy and further to strong medium and coarse angular blocky aggregates. The prisms (desiccation cracks?) extend throughout the horizon. Extremely firm consistence. Few fine roots. Gradual smooth boundary.	Stagnic properties
Bw2	37–62	Dark yellowish brown (10YR 4/4) (silty) clay. Few medium (strong) brown (7.5YR 4/4–6) redox concentrations and common small light yellowish brown (10YR 6/4) redox depletions. Few brown (10YR 5/3) illuvial clay coatings on prism faces. No pore linings. Moderate coarse prismatic structure parting to moderate coarse platy and further to strong medium and coarse angular blocky aggregates. Very firm consistence. Very few fine roots. Clear smooth boundary.	Stagnic properties Luvic?
BCtg	62–123	Light olive brown (2.5Y 5/4) and light yellowish brown (2.5Y 6/4) strata of silty clay loam, 1 mm and 3 mm, respectively. Common medium dark yellowish brown (10YR 6/4) redox concentrations as pore linings. Continuous dark yellowish brown (10YR 6/4) illuvial material on surfaces of horizontal sedimentation layers and brown (7.5YR 5/4) illuvial material as continuous coatings on prism faces. Common shiny mica particles in the sand strata. Rock structure (medium and coarse platy layers) with some desiccation cracks (incomplete prismatic aggregates). Friable consistence. No roots. Clear smooth boundary.	Luvic
BCg	123–155	Light olive brown (2.5Y 5/4) and grayish brown (2.5Y 5/2) strata of silt loam. Common medium brown (7.5YR 4/4) redox concentrations as pore linings in previous root channels; rock structure consisting of moderate coarse platy layers splitting to medium platy layers formed by the sedimentation. Friable consistence. No roots. Gradual smooth boundary.	Gleyic properties
Cg	155–170+	Light olive brown to light yellowish brown (2.5Y 5/3–6/4) silt loam as strata of 2 cm and dark reddish brown (5YR 2.5/2) sand mostly as 1–3 mm thin strata but occasionally with thicker pockets. Many mica particles in the sand strata. Brown (7.5YR 4/4) and dark yellowish brown (10YR 3/6) colours occur in the sand strata. Few strong brown (7.5YR 4/6) redox concentrations as pore linings in partly cemented previous root channels. Rock structure consisting of moderate coarse platy structure formed by the sedimentation layers. The layers fold easily along the sand strata. Friable consistence. No roots.	Gleyic properties

The following diagnostic features were identified or considered in the Anttila 3 pedon:

- Stagnic colour pattern (>50%) closer than 60 cm from mineral soil surface. -> Stagnosols
- Gleyic colour pattern starting at 123 cm -> Not close enough (<75 cm) to soil surface to be diagnostic for the Gleyic qualifier, but Bathyglyeyic can be used.
- Abundant illuvial clay at 62–123 cm (within 100 cm of soil surface) -> Luvic
- Base saturation >50% -> Eutric
- Texture becomes coarser upon depth (which is an exceptional situation), lithic discontinuity at 62 cm -> Raptic
- Textural qualifier Loamic (the clayic horizon at 37–62 cm is waived)
- Artificial drainage: Drainic
- Ploughed -> Aric

Table 69. Particle size distribution in the soil horizons of the pedon Maaninka 16.

Horizon	Depth (cm)	Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	Total silt	Total sand	Finnish soil type
Ap	0–26	30	18	17	31	4	35	35	HtS
Bw1	26–37	35	27	18	17	3	45	20	HeS
Bw2	37–62	53	26	11	9	1	37	10	HeS
BCtg	62–123	37	51	9	2	1	60	3	HsS
BCg	123–155	16	27	35	20	2	62	22	HHT
Cg	155–170	13	25	38	23	1	63	24	HHT

Particle-size limits: Clay = <0.002 mm ("S"); Fine silt = 0.002–0.02 mm ("HHs + KHs"); Coarse silt = 0.02–0.06 mm ("HHT"); Fine sand = 0.06–0.2 mm ("KHT"); Coarse sand = 0.2–2 mm ("HHk + KHk"), representing medium and coarse sand fractions. Words in brackets are the Finnish abbreviations of the size fractions (based on Atterberg's classification system).

Table 70. Bulk density of undisturbed samples (BD_{UD}) and measured from pre-treated samples (BD_{P-T}), pH and contents of total organic carbon (Org. C) and total nitrogen (Total N) in the soil horizons of the Maaninka 16.

Horizon	Depth (cm)	BD _{UD} (kg/l)	BD _{P-T} (kg/l)	pH (H ₂ O)	Org. C	Total N
					(%)	
Ap	0–26	1.39	0.99	5.7	4.01	0.23
Bw1	26–37	1.77	1.15	6.1	0.41	<0.08
Bw2	37–62	1.64	1.02	6.6	0.30	<0.08
BCtg	62–123	1.58	0.90	6.8	0.26	<0.08
BCg	123–155	1.68	1.16	6.7	<0.12	<0.08
Cg	155–170	-	1.16	6.7	<0.12	<0.08

Table 71. Potential cation exchange capacity (CEC), exchangeable calcium (Ca²⁺), potassium (K⁺), magnesium (Mg²⁺) and sodium (Na⁺), titratable acidity (Al³⁺+H⁺) and base saturation in the soil horizons of the pedon Maaninka 16.

Horizon	Depth (cm)	Ca	K	Mg	Na	Al+H	CEC (pH 7.0)	Base saturation (%)
		(cmol(+)/kg soil)						
Ap	0–26	7.9	0.18	1.7	0.06	8.7	18.5	53
Bw1	26–37	5.7	0.17	3.2	0.09	3.1	12.3	75
Bw2	37–62	6.9	0.27	5.4	0.17	1.9	14.7	87
BCtg	62–123	5.1	0.19	4.1	0.13	1.5	11.0	86
BCg	123–155	3.1	0.11	2.1	0.06	0.5	5.9	91
Cg	155–170	3.1	0.16	1.9	0.09	1.1	6.2	83

Table 72. Concentrations of acid ammonium acetate-extractable phosphorus (P_{AAC}), potassium (K_{AAC}), calcium (Ca_{AAC}), magnesium (Mg_{AAC}) and sulfur (S_{AAC}) in the soil horizons of the pedon Maaninka 16.

Horizon	Depth (cm)	P _{AAC}	K _{AAC}	Ca _{AAC}	Mg _{AAC}	S _{AAC}
		(mg/l soil)				
Ap	0–26	5.3	78	1 400	190	14
Bw1	26–37	2.6	88	1 300	430	7.8
Bw2	37–62	<1.5	120	1 600	750	6.4
BCtg	62–123	<1.5	85	1 100	510	<2.9
BCg	123–155	<1.5	64	760	320	3.9
Cg	155–170	<1.5	62	710	250	4.6

Table 73. Concentrations of acid oxalate-extractable aluminium (Al_{ox}) and iron (Fe_{ox}) oxides, total phosphorus (Total P) and hydrochloric acid-extractable phosphorus (P_{HCl}), potassium (K_{HCl}), calcium (Ca_{HCl}) and magnesium (Mg_{HCl}) in the soil horizons of the pedon Maaninka 16.

Horizon	Depth (cm)	Al _{ox}	Fe _{ox}	Total P (g/kg)	P _{HCl}	K _{HCl}	Ca _{HCl}	Mg _{HCl}
		(mg/kg)			(mg/l soil)			
Ap	0–26	2 339	7 540	1.52	490	1 700	2 700	5 100
Bw1	26–37	1 258	9 451	1.06	590	1 700	2 700	5 100
Bw2	37–62	1 301	8 420	0.86	400	2 400	2 700	7 200
BCtg	62–123	954	5 239	0.97	430	2 800	2 700	6 800
BCg	123–155	543	3 587	1.22	390	2 200	3 000	7 200
Cg	155–170	555	3 864	1.22	670	2 600	3 000	4 700

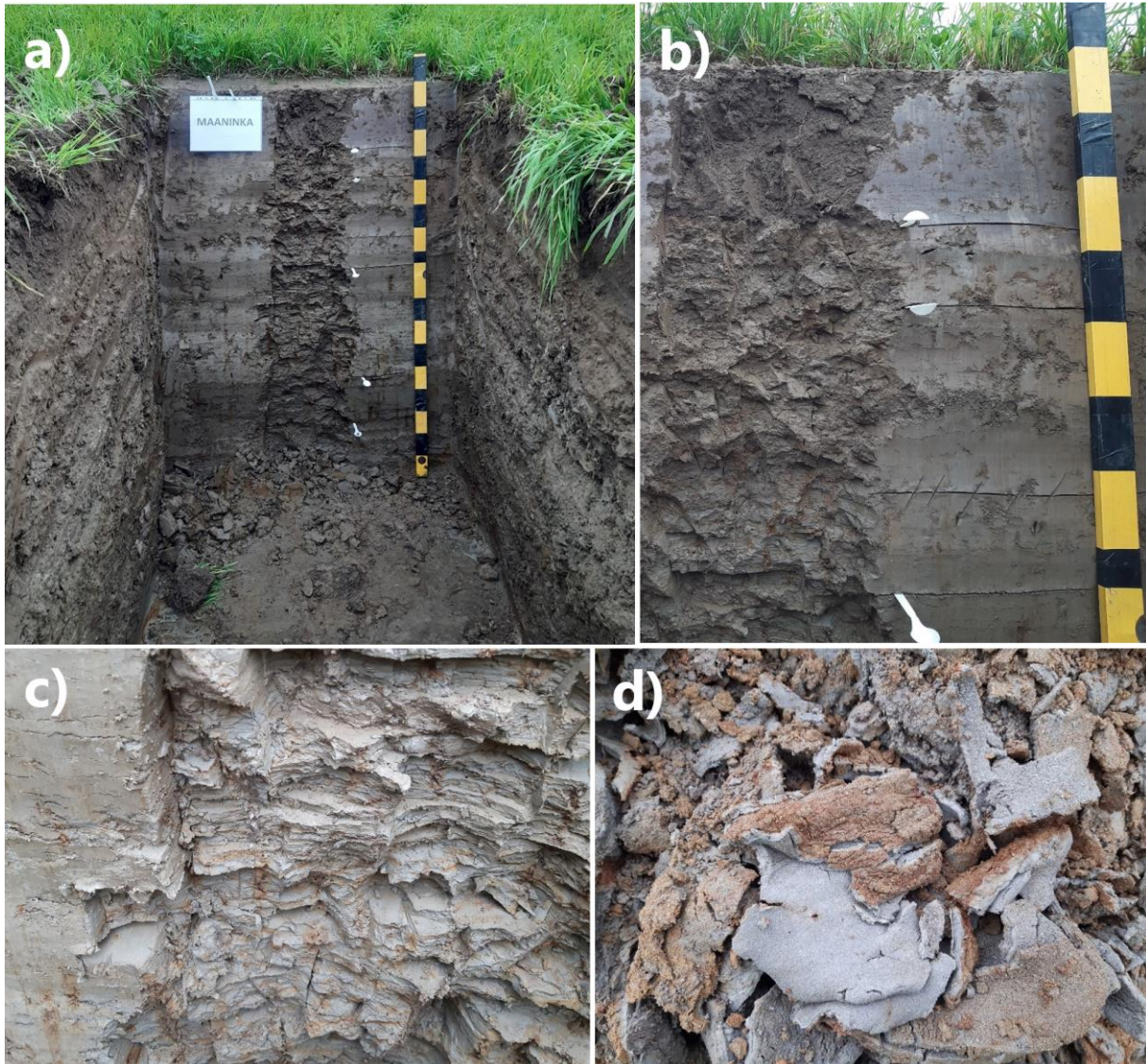


Figure 21. The Maaninka 16 pedon; Anttila 3. This soil had a rather uniform gray colour throughout the investigated depth (a). Typically, the plough layer had almost the same colour as the subsoil (b). The subsoil exhibited pronounced varving (c). In the excavated material, the thin sandy layers from between the clayey layers became clearly visible (d). Photos by Mari Rätty (Luke).

Maaninka 17: Anttila 4 (Pihapelto)

- Coordinates: x=3512038, y=7007070, k= 94
- Day of inspection: 14 September, 2022
- No groundwater observed
- Crop: Timothy
- Classification: Eutric Luvisol Albic Mollic **Planosols** (Loamic, Aric, Drainic, Raptic)
- Short classification: Mollic Planosols

The pedon Anttila 4 is on the top of a drumlin-like small esker about 500 m from the GHG field. This pedon is clearly a coarse-textured one. It is obvious that the core of the drumlin consists of glacial till. While there were no stones in the uppermost sandy loam horizons, stones started to appear at 78 cm, and finally at about 135 cm, the abundance of larger

stones (20 cm) (Table 74, Figure 22) practically prevented going deeper with the small excavator. Fine sand was the dominant particle size class while coarse silt and medium sand were also rather abundant (Table 75). This site is definitely representative of many fields in the North Savo area, obviously not frequently occurring around Lake Maaninka agricultural landscape.

The plough layer was classified as a Mollic horizon. It is typical that coarse-textured soils have sufficiently dark colours to meet the requirements of an umbric or mollic horizons in spite of only moderate organic C content. In Anttila 4, the plough layer contained 1.92% of organic C (Table 76), while in the neighbouring more fine-textured soils of the GHG field, none of the plough layers were sufficiently dark to be an umbric or a mollic horizon even though they had higher organic C contents (up to 4%). The base saturation, in spite of a rather coarse texture, was surprisingly high throughout the investigated depth, exceeding the base saturation of many horizons of clayic texture in the Maaninka area. This high base saturation of all subsoil horizons justifies a conclusion that the base saturation in the plough layer is a native soil characteristic and not temporarily created by agricultural liming. In spite of the rather coarse texture, the entire soil, except the plough layer, contained redox depletions and concentrations. The horizon at 42–49 cm even consisted of claric material (In the earlier WRB versions called albic material), which suggests bleaching of iron hydroxides by reducing conditions. This albic horizon had a higher base saturation and higher clay content than is usual for albic horizons.

Table 74. Morphological properties of the pedon Maaninka 17.

Horizon	Depth (cm)	Morphological description	Diagnostic features
Ap	0–27	Dark brown (7.5YR 3/2 moist) or reddish brown (5YR 5/3 dry) sandy loam. Moderate coarse subangular blocky structure parting to moderate fine subangular blocky and granular aggregates. Friable consistence. Common fine roots. No stones. Abrupt smooth boundary.	Mollic horizon
Bw1	27–42	Brown (10YR 4/3) and grayish brown (10YR 5/2) sandy loam. This horizon is a mosaic of redox concentrations and depletions. Common large dark yellowish brown (10YR 4/6) diffuse redox concentrations. Weak coarse subangular blocky structure, close to no aggregation. Very friable consistence. Common fine roots. No stones. Abrupt smooth boundary.	Stagnic properties
2Bw2	42–49	Dark grayish brown (2.5Y 5/2 moist), olive brown (2.5Y 4/3 moist), olive gray (5Y 5/2 moist) and light gray (2.5Y 7/2 dry) silt loam. Few medium brown (10YR 4/3) redox concentrations. No pore linings. Moderate coarse platy structure parting to moderate coarse angular blocky aggregates. Extremely firm consistence. Very few fine roots. No stones. Clear smooth boundary.	Cloric material Abrupt textural change at the bottom
3BCtg	49–78	Olive brown (2.5Y 4/3) loam. Common medium brown (7.5YR 4/4) redox concentrations as diffuse pore linings. Common large coatings of gray (5Y 5/1) illuvial material on surfaces of desiccation cracks. Incomplete coarse prismatic structure parting to moderate coarse platy and further to moderate medium angular blocky aggregates. Very firm consistence. Very few fine roots. 1% stones (diameter max 2 cm). Gradual smooth boundary.	Luvic Stagnic properties
3BCg	78–95	Dark grayish brown (2.5Y 4/2) sandy loam. Common medium brown (7.5YR 4/4) redox concentrations and dark gray (5Y 4/1) redox depletions as pore linings in previous root channels. Few medium yellowish red (5YR 4/6) redox concentrations. Moderate coarse platy structure parting to moderate medium angular blocky aggregates. Firm consistence. No roots. 3% stones (diameter max 5 cm). Gradual smooth boundary.	Gleyic properties
3Cg	95–135+	Dark grayish brown (2.5Y 4/2) sandy loam. Common large brown (7.5YR 4/4) redox concentrations and common medium gray and grayish brown (5Y 5/1, 2.5Y 5/1–2) redox depletions as pore linings in previous root channels. Few occurrences of dark brown (7.5YR 3/4) sand as continuous coatings around large stones. Moderate coarse platy structure (primary sedimentation layers) parting to moderate medium angular blocky aggregates. Friable or firm consistence. No roots. 5% of stones (diameter max 20 cm).	Gleyic properties

The following diagnostic features were considered or identified in the Anttila 4 pedon:

- Abrupt textural difference at 49 cm and Stagnic colour pattern (>50%) at 42–78 cm -> Planosols
- Gleyic colour pattern starting at 78 cm -> Not close enough (<75 cm) to soil surface to be diagnostic for the Gleyic qualifier. The topographic position makes it questionable to use the Bathyglyeyic qualifier because the soil does not exhibit wetness in spite of gleyic colours.
- Claric material at 42-49 cm -> Albic horizon
- Abundant illuvial clay at 49–78 cm (within 100 cm of soil surface) -> Luvic
- Base saturation >50% -> Eutric
- Lithic discontinuity at 42 and 49 cm -> Raptic
- Textural qualifier: Loamic
- Artificial drainage: Drainic
- Ploughing: Aric

Table 75. Particle size distribution in the soil horizons of the pedon Maaninka 17.

Horizon	Depth (cm)	Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	Gravel	Total silt	Total sand	Finnish soil type
		(%)								
Ap	0–27	7	13	16	48	16	0	29	63	KHt
Bw1	27–42	3	8	16	57	16	0	24	73	KHt
2Bw2	42–49	7	28	22	25	14	3	50	39	HtMr
3BCtg	49–78	11	17	16	29	23	4	33	52	HtMr
3BCg	78–95	9	17	16	30	24	5	32	53	HtMr
3Cg	95–135	5	14	15	31	27	7	29	58	HtMr

Particle-size limits: Clay = <0.002 mm ("S"); Fine silt = 0.002–0.02 mm ("HHs + KHs"); Coarse silt = 0.02–0.06 mm ("HHt"); Fine sand = 0.06–0.2 mm ("KHt"); Coarse sand = 0.2–2 mm ("HHk + KHk"), representing medium and coarse sand fractions; Gravel = >2 mm ("Sr"). Words in brackets are the Finnish abbreviations of the size fractions (based on Atterberg's classification system).

Table 76. Bulk density of undisturbed samples (BD_{UD}) and measured from the pre-treated samples (BD_{P-T}), pH and contents of total organic carbon (Org. C) and total nitrogen (Total N) in the soil horizons of the Maaninka 17.

Horizon	Depth (cm)	BD _{UD}	BD _{P-T}	pH (H ₂ O)	Org. C	Total N
		(kg/l)	(kg/l)		(%)	
Ap	0–27	1.48	1.06	6.3	1.92	0.16
Bw1	27–42	1.50	1.27	6.6	0.34	<0.08
2Bw2	42–49	-	1.44	6.6	<0.12	<0.08
3BCtg	49–78	2.04	1.40	6.4	<0.12	<0.08
3BCg	78–95	-	1.30	6.5	<0.12	<0.08
3Cg	95–135	-	1.34	6.4	<0.12	<0.08

Table 77. Potential cation exchange capacity (CEC), exchangeable calcium (Ca²⁺), potassium (K⁺), magnesium (Mg²⁺) and sodium (Na⁺), titratable acidity (Al³⁺+H⁺) and base saturation in the soil horizons of the pedon Maaninka 17.

Horizon	Depth (cm)	Ca	K	Mg	Na	Al+H	CEC (pH 7.0)	Base saturation (%)
		cmol(+)/kg soil						
Ap	0–27	6.4	0.28	1.15	0.05	1.51	9.4	84
Bw1	27–42	2.0	0.33	0.41	0.02	0.54	3.3	84
2Bw2	42–49	1.1	0.20	0.35	0.02	0.66	2.4	72
3BCtg	49–78	1.9	0.20	0.83	0.01	0.41	3.4	88
3BCg	78–95	1.5	0.19	0.66	0.02	0.95	3.4	72
3Cg	95–135	1.1	0.13	0.50	0.02	0.10	1.8	94

Table 78. Concentrations of acid ammonium acetate-extractable phosphorus (P_{AAc}), potassium (K_{AAc}), calcium (Ca_{AAc}), magnesium (Mg_{AAc}) and sulfur (S_{AAc}) in the soil horizons of the pedon Maaninka 17.

Horizon	Depth (cm)	P _{AAc}	K _{AAc}	Ca _{AAc}	Mg _{AAc}	S _{AAc}
		(mg/l soil)				
Ap	0–27	26	125	1323	133	7
Bw1	27–42	8.8	206	629	69	6
2Bw2	42–49	3.1	130	360	52	4
3BCtg	49–78	1.6	137	595	129	10
3BCg	78–95	4.9	110	530	112	8
3Cg	95–135	2.2	80	417	83	7

Table 79. Concentrations of acid oxalate-extractable aluminium (Al_{ox}) and iron (Fe_{ox}) oxides, total phosphorus (Total P) and hydrochloric acid-extractable phosphorus (P_{HCl}), potassium (K_{HCl}), calcium (Ca_{HCl}) and magnesium (Mg_{HCl}) in the soil horizons of the pedon Maaninka 17.

Horizon	Depth (cm)	Al _{ox}	Fe _{ox}	Total P (g/kg)	P _{HCl}	K _{HCl}	Ca _{HCl}	Mg _{HCl}
		(mg/kg)						
Ap	0–27	1 230	2 655	1.53	1 485	2 754	3 128	3 633
Bw1	27–42	1 209	2 841	0.98	1 168	2 891	2 583	3 987
2Bw2	42–49	388	1 783	0.82	1 049	2 568	2 646	2 799
3BCtg	49–78	390	2 380	0.67	753	3 108	2 388	3 431
3BCg	78–95	341	2 452	0.65	748	2 656	2 335	2 952
3Cg	95–135	238	1 731	0.68	820	2 113	2 271	2 376

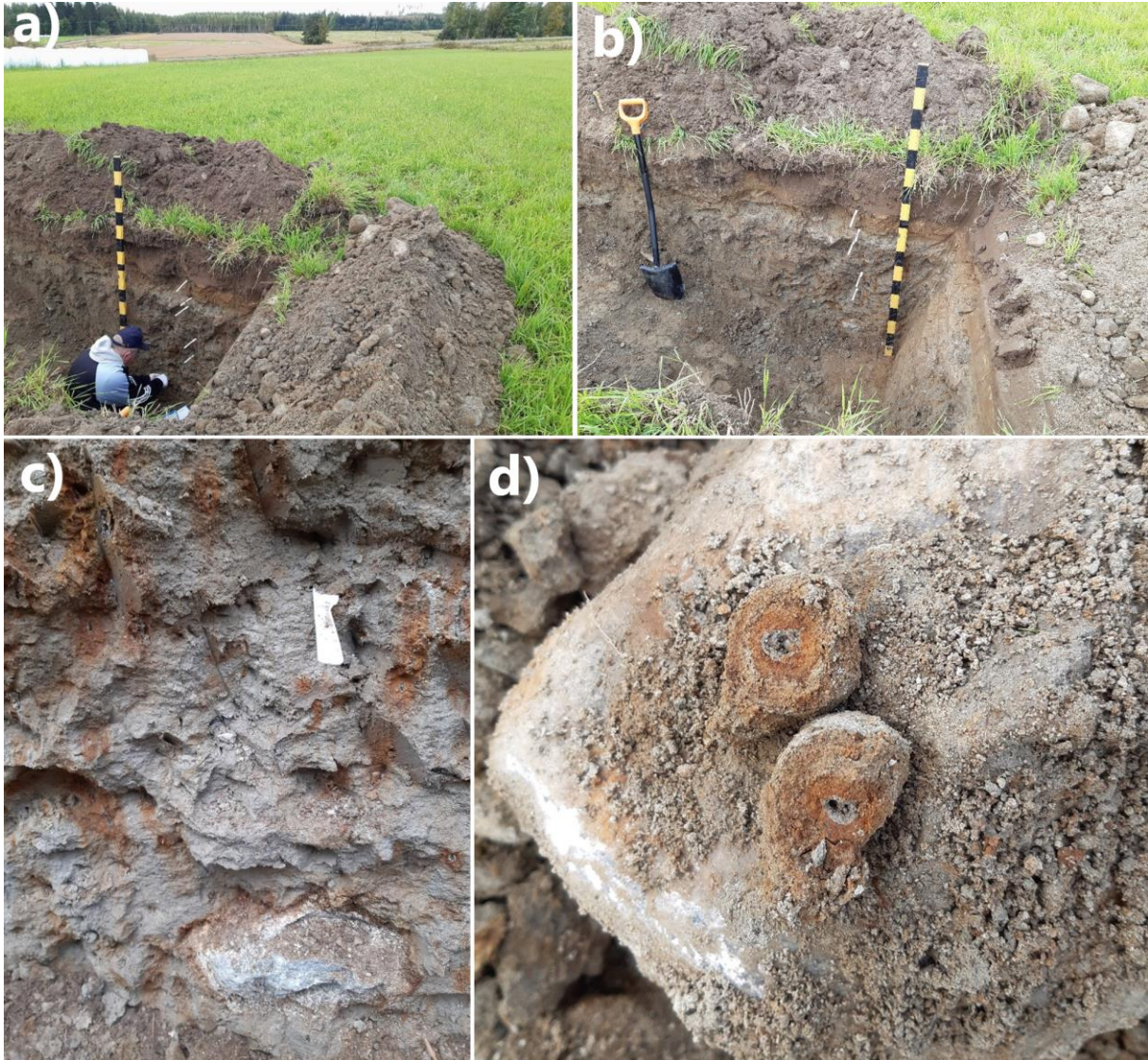


Figure 22. The Maaninka 17 pedon: Pihapelto. A general view of the site at the top of a drumlin (a). The albic horizon is clearly visible; observe the stones from the glacial till in the piled excavated material (b). In spite of a rather coarse texture, there were plenty of prominent redox concretions and depletions; observe the stones of glacial till at the bottom (c). Short, cemented precipitates were found around previous root channels (d). Photos by Mari Rätty (Luke).

4.5. Kirmanjärvi catchment

Two soil profiles were investigated in the catchment area of Lake Kirmanjärvi about 35 km from the research station in Maaninka. Studies of nutrient loading to watercourses have been carried out in this area. The fields of the area are gently undulating.

lisalmi 01: the catchment area of Lake Kirmanjärvi

- Day of investigation: 30 August, 2023
- Crop: Barley
- Groundwater at 119 cm
- Classification: Epidystric **Gleysols** (Loamic, Geoabruptic, Aric, Drainic, Hyperhumic, Mulmic)
- Short classification: Dystric Gleysols

This pedon is at the lowest point of the field, next to a major ditch and the small building where the monitoring and sampling of water is carried out. General wetness of the soil and the gleyic colour pattern is demonstrated by the occurrence of groundwater at 119 cm, strong pore linings throughout the subsoil and even short pipestems at 81–124 cm (Table 80, Figure 23). It is likely that this site has been a wetland because the 0–33 cm topsoil is rich in organic C (Table 83), meeting the criteria of Mulmic material (organic C 8–20%) and receives also the Hyperhumic qualifier. At the bottom of the Ap horizon, there is an abrupt textural change (-> Geoabruptic). The horizon at 23–33 cm has a very high clay content of 74% (Table 81), almost double or triple compared to the horizons above or below. This clayic material may have sedimented on the bottom of the wetland. The uppermost (Ap) horizon may consist of material that has been eroded from the upper parts of the field sloping towards the present pedon or may be dredged material from the ditch. It was not regarded as a lithological discontinuity (and the Raptic qualifier is waived) because the differing clay contents may be consequences of variations in sedimentation of material from the same source. Siltic texture in the subsoil with very little sand and no coarse fragments (Table 81) below 33 cm contributes to very low hydraulic conductivity and firm consistence. The two uppermost horizons had a base saturation <50% (-> Epidystric) (Table 82). In the deeper horizons, the base saturation was slightly above 50%, but due to the low pH throughout the pedon, the attribute Endoeutric is not included in the soil name.

Table 80. Morphological properties of the pedon lisalmi 01.

Horizon	Depth (cm)	Morphological description	Diagnostic features
Ap	0–23	Brown (10YR 3/3 moist) or light yellowish brown (2.5Y 6/3 dry) silty clay loam. Moderate medium subangular blocky structure parting to moderate medium granular aggregates. Friable consistence. Common fine roots. Clear smooth boundary.	The colours too light for a mollic horizon. Abrupt textural difference at the bottom.
Ah	23–33	Very dark brown (7.5YR 2.5/2) heavy clay, almost sapric material, likely mud accumulated in a wetland. Few medium prominent dusky red (2.5YR 3/3) pieces of wood. Moderate medium platy structure parting to moderate medium subangular blocky aggregates. Very friable consistence. Common fine roots. Abrupt smooth boundary.	
Bg1	33–62	Light olive brown (2.5Y 3/3) silt loam. Many medium prominent brown (7.5YR 4/4) and dark yellowish brown (10YR 4/4) redox concentrations as broad (8 mm) pore linings and few mottles not associated to old root channels. Brightest colours of the profile. Weak very coarse prismatic structure parting to moderate and coarse medium angular blocky aggregates. Firm consistence. Few fine roots. Gradual smooth boundary.	Gleyic properties
Bg2	62–81	Olive brown (2.5Y 4/3) and dark grayish brown (10YR 4/2) silt loam. Common medium prominent dark yellowish brown (10YR 4/4) redox concentrations as narrow pore linings and separate mottles not associated with old root channels. Black <i>Equisetum</i> plant material in the old root channels. Weak coarse incomplete prismatic structure (desiccation cracks) parting to moderate medium angular blocky aggregates. Firm consistence. Very few roots. Gradual smooth boundary.	Gleyic properties
Btg	81–124+	Light olive brown (2.5Y 5/4) and grayish brown (2.5Y 5/2) strata of silty clay loam. Common medium distinct (dark yellowish) brown (10YR 4/4–5/3) redox concentrations as pore linings in previous root channels; short (2 cm) cemented pipe stems. Some of the old root channels have gray interiors. Illuvial material on prism faces. Weak coarse incomplete prismatic structure (desiccation cracks) parting to weak medium angular blocky aggregates. Firm consistence. Few fine and medium roots.	Gleyic properties

Table 81. Particle size distribution in the soil horizons of the pedon lisalmi 01.

Horizon	Depth (cm)	Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	Total silt	Total sand	Finnish soil type
		(%)							
Ap	0–23	37	43	15	2	2	58	5	HsS
Ah	23–33	74	21	4	1	0	25	1	AS
Bg1	33–62	26	51	21	2	0	73	2	KHs
Bg2	62–81	25	48	25	2	0	73	2	He
Btg	81–124+	28	50	20	1	0	70	1	Hs/He

Particle-size limits: Clay = <0.002 mm ("S"); Fine silt = 0.002–0.02 mm ("HHs + KHs"); Coarse silt = 0.02–0.06 mm ("HHt"); Fine sand = 0.06–0.2 mm ("KHt"); Coarse sand = 0.2–2 mm ("HHk + KHk"), representing medium and coarse sand fractions. Words in brackets are the Finnish abbreviations of the size fractions (based on Atterberg's classification system).

Table 82. Potential cation exchange capacity (CEC), exchangeable calcium (Ca²⁺), potassium (K⁺), magnesium (Mg²⁺) and sodium (Na⁺), titratable acidity (Al³⁺+H⁺) and base saturation in the soil horizons of the pedon lisalmi 01.

Horizon	Depth (cm)	Ca	K	Mg	Na	Al+H	CEC (pH 7.0)	Base saturation (%)
		(cmol(+)/kg soil)						
Ap	0–23	7.9	0.67	1.8	0.04	17.2	27.6	38
Ah	23–33	8.3	0.71	2.8	0.08	24.7	36.6	33
Bg1	33–62	4.6	0.24	1.6	0.06	5.1	11.6	56
Bg2	62–81	3.3	0.21	1.7	0.08	4.2	9.5	56
Btg	81–124+	3.1	0.20	2.0	0.09	3.9	9.2	58

Table 83. Soil pH, bulk density (BD_{P-T}) of pre-treated samples, contents of total organic carbon (Org. C) and total nitrogen (Total N), and concentrations of acid ammonium acetate-extractable phosphorus (P_{AAC}), potassium (K_{AAC}), calcium (Ca_{AAC}), magnesium (Mg_{AAC}) and sulfur (S_{AAC}) in the soil horizons of the pedon lisalmi 01.

Horizon	Depth (cm)	pH (H ₂ O)	BD _{P-T} (kg/l)	Org. C	Total N	P _{AAC}	K _{AAC}	Ca _{AAC}	Mg _{AAC}	S _{AAC}
				(%)		(mg/l soil)				
Ap	0–23	5.1	1.34	9.44	0.57	7.0	148	943	138	17
Ah	23–33	4.7	1.04	9.89	0.68	2.3	152	999	189	27
Bg1	33–62	5.0	1.74	0.94	<0.08	2.2	66	675	139	11
Bg2	62–81	4.9	1.70	0.73	<0.08	8.6	58	517	149	12
Btg	81–124+	5.1	1.67	0.80	<0.08	3.6	62	450	163	10

Table 84. Concentrations of acid oxalate-extractable aluminium (Al_{ox}) and iron (Fe_{ox}) oxides, total phosphorus (Total P) and hydrochloric acid-extractable phosphorus (P_{HCl}), potassium (K_{HCl}), calcium (Ca_{HCl}) and magnesium (Mg_{HCl}) in the soil horizons of the pedon lisalmi 01.

Horizon	Depth (cm)	Al _{ox}	Fe _{ox}	Total P	P _{HCl}	K _{HCl}	Ca _{HCl}	Mg _{HCl}
		(mg/kg)		(g/kg)	(mg/l soil)			
Ap	0–23	4 415	11 893	2.12	1 152	1 806	2 999	4 217
Ah	23–33	4 997	18 654	1.21	459	2 235	2 057	3 738
Bg1	33–62	998	7 569	0.85	811	2 122	2 812	4 868
Bg2	62–81	875	6 497	0.87	916	2 227	2 447	4 380
Btg	81–124+	835	7 218	0.83	950	2 268	2 347	4 313



Figure 23. The Kirmanjärvi pedon: lisalmi 1. The pedon was at the lowest point of the landscape and had been a site for the accumulation of organic matter seen as a dark brown horizon (a, b and c). The subsoil was a mixture of brown redox concentrations and grey redox depletions (d). Photos by Mari Rätty (Luke).

lisalmi 02: the catchment area of Lake Kirmanjärvi

- Day of investigation: 30 August, 2023
- Crop: Barley
- No groundwater observed
- Classification: Eutric **Stagnosols** (Siltic, Aric, Drainic, Humic)
- Short classification: Eutric Stagnosols

Pedon lisalmi 02 (Figure 24) is located about 500 m upslope from lisalmi 1. It is one of the few pedons investigated in this study that contained horizons of glacial till (27–99 cm). The horizons of this pedon had consistencies that ranged from friable to very firm (Table 85) even

though the texture was silt loam or silt throughout the investigated depth. The rooting depth in this soil was less than 45 cm. Water permeability is also very poor, suggested by a stagnic colour pattern right below the plough layer. Varving and the platy structure below 27 cm also contribute to poor water transport through the soil. There is some illuvial material on prism faces in the Bg1 horizon but not enough to be diagnostic. The deepest horizon starting at about 100 cm contained as much as 52% of fine silt (Table 86). This horizon was massive and even though there was no groundwater, the material had kind-of a semi-fluid jellyish appearance and had a gray gleyic colour. The base saturation was high, except in the deepest silty horizon (Table 87). Relatively high content of the organic C justifies the humic qualifier. The Aric qualifier stands for ploughing and the Drainic qualifier for artificial drainage.

Table 85. Morphological properties of the pedon Iisalmi 2.

Horizon	Depth (cm)	Morphological description	Diagnostic features
Ap	0–14	Dark brown (10YR 3/3 moist) or light yellowish brown (2.5YR 6/4 dry) silt loam. Moderate coarse subangular blocky structure parting to moderate medium subangular blocky and granular aggregates. Friable consistence. No coarse fragments. Common fine roots. Abrupt smooth boundary.	The colours are too light for a mollic horizon.
Bw1	14–27	Brown (10YR 4/3, 30% and 7.5YR 4/4, 70%) silt loam; mixture of two colours. Moderate medium prismatic structure parting to moderate coarse subangular blocky aggregates. Firm consistence. No coarse fragments. Few fine roots. Gradual smooth boundary.	Stagnic properties
Bw2	27–45	Dark grayish brown (10YR 4/2, 50%) and brown (7.5YR 4/4, 50%) silt loam. Varves are visible. Weak very coarse platy structure parting to moderate coarse angular blocky aggregates. Friable consistence. No coarse fragments. Very few fine roots. Clear smooth boundary.	Stagnic properties
Bg1	45–69	Dark grayish brown (2.5Y 4/2) silt loam. Common medium prominent brown (7.5YR 4/4) and few small prominent dusky red (2.5YR 3/2) redox concentrations as pore linings and few separate mottles. Some illuvial material on prism faces. Weak very coarse prismatic structure parting to moderate coarse platy and further to moderate coarse angular blocky aggregates. Firm consistence. 5% coarse materials, up to 2 cm diameter. No roots. Clear smooth boundary.	
Bg2	69–99	Dark grayish brown (2.5Y 4/2) silt loam. Common medium prominent dark yellowish brown (10YR 4/4) and common large prominent dusky red (2.5YR 4/3–4/4) redox concentrations continuously around coarse fragments. Moderate coarse angular blocky structure. Very firm consistence. 15% coarse fragments up to 5 cm diameter. No roots. Clear smooth boundary.	
2Cg	99–106+	Dark gray (2.5Y 4/1) silt. Massive. No coarse fragments. Firm consistence. No roots. Even though no groundwater was observed, this horizon had a wet appearance after walking on it. Under the foot, the soil material was shaking and quaking as if it had been thick fluid material, but the foot did not sink into the soil material anyway.	Gleyic but too deep to be diagnostic

Table 86. Particle size distribution in the soil horizons of the pedon lisalmi 02.

Horizon	Depth (cm)	Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	Gravel	Total silt	Total sand	Finnish soil type
		(%)								
Ap	0–14	23	51	11	7	8	0	62	14	KHs
Bw1	14–27	21	48	14	8	8	0	62	16	He
Bw2	27–45	10	38	17	9	20	5	55	30	HsMr
Bg1	45–69	10	39	23	13	11	5	62	23	HtMr
Bg2	69–99	9	35	20	18	14	3	55	32	HtMr
2Cg	99–106+	11	52	31	5	0	0	83	6	KHs

Particle-size limits: Clay = <0.002 mm ("S"); Fine silt = 0.002–0.02 mm ("HHs + KHs"); Coarse silt = 0.02–0.06 mm ("HHt"); Fine sand = 0.06–0.2 mm ("KHt"); Coarse sand = 0.2–2 mm ("HHk + KHk"), representing medium and coarse sand fractions; Gravel = >2 mm ("Sr"). Words in brackets are the Finnish abbreviations of the size fractions (based on Atterberg's classification system).

Table 87. Potential cation exchange capacity (CEC), exchangeable calcium (Ca²⁺), potassium (K⁺), magnesium (Mg²⁺) and sodium (Na⁺), titratable acidity (Al³⁺+H⁺) and base saturation in the soil horizons of the pedon lisalmi 02.

Horizon	Depth (cm)	Ca	K	Mg	Na	Al+H	CEC (pH 7.0)	Base saturation (%)
		cmol(+)/kg soil						
Ap	0–14	10.1	0.32	2.8	0.10	3.3	16.6	80
Bw1	14–27	9.3	0.23	2.8	0.08	3.8	16.2	76
Bw2	27–45	6.8	0.14	2.6	0.06	3.2	12.8	75
Bg1	45–69	2.5	0.10	1.3	0.04	0.0	4.0	100
Bg2	69–99	1.7	0.10	1.0	0.03	0.1	3.0	98
2Cg	99–106+	1.3	0.13	0.7	0.04	1.7	3.8	57

Table 88. Soil pH, bulk density (BD_{P-T}) of pre-treated samples, contents of total organic carbon (Org. C) and total nitrogen (Total N), and concentrations of acid ammonium acetate-extractable phosphorus (P_{AAc}), potassium (K_{AAc}), calcium (Ca_{AAc}), magnesium (Mg_{AAc}) and sulfur (S_{AAc}) in the soil horizons of the pedon lisalmi 2.

Horizon	Depth (cm)	pH (H ₂ O)	BD _{P-T} (kg/l)	Org. C	Total N	P _{AAc}	K _{AAc}	Ca _{AAc}	Mg _{AAc}	S _{AAc}
				(%)						
Ap	0–14	6.0	1.51	2.66	0.15	3.1	83	1 590	256	6.9
Bw1	14–27	5.9	1.57	2.34	0.11	3.3	67	1 590	306	19
Bw2	27–45	5.9	1.59	1.17	<0.08	1.6	51	1 341	302	12
Bg1	45–69	5.9	1.96	0.21	<0.08	2.3	55	661	181	13
Bg2	69–99	6.1	2.01	0.20	<0.08	1.6	59	469	154	5.5
2Cg	99–106+	5.7	1.62	0.20	<0.08	1.1	62	276	92	11

Table 89. Concentrations of acid oxalate-extractable aluminium (Al_{ox}) and iron (Fe_{ox}) oxides, total phosphorus (Total P) and hydrochloric acid-extractable phosphorus (P_{HCl}), potassium (K_{HCl}), calcium (Ca_{HCl}) and magnesium (Mg_{HCl}) in the soil horizons of the pedon lisalmi 02.

Horizon	Depth (cm)	Al_{ox}	Fe_{ox}	Total P (g/kg)	P_{HCl}	K_{HCl}	Ca_{HCl}	Mg_{HCl}
		(mg/kg)						
Ap	0–14	1 622	22 081	1.49	1 178	2 029	3 981	4 900
Bw1	14–27	1 650	33 225	1.67	1 235	1 600	3 739	3 795
Bw2	27–45	1 046	32 966	1.75	1 201	1 906	3 554	3 634
Bg1	45–69	318	3 907	0.71	1 038	2 410	3 348	3 781
Bg2	69–99	311	3 129	0.56	1 008	2 201	3 053	3 356
2Cg	99–106+	476	3 181	0.64	1 032	3 198	3 046	4 487

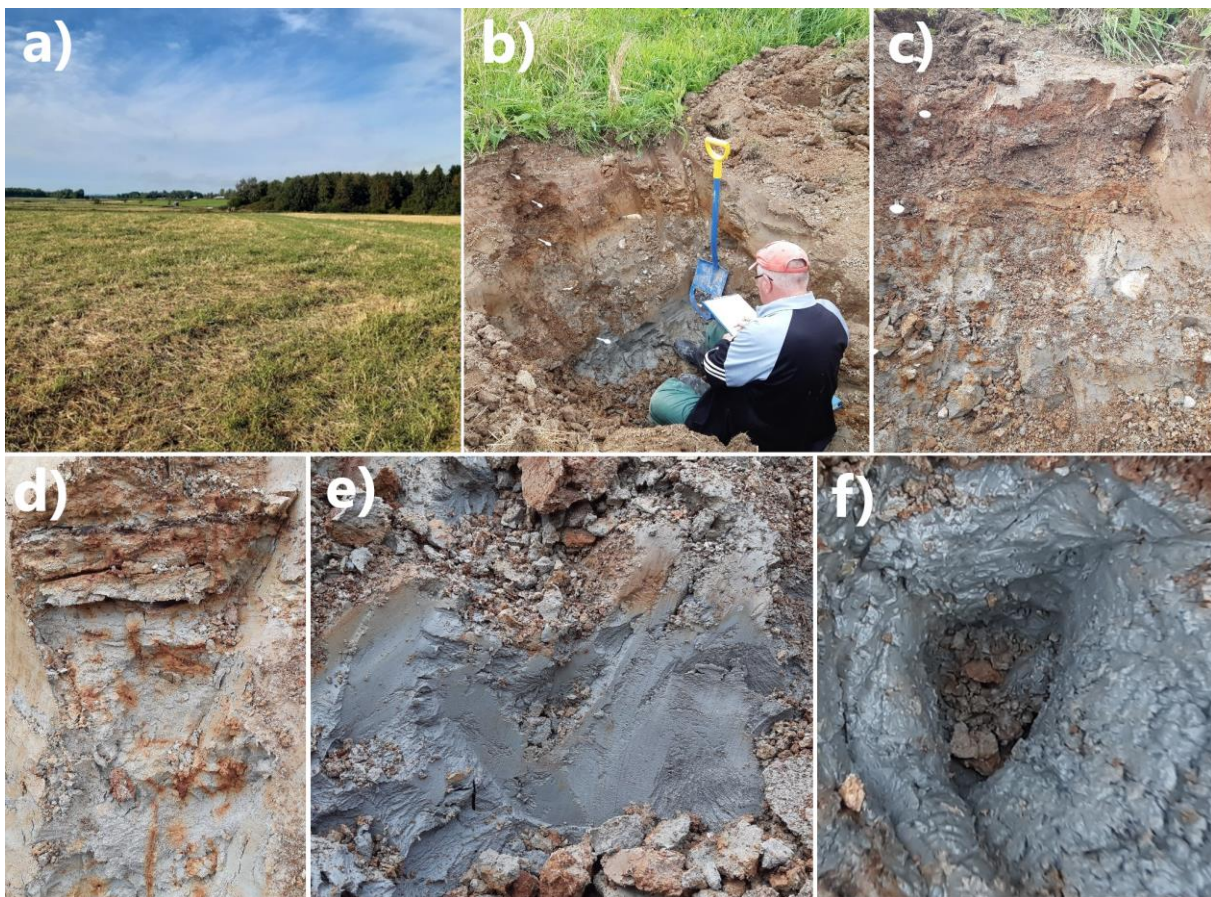


Figure 24. The Kirmanjärvi pedon: lisalmi 2. The location of this soil was upslope of a slightly undulating field (a). The profile was colourful (b and c). Observe the stones of the glacial till at the bottom (c). The subsoil had a varved appearance (d). There were plenty of rust precipitates (e), and the soil of the subsoil below 99 cm was silty, homogeneously gray jelly-like material (f). Photos by Mari Rätty (Luke).

4.6. Classification of organic soils in the WRB system

Compared with the detailed classification of mineral soils, classification of organic soils in the WRB system is pretty straightforward and general. The same statement applies also to the other universal classification system, the U.S. Soil Taxonomy. If a soil has a layer of organic soil material (>20 % organic C, i.e., >34.6% organic matter, conversion coefficient 1.732), the thickness of this layer is a major factor influencing classification. If the thickness is 40 cm or more, the soil belongs to Histosols. This is the only class for organic soils, while there are 31 classes for mineral soils in the WRB system. If the layer of organic soil material is less than 40 cm, the soil belongs to mineral soils and the presence of the organic soil material is indicated by the Histic attribute. Organic layers of less than 10 cm are not diagnostic, i.e., not indicated in the soil name.

If the thickness of the organic layer is more than 80 cm, the thickness is not specified further in the classification nomenclature. From the soil name it is thus not possible to conclude whether the subsurface drainage pipes are within the organic soil layer or surrounded by mineral soil material. If the thickness of the organic layer is 40–80 cm, the attribute Mineral is used to express the presence of mineral soil material in the pedon.

The content of organic C is not used as a diagnostic criterion within the Histosols. So, the name Histosols indicates that the soil has a sufficiently thick layer of soil material with an organic C content >20%, but more detailed information of the organic C content cannot be extracted from the name. Most of those agricultural soils classified as peat in the Finnish soil testing fall in the class of Histosols because the thickness of the organic layer is commonly at least 40 cm. In some cases, the thickness of the peat may be insufficient, and the soil is a Histic mineral soil, falling into one of the 31 main classes of mineral soils.

In the agricultural soil classification used in Finland, soils that have 20–39.9% organic C are also included in the organic soils under the category of mull soils ("multamaat"). Most of these soils do not meet the organic C requirement of Histosols in the WRB system, because the Finnish range for organic matter for mull soils stands for 11.6–23.0% organic C. Moreover, in many mull soils, the organic layer is too thin (<40 cm) for a Histosols. These soils are commonly Hyperhumic mineral soils. The attribute Hyperhumic indicates that the organic C content in 0–50 cm is at least 5%, calculated as the weighted average.

The degree of humification is indicated roughly using a three-step scale Fibric – Hemic – Sapric. It is justified to conclude that agricultural Histosols belong to the Sapric category which represents the most humified organic soil materials while Hemic and Fibric Histosols occupy other land uses. Many of the same attributes are used for Histosols and mineral soils. It may be pointed out that, differing from mineral soils, the attributes Eutric and Dystric are defined on the basis of soil pH in Histosols. A Dystric Histosol has a pH (H₂O) <5.5 while an Eutric Histosol has a pH ≥5.5.

Two agricultural peat soils, Pappilansuo and Särkisuo, were investigated on 14–15 September, 2022 using an Edelman auger (Figure 25). A soil pit was not excavated because of high groundwater. In both soils, the thickness of the peat layer was 120 cm (Table 90). The top horizons were almost black but the colour was lighter in the deeper horizons. The mineral soil below the peat layer was fluid and completely structureless. No chemical analyses were made.

Table 90. Brief descriptions of two peat soils.

Depth (cm)	Maaninka 18, Särkisuo		Maaninka 19, Pappilansuo	
	Colour	Soil material	Colour	Soil material
0–20	2.5YR 2.5/2 reddish black	O, sapric	10YR 2/2 very dark brown	O, sapric
20–40	2.5YR 2.5/2 reddish black	O, sapric	10YR 2/2 very dark brown	O, sapric
40–60	2.5YR 3/3 dusky red	O, sapric	7.5YR 2.5/3 very dark brown	O, sapric
60–80	5YR 3/3 dark reddish brown	O, sapric	2.5YR 2.5/3 very dusky red	O, sapric
80–100	7.5YR 4/3 brown	O, sapric	7.5YR 4/3 brown	O, sapric
100–120	7.5YR 4/3 brown	O, sapric	5YR 2.5/2 dark reddish brown	O, sapric
120+	5Y 4/2 olive gray	Clay loam	5Y 4/1 dark gray	Clay loam

Both fields have a subsurface pipe drainage system. It is assumed that the subsoil has a $\text{pH} < 5.5$. On this basis, both soils belong to **Dystric Drainic Sapric Histosols**, or briefly **Sapric Histosols**. If the fields have areas of shallower peat (40–80 cm), they belong to **Dystric Drainic Sapric Histosols (Mineralic)**, or briefly **Sapric Histosols (Mineralic)**.

In order to characterize these peat soils more accurately in scientific papers, chemical and physical analyses by the horizon are needed. Recommended measurements include pH, bulk density and content of organic C.

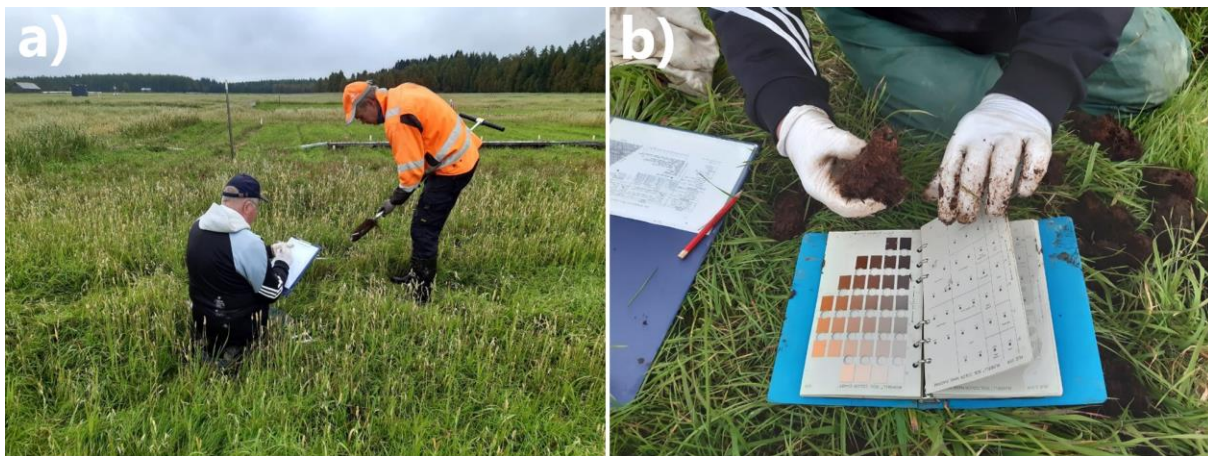


Figure 25. The peat soils were sampled with an auger, due to the high groundwater (a). The peat samples were almost black (b). Photos by Mari Rätty (Luke).

5. General discussion

This report presents results of 21 pedons, and on this basis, generalizations can be made about the characteristics of the agricultural soils in the investigated region. The agricultural soils of the Maaninka-lisalmi area show substantial diversity. Out of the 32 reference groups of the WRB system, six reference groups were identified, namely Histosols, Gleysols, Planosols, Stagnosols, Arenosols and Regosols.

The investigated area has a general pattern that within the 1.5 m deep soil, clayic or clay loam layers at the bottom are covered with more coarse-textured soil material. In certain depositional esker areas (part of Pohjoispelto, part of Kauraniemi, Anttila 4), the coarse soil layers are so thick that the fine-textured layers are not found within the investigated depth. In turn, in some sites (Hämeensuo), loamy or sandy topsoil is absent and even the plough layer consists of clayic soil material. Very seldom was glacial till found in the investigated sites (Anttila 4, Kirmanjärvi) but in most sites the till, deeper than 1.5 m) is obviously covered with sorted fine- or medium-textured soil material. The clayic layers have a substantial influence on soil fertility and permeability and these fine-textured soil materials can be regarded as a typical feature of the area.

Most agricultural mineral soils of this area have loamic textures (sandy loam, sandy clay loam). In most cases, silt (0.002–0.06 mm) was the dominant particle size fraction, with the emphasis in coarse silt (0.02–0.06 mm). Some 15% of clay was commonly detected. This kind of texture implies that the soil contains a stock of weatherable minerals and has a rather high (usually above 50%) base saturation, explaining why there was no sign of podsolization. In soils that have developed into podzols, the clay content is almost without exception well below 5% and the base saturation is below 10% (Mokma et al. 2004, Yli-Halla et al. 2006b).

In the Finnish soil classification, most of the investigated pedons are characterized as “karkea hieta” (almost identical to fine sand), which suggests a pretty coarse soil and easily leads to the Arenosols interpretation if translated without checking the particle size distribution. Arenosols have a texture of loamy sand or coarser, which is clearly coarser than most of the present soils that almost always have a loamy texture, and besides fine sand, have considerable contents of silt and clay. Characterizing these soils as “sandy” or Arenosols gives a wrong impression of the soil. Internationally, soils of a sandy texture contain usually marginal amounts of clay and silt fractions. It is strongly advised that for international presentation the Finnish textural names be not translated to English, but the textural name should be derived from the international textural triangle using the data of particle size distribution. If such data is unavailable, loamic attributes (e.g., sandy loam, silt loam) should be preferred over the sandy ones (e.g., loamy sand, fine sand).

Another marked source of diversity is hydrology. All the studied pedons had signs of wetness, but they were expressed at different degrees from peat soils to mineral soils that had redoximorphic features throughout the investigated depth and finally to mineral soils that had those features only in the deeper subsoil. The reference groups Histosols, Gleysols, Planosols and Stagnosols occupy 14 out of the 21 investigated sites. These reference groups are influenced by wetness to the extent that the signs of wetness are the major feature taken into account in classification. The remaining reference groups, Arenosols and Regosols represent soils that have less pronounced signs of wetness and are pedogenically the least developed soils in the WRB system.

The initial stage of soil formation was indicated by the prominent varved appearance of clayic and clay loam horizons. The inheritance of the parent sediment was exhibited also in the platy structure of coarse mineral soils where the aggregates were split along the original sedimentation strata that were still visible. This *rock structure* was obvious in many pedons below the frost depth where the soil has not been disturbed by freezing and thawing.

It has been traditionally claimed that soils of Finland are pedogenically poorly developed. This study confirmed this historical statement, showing that wetness and particle size distribution are the principal factors determining the name of these soils in the WRB system. At the same time, this study showed that in spite of scant pedogenesis, the soils represented six out of 32 major soil classes of the WRB system. Furthermore, the multitude of attributes assigned to the pedon of a main category allows the expression of soil properties in a vivid manner. A comprehensive list of the classification of the 21 pedons is presented in Table 91.

The two Histosols of this study were undisputed examples of soils where wetness had prevented decomposition of dead plant material. Even after artificial drainage, the soils were still so wet that the mineral subsoil at 1 m was almost fluid and structureless, indicating that it had never dried.

In all four Gleysols of this study, groundwater was at such a high level that in late summer or early autumn it entered the soil pit. The fifth site where groundwater was observed belonged to Gleyic Planosols. All these sites were at the lowest positions of the landscapes and their lowest horizons were soft and almost structureless and had a uniform gray colour (with no mottling). It is typical of Gleysols that the aggregates (often prismatic aggregates) right above the groundwater level are covered with a continuous coating of iron hydroxide while the interiors of the aggregates are gray without brown mottles. These soils can thus be easily recognized. It is important to realize that in Gleysols the gleyic colour pattern has to start within 40 cm of the mineral soil surface. If this characteristic occurs deeper in the soil, the soil goes into another class and may get the Gleyic, Endogleyic or Bathygleyic qualifier, depending on the depth of occurrence.

Planosols, a soil group traditionally unknown in Finland, appeared to commonly occur in the present study area. In a humid climate, a Planosol classification can be expected whenever a pedon consists of a fine-textured subsoil and a coarse-textured topsoil, and there is an abrupt textural difference at the boundary of these horizons. Rain and snowmelt water infiltrates easily into the coarse-textured surface horizons but has difficulty in entering the fine-textured horizon underneath. Stagnant water causes reducing conditions and is recognized from brown redox concentrations and gray redox depletions which sometimes develop into a bleached Albic horizon. Finnish soils have received their parent material during and after the Weichselian glaciation and it is common that a pedon has horizons of sharply different textures with abrupt boundaries. These layers may have deposited during different stages of water bodies covering the landscape and they may contain sediment material of different origins. The Finnish soils are thus conducive to the formation of Planosols.

Stagnosols were introduced into the WRB system in 2006 and this group was rapidly adopted in the Norwegian soil mapping project. In Stagnosols, the wetness comes from above. When soil texture becomes finer when going deeper in the soil, water movement slows down and water stagnates in the soil profile, and alternating reduced and oxidized conditions give rise to brown redox concentrations and gray redox depletions, very common features in soils of

Finland. In Stagnosols, the stagnic colour pattern has to start within 50 cm of the mineral soil surface. If this characteristic occurs deeper, the soil goes into another class and can get the Stagnic qualifier.

Arenosols are seldom in agricultural use because they are usually poor in nutrients and due to their coarse texture have a very low water holding capacity and have not been reclaimed for agricultural use. The texture of Arenosols has to be sandy within the top 1 m, with the allowance of only 15 cm of more fine-textured soil material. In the climatic conditions of Finland, soils that have this coarse texture often key out as Podzols. Glacial till soils do not necessarily have a sufficiently coarse texture to be Arenosols. Particularly those glacial till soils that have been reclaimed for agricultural use, commonly have appreciable silt contents and the texture is loamy, not sandy. Instead, forested glacial tills often belong to Arenosols. It should also be pointed out that Arenosols can exhibit morphological signs of podzolization but the colours may not be dark enough or the chemical criteria may not be met to be classified as Podzols, but those soils can be Protosodic Arenosols instead.

Regosols are soils of little pedogenic development. They usually have medium textures and have a sufficient water permeability that stagnic or gleyic colour patterns have not developed close enough (50 cm or 40 cm) to the mineral soil surface. Regosols with medium- or coarse-textured top layers may well be classified as Gleyic Regosols or Stagnic Regosols if the gleyic or stagnic colour patterns occur deeper than required for Gleysols and Stagnosols. It should also be realized that Regosols may have several morphological signs of pedogenesis, but they may be too weakly developed to meet the diagnostic criteria of another main class.

The lack of Cambisols that used to be considered the typical class of Finnish agricultural soils of Finland needs some clarification. First of all, the wetness as an all-embracing soil characteristic was not sufficiently comprehended until the recent revision of the Soil Map of Finland (Lilja et al. 2017). Moreover, Stagnosols that now encompass many agricultural soils of Finland, was introduced only in 2006, and the stagnic properties required for the Planosols classification were not recognized earlier. Cambisols were a safe choice because by definition Cambisols exhibited some pedogenic development, which was seen in agricultural soils of Finland. Now most of the agricultural soils that used to be classified as Cambisols get the classification of Planosols or Stagnosols.

Another group that is missing from the presently investigated pedos is Podzols, which has always been the dominant soil class displayed in soil maps of Finland (Figures 1 and 2). It needs to be emphasized that the colours in small-scale (e.g., 1:250,000 and 1:1000,000) soil maps indicate the dominant soil type. In most areas of Finland, forest is the dominant land use, and agriculture occupies a tiny fraction. Therefore, it is the soil type of the forest (or peatlands) that appears in the map, except the southwestern corner of Finland. It has been generalized that most mineral forest soils are Podzols, so it is the soil type exhibited on small-scale soil maps. Podzols appear also in agricultural soils that have sandy textures but not in soils of loamy textures. Such sandy soils did not occur in the material investigated in this survey.

Table 91. Classification of the 21 pedons investigated in the Maaninka – Iisalmi area.

	Location	Complete classification	Short classification
1	Leaching field, central 2001	Epidystric Regosols (Loamic, Endoarenic, Aric, Drainic, Ochric)	Dystric Regosols
2	Leaching field, coarse 2001	Dystric Arenosols (Aric, Oxyaquic, Ochric)	Dystric Arenosols
3	Leaching field, low part 2001	Epidystric Planosols (Epiloamic, Endoclayic, Aric, Drainic, Raptic)	Dystric Planosols
4	Pohjoispelto, central 2023	Endeutric Albic Planosols (Epiloamic, Endoclayic Aric, Drainic, Humic, Raptic)	Albic Planosols
5	Keskilohko, spruce fence 2022	Endodystric Bathyglyeyic Stagnic Regosols (Loamic, Aric, Drainic, Ochric)	Stagnic Regosols
6	Keskilohko, central 2022	Stagnic Regosols (Loamic, Aric, Drainic, Ochric)	Stagnic Regosols
7	Kauraniemi, tip, buffer strip 2005	Eutric Stagnic Regosols (Loamic, Aric, Fluvic, Ochric)	Stagnic Regosols
8	Kauraniemi, shore 2001	Eutric Planosols (Epiloamic, Endoclayic, Aric, Drainic, Raptic)	Eutric Planosols
9	Kauraniemi, upper 2001	Eutric Gleyic Planosols (Epiloamic, Endoclayic, Aric, Drainic, Raptic)	Gleyic Planosols
10	Hämeensuo 1 2023	Eutric Mollic Gleysols (Loamic, Aric, Drainic, Hyperhumic, Mulmic)	Mollic Gleysols
11	Hämeensuo 4 2022	Eutric Mollic Gleysols (Loamic, Endoclayic, Luvic, Aric, Drainic, Hyperhumic)	Mollic Gleysols
12	Hämeensuo 3 2021	Eutric Luvic Stagnosols (Epiclayic, Endoloamic, Aric, Drainic, Humic)	Luvic Stagnosols
13	Hirsisuo	Eutric Luvic Planosols (Epiclayic, Endoloamic, Aric, Drainic, Raptic)	Luvic Planosols
14	Anttila 1, central 2022	Epidystric Endeutric Luvic Bathyglyeyic Stagnosols (Siltic, Endoclayic, Aric, Drainic, Humic, Raptic)	Gleyic Stagnosols
15	Anttila 2, low part 2022	Dystric Gleysols (Loamic, Bathyclayic, Luvic, Aric, Drainic, Humic)	Dystric Gleysols
16	Anttila 3, high part 2022	Eutric Luvic Bathyglyeyic Stagnosols (Epiclayic, Endoloamic, Aric, Drainic, Raptic)	Gleyic Stagnosols
17	Anttila 4, Pihapelto 2022	Eutric Luvic Albic Mollic Planosols (Loamic, Aric, Drainic, Raptic)	Mollic Planosols
18	Särkisuo 2022	Dystric Drainic Sapric Histosols	Sapric Histosols
19	Pappilansuo 2022	Dystric Drainic Sapric Histosols	Sapric Histosols
20	Iisalmi 1, low part 2023	Epidystric Gleysols (Loamic, Geoabruptic, Aric, Drainic, Hyperhumic, Mulmic)	Dystric Gleysols
21	Iisalmi 2, high part 2023	Eutric Stagnosols (Siltic, Aric, Drainic, Humic)	Eutric Stagnosols

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