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Monitoring of silicon, soil pH, nitrogen and organic carbon in the Lower Austrian Chernozem / Phaeozem region

Master Thesis

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Wien, September 2019

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Acknowledgements

Looking back on the creation of this master thesis I can distinguish three stages: The first was marked by hands on work on the field, wonderful nature experience and observation of the landscape. I enjoyed the peace out on the fields and the insight I got into our rich black soils.

The second stage was the handling and analysis of the soils in the research center in Tulln. I felt very lucky for the pleasant working climate in the Rhizosphere Ecology and Biogeochemistry Group. The team in Tulln is a unique community. I am forever grateful how we supported each other, the laugh we shared in the lunch breaks and the nice trips we had together. Veronika and Olivier I especially want to thank you for your help during the time of lab work.

The final step to accomplishing this master thesis was the writing part. I am very thankful for the support of my whatsapp writing group „Masterarbeit Deluxe“, who helped me by having a community and enabled me to find joy in the writing. Anne and Lisa, I especially want to thank you for the many hours we spent together writing, for the breaks in between and the walks through the park.

I want to thank my supervisors Prof. Walter Wenzel and Dr. Markus Puschenreiter who have kept an eye on me through all stages of the master thesis creation. Walter and Markus, thank you for your patient guidance, the interesting conversations and for opening my eyes to the scientific approach.

Anna, I am so grateful that we met and accompanied each other throughout our master theses. I will forever remember our good times together in the Rhizo Car driving through the beautiful landscape of Lower Austria, soil sampling on the fields in every weather and also the time together in the laboratory. Thank you for being there with me, thank you for your friendship. I couldn't have done it without you.

Last but not least I want to thank my dear family and friends. Thank you for your support, for cheering me up when I was losing hope and for your patience throughout my study career. Mama, danke, dass Du sogar mit mir mitgekommen bist Bodenproben holen. Maria, thank you for proof reading my master thesis, you did a wonderful job. Simão, thank you for holding my hand and calming me down.

Abstract

Recently, Silicon (Si) has been receiving increasing attention as a beneficial element for plants. Research has shown that Si bioavailability is an important factor for plant health and plant growth. Information about the Si concentrations in Austrian or European soils is not available apart from recent master theses conducted in our research group.

To obtain information about Silicon and key soil factors like pH, nitrogen and organic carbon in the Lower Austrian Chernozem region near Vienna I collected 99 topsoils between November 2016 and March 2017 from the same cultivated sites where 20-30 years ago the Austrian soil mapping services had sampled and archived part of the material. This approach is different to the soil monitoring on Austrian and European level which mainly compares soil samples of the same regions but rarely compares soils from the exact same places.

To obtain information on the Si status of soils I extracted potentially plant-available (0.01 M CaCl_2 extraction) and amorphous Si fractions (0.2 M NaOH extraction) in the archived and the re-sampled soils. The Si concentrations in both extracts were measured using the molybdenum blue method and spectrophotometry. Furthermore, the organic carbon concentration, the pH of the resampled and the archived soils and the nitrogen concentration of the resampled soils was measured.

Initially we hypothesized that the amorphous Si concentrations might have decreased during the monitoring period because of Si-depleting management practices such as straw removal and depletion of organic carbon. In contrast, our findings indicate no relevant change of amorphous Si (mean 2560 mg/kg) and potentially plant-available Si (mean 44 mg/kg), however, at both sampling times nearly half of the soils were below the upper limit of Si deficiency for rice (< 43 mg/kg). Similarly, no change was observed for soil pH (mean 7.2) while organic carbon showed a substantial increase of nearly 40% from a mean of 19.6 g/kg to 29.3 g/kg during the monitoring period.

Multiple regression analyses were run to observe the influence of soil texture, mean annual precipitation, mean annual temperature, pH and organic carbon on the Si fractions. As the main influencing factors could be emphasized: Organic carbon and temperature showed a decreasing effect on the Si fractions, clay showed an increasing effect.

Kurzfassung

Silicium (Si) steht in den letzten Jahren zunehmend als vorteilhaftes Element für Pflanzen im Fokus der Aufmerksamkeit. Wissenschaftliche Erkenntnisse haben gezeigt, dass die biologische Verfügbarkeit von Si einen wichtigen Einflussfaktor für die Pflanzengesundheit und das Pflanzenwachstum darstellt. Abgesehen von Masterarbeiten unserer Forschungsgruppe mangelt es an Informationen über die Si Konzentrationen in den Böden Österreichs und Europas.

Um Informationen über Si und weitere Schlüsselbodenparameter wie pH, Stickstoff (N) und organischen Kohlenstoff (SOC) zu generieren beprobte ich zwischen November 2016 und März 2017 99 Oberböden von Äckern auf niederösterreichischen Tschernosemen, Paratschernosemen und Feuchtschwarzerden. 20 bis 30 Jahre alte Archivproben dieser Oberböden waren von der Österreichischen Bodenkartierung verfügbar. Der Zugang des Bodenmonitorings dieser Studie unterscheidet sich deutlich von den Bodenmonitoringmethoden auf österreichischer und europäischer Ebene, die zumeist nur Böden der selben Regionen vergleichen jedoch nicht zum selben Standort zurückkehren.

Um Informationen über den Si Gehalt zu generieren extrahierte ich potentiell pflanzenverfügbare (Extraktion in 0.01 M CaCl₂) und amorphe Si Fraktionen (Extraktion in 0.2 M NaOH) aus den archivierten und neu beprobten Böden. Die Si Konzentration wurde in beiden Extrakten mithilfe der Molybdän Blau Methode und einem Photospektrometer gemessen. Außerdem wurden der organische Kohlenstoffgehalt und der pH Wert der archivierten und neu beprobten Böden, sowie der N Gehalt der neu beprobten Böden gemessen.

Die ursprüngliche Hypothese, dass sich der amorphe Si Gehalt aufgrund von Si mindernden Bodenbearbeitungsmethoden wie Stroheseitigung oder dem Abbau von organischem Kohlenstoff über den Beobachtungszeitraum hinweg verringert hat, wurde widerlegt: Es wurden keine maßgeblichen Veränderungen des amorphen (Mittelwert 2560 mg/kg) und potentiell pflanzenverfügbaren (Mittelwert 44 mg/kg) Si Gehaltes beobachtet. Dennoch lagen die pflanzenverfügbaren Si Gehalte zu beiden Beprobungszeitpunkten bei fast der Hälfte der Böden unter dem oberen Limit eines Si Mangelzustandes für Reis (< 43 mg/kg). Ebenso konnte keine Änderung des pH Wertes beobachtet werden (Mittelwert 7.2). Der organische Kohlenstoffgehalt zeigte jedoch eine signifikante Zunahme von fast 40% von einem Mittelwert von 19.6 g/kg auf 29.3 g/kg über den Beobachtungszeitraum.

Zur Feststellung des Einflusses der Bodentextur, des mittleren Jahresniederschlages, der mittleren Jahrestemperatur, des pH Wertes und des organischen Kohlenstoffes auf die Si

Fraktionen wurden multiple Regressionen gerechnet. Als Haupteinflussfaktoren können die folgenden Bodenparameter hervorgehoben werden: Organischer Kohlenstoff und Temperatur hatte eine mindernde Wirkung auf die Si Fraktionen, Ton hatte eine erhöhende Wirkung.

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Abbreviations

AGES	Agentur für Gesundheit und Ernährungssicherheit (Austrian Agency for health and food security)
BZI	Bodenzustandsinventur (soil observation)
CaCl ₂	Calciumchloride
CaCO ₃	Calciumcarbonate
CAP	common agricultural policy
CEC	cation exchange capacity
eBod	online GIS-application for digital soil mapping in Austria (scale 1:25.000)
ENVASSO	Environmental Assessment of Soil Monitoring
extr.	extraction / extracted
H ₄ SiO ₄	monomeric silicic acid
LUCAS	Land Use/Land Cover Area Frame Survey
NaOH	Sodiumhydroxide
OC	organic carbon
ÖPUL	Österreichisches Programm zur Förderung einer umweltgerechten, extensiven un den natürlichen Lebensraum schützenden Landwirtschaft (Austrian Agri-environmental programme)
rpm	revolutions per minute
PE	polyethylene
precip.	precipitation
SiO ₂	Silica
TC	total carbon
temp.	temperature

1 Introduction

The beginning of agriculture on the territory of Austria lies in the very fertile loess based Chernozem and Phaeozem soils of Lower Austria. It dates back to the Linear Pottery Culture which heralded the Neolithic around 5.500 BC (Lenneis 2001). Chernozem and Phaeozem soils are mainly located at an altitude of maximum 400-450 m in the driest and warmest areas of Austria. The area with the most fertile soils like chernozems and phaeozems, is located in the north east of Lower Austria (Hösl et al. 2016), the state surrounding Vienna.

1.1 Chernozems and Phaeozems

Chernozems were the first soils to be studied properly and have, ever since, been a symbol of fertility (Vysloužilová et al. 2016). The fertility of the chernozem results from its high amount of organic matter, which is also linked to its black colour. The parent material consists mostly of loess, which is chalky and loosely packed (Scheffer et al. 2010). Chernozems can be found in regions of continental, for most of the year, dry climate with cold winters and hot summers. To distinguish chernozems from other soils a chernic horizon needs to be found. This is a “relatively thick, well-structured blackish surface horizon, with a base saturation, a high biological activity and with a moderate to high concentration of organic carbon”. Furthermore there is a calcic horizon which starts 50 cm below the lower boundary of the chernic horizon (Vysloužilová et al. 2016). Around the world 230 million ha of land are covered with chernozem soils, mostly in Eurasia and North America (FAO 2014).

Chernozems are very good soils for agriculture. Their excellent location characteristics speak for them: The deep surface horizons and the high humus accumulation promise excellent nitrogen availability; the adequate base saturation provides exceptionally good growth conditions for most crops. Limited yield potential is solely caused by the climate: Chernozems usually occur in areas with low mean annual precipitation. Drought, therefore, generally reduces the theoretically unlimited soil fertility of Chernozems (Stahr 2012). Still, middle European Chernozems can store up to 200 mm precipitation in their first meter because of their relatively high pore volume which makes them very well aerated and easily accessed by roots. Consequently the vegetation can also survive slightly longer drought periods without bigger losses (Scheffer et al. 2010).

Phaeozems are similar to Chernozems but are more intensively leached (FAO 2014) and in the upper part entirely decalcified (Stahr 2012): Either they are free of carbonates or secondary carbonates only start in greater depths. In the upper meter they have a high base saturation. They also have dark and humus-rich surface horizons but are, in comparison to Chernozems, less rich in bases. Worldwide Phaeozems cover 190 million ha of land surface (FAO 2014). Because of their balanced water-, air- and nutrient-household Phaeozems are, in spite of their acidification, quite fertile soils (Stahr 2012).

The FAO (2001) ranks Chernozems and Phaeozems among the best soils in the world. Scheffer et al. (2010) count them to the most important soils for wheat production worldwide. 200 million ha of Chernozems and Phaeozems could potentially be used as cropland.

1.2 Soil monitoring in Europe and Austria

Várallyay (1993) defines soil monitoring as the systematic determination of soil variables to record their temporal and spatial changes. Soil monitoring enables the early detection of changes in soil quality. This makes the design and implementation of policy measures possible that make sure soils stay sustainably used in order for them to continually deliver ecosystem services and goods. It is essential to use harmonised methodology to gain data that is comparable among sites and between countries (Morvan et al. 2008).

In almost all European countries the following most conventional parameters are measured: Total carbon, macroelements, heavy metals, nitrates, pH, particle-size distribution and cation exchange capacity (CEC) (Medvedev and Laktionova 2012).

To create a coherent pan-European physical and chemical topsoil database, the EU integrated soil monitoring into the LUCAS (Land Use/Land Cover Area Frame Survey) project. In 2009 around 20 000 topsoil samples were collected in 25 EU member states (Tóth et al. 2013). To make sure all soil samples are comparable, the samples were collected following the same sampling protocol and all samples were analysed by a single laboratory using standard analytical methods (Orgiazzi et al. 2018). The samples were analysed for basic soil properties including particle size distribution, pH, OC, carbonates, N, P, K, CEC and multispectral properties. Within this survey 420 samples were taken in Austria (Tóth et al. 2013). In 2015 and 2018 follow up soil samplings with slightly extended sampling sites (also outside the EU) and more soil analysis parameters took place. The analyses are being repeated at fixed locations in intervals of three years. All results from the LUCAS Soil surveys are published with open-access by the EU. Outputs from LUCAS Soil are already being taken into account by the EU to implement the Common Agricultural Policy (CAP) (Orgiazzi et al. 2018).

The ENVASSO (ENVironmental ASsessment of Soil for mOnitoring) developed a system to harmonise already existing, mostly national, soil monitoring networks and databases. The aim was to create a reference to support the sustainable management of soil resources on the European level by providing the needed data. The condition of the soils should be monitored especially regarding nine defined soil threads including organic matter decline, soil sealing, contamination and compaction. The community agreed upon recommendations to have a minimum coverage of one site per 300 km² across Europe (Jones et al. 2008). To reach this goal 4100 new monitoring sites would be required. In comparison to other European countries Austria already has a quite dense soil monitoring network (Morvan et al. 2008).

Blum et al. (2003) described the soil monitoring in Austria. Since 1989 there has been a new methodological approach, therefore, all data collected after 1989 is comparable throughout the whole soil surface of Austria. On agricultural land, the soil taxation survey and the soil management survey collected soil samples. All soil data obtained from different surveys in Austria is collected in the soil information system BORIS (Umweltbundesamt). It provides data of more than 10.000 sites in Austria and describes up to 600 soil parameters from over 40 different surveys. The data is not available for the public without confirmation from the data owner. BORIS would also provide some data about Si.

To report and evaluate the effectiveness of ÖPUL measures in Austria AGES - Agentur für Gesundheit und Ernährungssicherheit provides and collects soil information.

In the time between 1991 and 2009 AGES analysed 450.000 soil samples of agricultural land. The samples were compared in 4 to 5-year periods (1991-1995; 1996-2000; 2001-2005; 2006-2009). To this end farmers took soil samples on their fields, AGES analyzed the soils and later compared the data of all soils. For these soils, the exact sampling spot cannot be traced back as it is only connected to the farmer's resident place. Because of the big amount of taken soil samples a comparison is possible.

The soil analysis provided by AGES were originally offered to the farmers to give them an easy indicator of the nutrient status of their soils and for them to more easily be able to make farming recommendations. Since soil sampling is only obligatory for areas supported by ÖPUL, the soils provided for the analyses decreased in the last years and the samplings are mainly carried out for ÖPUL supported areas. AGES recommends to not only measure pH and nutrient availability but also humus concentrations.

In the years 1990 to 1992 the Bundesanstalt für Bodenkultur examined 3130 Lower Austrian soil samples in the course of the Bodenzustandsinventur (BZI). They stressed the need to examine soils in certain intervals to be able to make the right decisions for the effective

protection of the soil's most important functions. These single case observations brought interesting results about Lower Austria.

The oldest information about Austrian agricultural soils is provided by the national soil map "Digitale Bodenkarte" (eBod 2000). It consists of 219 mapping areas. Meanwhile, the soil mapping, started in 1979, provides a nearly all-encompassing soil map of Austria. Information is provided for public access and covers soil type, parent material, a detailed description of the soil horizons and analysis of the key soil parameters particle size distribution, pH, humus concentration and carbonates. Unfortunately, only around one quarter of these soil samples is left in the archive of Bundesamt für Wasserwirtschaft in the Institut für Kulturtechnik und Bodenwasserhaushalt in Petzenkirchen. The rest was disposed.

Nevertheless, very recently two master theses were conducted in the institute of soil research using these archived samples. Schiefer (2019) and Cocuzza (2017) resampled Lower Austrian topsoils that were available in the archive and analysed the key soil properties as well as the Si concentrations in archived and resampled soils. Schiefer's research focused on Cambisols. Cocuzza aimed to sample soils that are characteristic for various regions across Lower Austria.

1.3 Silicon

Silicon (Si) is the second most abundant element in the earth crust (Struyf et al. 2009). Si is practically ubiquitous and 90% of all minerals consist of Si. It has various industrial application, it is especially very much used in the high-tech industry – so much that there is even the term "semiconductor silicon industry" (Walsh et al. 2005). Silicon is also an important part of cosmetics and pharmaceuticals. It is present in all plants and animals in different amounts and the human body contains around 1 g of Si (Vasanthi et al. 2012).

1.3.1 Silicon in Soils

In soils, Si can be subdivided into two fractions: The liquid phase and the solid phase on which also the fractions of dissolved silicic acid are adsorbed onto (Matichenkov and Bocharnikova 2001). Figure 1 illustrates the different Si fractions. Silicon is sometimes deficient as a nutrient despite its abundance because it occurs mostly as silica (SiO_2), a form that is not available for plant uptake (Paye et al. 2018).

Industrial by-products such as blast furnace slag, steel slag and phosphorous slag are most commonly used Si fertilizers. The application of Si fertilizers results in increased yields due to the rise of the plant's tolerance to a wide range of biotic and abiotic stresses (Meena et al. 2014).

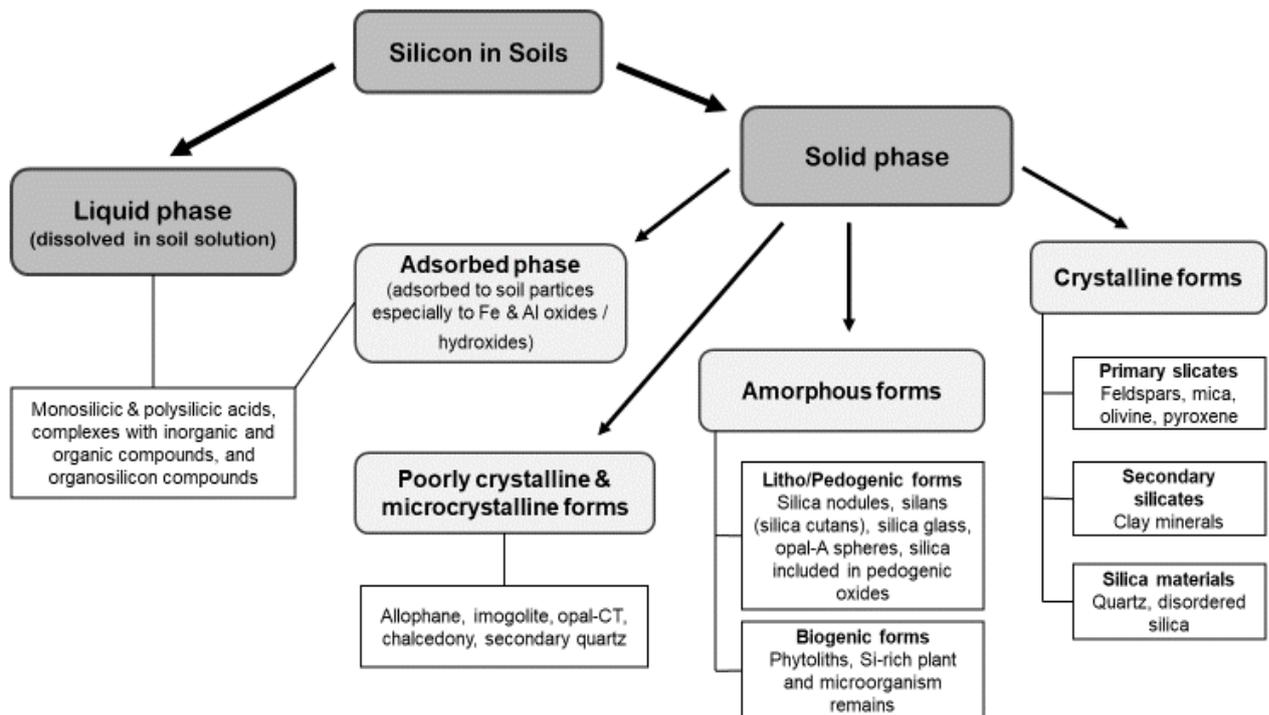


Figure 1 Different fractions of Si in soils, modified from Tubaña and Heckman (2015)

1.3.1.1 Silicon in the solid phase

The solid phase of Si can be divided into three primary groups (Figure 1): The **amorphous** form, the **crystalline** form and the **poorly crystalline and microcrystalline** forms. The largest fraction of the solid phase are the **crystalline** forms that are present as primary and secondary silicates and silica materials. Primary silicates in soils occur in sand and silt particles; secondary silicates are contained in clay particles. Si is also found in poorly crystalline and microcrystalline forms (Allen and Hajek 1989).

The **amorphous** forms of Si include forms of biogenic and of litho-/pedogenic origins. They are present in the total soil in amounts in a range from <1 to 30 mg/g (Drees et al. 1989). The biogenic forms arise from plant residues and the remains of microorganisms. Phytoliths are Si absorbed by plants (Sauer et al. 2006).

Haynes (2017) summarizes that especially in agricultural soils the biogenic Si often decreases with time. In arable land crop residues, like straw and husks, are often removed with the harvest of the crop. With the removal of the plant residues also the phytoliths are withdrawn. For Guntzer et al. (2012) the return of crop residues is most important to maintaining the biogenic Si pool in agricultural soils.

Silicon complexes with Al, Fe, heavy metals and soil organic matter are litho- and pedogenic forms of Si (Matichenkov and Bocharnikova 2001). The concentration of Si in the soil solution depends very much on the solubility of the different forms of Si in the solid phase. Solubility is determined by temperature, particle size, pH, chemical composition (type of Al and Fe oxides), organic matter concentration and exposed surface area (Sommer et al. 2006).

Amorphous Si has a high solubility and is therefore expected to contribute more to the total Si concentration in the soil solution, than quartz. The solubility of solid Si is constant between pH values between 2 and 8.5. It increases rapidly at a pH of ~9 (Tubaña and Heckman 2015). For CaCl₂-extractable Si it could be observed that more weathered soils with lower pH values also show lower Si concentrations (Haynes 2014). In general when observing large groups of soils in a region, positive relationships between pH and Si availability and extractability can be observed (Miles et al. 2014).

The concentration of silicic acid in soils is the main determinant for the Si concentration in plants (Ding et al. 2005). The Si availability in the soil influences the amount of Si absorbed by plants (Guntzer et al. 2012).

1.3.1.1 Silicon adsorbed on the solid phase

The dissolved Si fractions are adsorbed to a variety of solid phases in the soil like clay particles, Al and Fe hydroxides (Bruun Hansen et al. 1994). Al and Fe hydroxide can significantly reduce the amounts of dissolved Si in the soil solution with their strong adsorption capacity. The influence of secondary clay minerals is much more gentle (McKeague and Cline 1963).

1.3.1.2 Silicon in the liquid phase

In the soil solution Si occurs mainly as monomeric, oligomeric or polymeric acid. Monomeric silicic acid (H₄SiO₄⁰) is the plant available form and is relevant for plant absorption and nutrition while the polymeric form influences the soil aggregation (Iler 1979). Water holding and buffering capacity of the soils is improved through the creation of silica bridges by polysilicic

acid that enhance the soil aggregates (Tubaña and Heckman 2015). In common soils with a pH <8 the uncharged silicic acid H_4SiO_4 is mostly present (Iler 1979). The Si concentrations range from 0.09 to 23.4 mg/L in soils with pH <10 (Kovda 1985).

Wada and Inoue (1974) found pH as one of the main determining factors of the plant available Si concentration in soils, with a maximum at pH 9 to 10. Yanai et al. (2016) also observed that there is an increase of available Si concentration in accord with a pH increase. The adsorption of monosilicate by soil minerals increased with soil pH from 4 to 10.

In their experiments Yanai et al. (2016) also found positive correlations of plant available Si with clay content and negative correlations with the sand content. This brought them to the conclusion that plant available Si is essentially released from the finer fractions of soils.

Silicon dioxide (SiO_2), silicate minerals and plant residues are the main source of silicic acid in the soil solution. The physico-chemical properties in the soil are decisive for the amount of H_4SiO_4 released by the various forms of SiO_2 (Tubaña and Heckman 2015). Si is released into the soil solution by the weathering of silicate minerals. Clay minerals can be formed in combination with other elements, Si can be released into the streams and oceans or be used for the uptake by plants and microorganisms. Insoluble minerals that are resistant to weathering like feldspar and some complex silicates also contribute a small amount to the Si in the soil solution (Kovda 1985). The amount of H_4SiO_4 in the soil is influenced by the solubility of Si containing minerals, which is affected by pH, particle size, temperature, water, organic matter concentration and redox potential (Savant et al.). At pH 9-10 the maximum amount of H_4SiO_4 is adsorbed (Brown and Mahler 1988). During evaporation, transpiration and freezing, the deposition of SiO_2 is enhanced (McKeague and Cline 1963).

The concentration of Si in soil solution is also strongly related to the stage of soil development (and thus content of weatherable minerals) (Sommer et al. 2006), therefore, the soluble Si concentration of temperate soils is 5-10 times higher than in tropical soils (Foy 1992).

1.3.1.3 Interaction of Silicon with other Elements

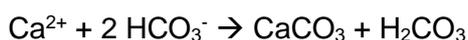
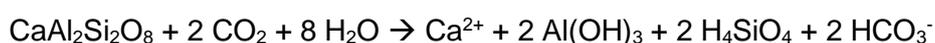
Silicon influences the dynamics of various elements in the soil: The absorption of N, P and K fertilizers is improved by Si in the soil. (Jang et al. 2018; Guntzer et al. 2012; Savant et al. 1997; Tubaña and Heckman 2015). In their work Tubaña and Heckman (2015) summarized various studies that through Si mediated mechanisms in the soil, plants are more tolerant to heavy metals like Aluminum, Arsenic, Cadmium, Lead or Zinc.

1.3.2 The Silicon Cycle

The Si Cycle in soil consists mainly of the above mentioned solid, liquid and adsorbed phases of Si. The uncharged form of H_4SiO_4 is the only form absorbed by plants and microorganisms (Tubaña and Heckman 2015). Within the plant tissue of the cell or of the microorganism the absorbed Si is deposited as polymerized silica. Through litter fall and the remains of microorganisms the polymerized silica returns to the topsoil and eventually enters the highly soluble silica pool that adds to the Si in the soil solution (Farmer et al. 2005). The decomposition of Si-rich manure can contribute to the level of available Si in the soil (Song et al. 2014) and it is recommended to spread manure from housed animals back onto agricultural lands to increase Si availability (Haynes 2017).

A number of processes control the Si concentration in the liquid phase: (a) the dissolution of Si, (b) the absorption of H_4SiO_4 in the soil solution by the vegetation and microorganisms, (c) the Si adsorption on and the desorption from various solid phases, (d) the preservation of the stable Si in the soil profile in the form of silica polymorphs, (e) leaching, and (f) addition (i.e., fertilization, irrigation, plant litter, animal manure and remains of microorganisms) (Tubaña and Heckman 2015). Wind-blown dust and phytolith particles that are deposited via the atmosphere also add Si to the soil. Still the contribution of atmospheric deposition of Si to the soil is low compared to other Si inputs in the soil-plant system (Street-Perrott and Barker 2008).

The weathering of silicates consumes CO_2 (Stumm and Morgan 1971):



Here Anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$) is weathered under the presence of water and CO_2 to Gibbsite ($2 \text{Al}(\text{OH})_3$). Hereby carbonates arise converted from the carbondioxide. Therefore the weathering of silicates is a CO_2 sink on terrestrial timescales (Berner et al. 1983).

1.3.3 Silicon in plants

As mentioned above plants take up Si from the soil solution in the form of H_4SiO_4 . The absorbed H_4SiO_4 is then transported to the leaf epidermal surface, where it is condensed into a hard, polymerized silica gel, called phytolith (Yoshida et al. 1962). Guntzer et al. (2012) summarized, that seven of the ten most produced crops in the world are Si accumulator plants: Sugar cane, rice, wheat, soybeans, sugar beet, barley and maize. The Si concentration in

these plants exceeds 10 g/kg and Si plays a substantial role to maintain their crop productivity. Plants with Si concentrations in the tissue below 5 g/kg are termed excluders and plants with values in between as intermediates (Ma and Takahashi 2002).

Silicon is beneficial for most plants but an essential plant nutrient for only two groups: The diatoms and the scouring rushes (Epstein 1999). For all other plants Si is not considered an essential nutrient. Contrary to the need of plants, Si is an essential nutrient for humans and animals, therefore soils need sufficient Si to produce highly nutritious food (Amelung et al. 2018). Although “only beneficial” the Si uptake of the high Si-accumulator plants mentioned before, is exceeding the uptake of the essential nutrients by far. Nitrogen is taken up in the largest amount among the essential plant nutrients and still rice accumulates twice as much Si as N (Tubaña and Heckman 2015). The Si concentration in high Si-accumulator plants ranges between 1% to 10% in dry weight (Liang et al. 2007). Silicon is a very important element for plants. It increases the plant’s tolerance to a wide range of biotic (insect pests and plant pathogens) and abiotic stresses (freezing, drought, heavy metal toxicities, salinity/sodicity) (Haynes 2017). The beneficial effects of Si become more evident in plants under stressed conditions than for plants growing under optimal conditions (Epstein 1999).

Plants can cope better with the lack of moisture when fertilized with Si because they have thicker and larger leaves which reduces the loss of water through transpiration and decreases the uptake of water. Also the roots are more resistant to dry soils and grow faster to be able to explore a larger volume of soil than plants which are not treated with Si (Hattori et al. 2005).

Silicon is reactive to heavy metals and impairs their translocation within plants. So eventually their toxicity is reduced (Ma et al. 2004).

Wang et al. (2017) explained how Si alleviates plant diseases on four paths: (1) Silicon improves the overall mechanical strength of the plant so that the pathogen cannot enter the host plant. A hard, protective outer layer is built by Silica deposits. This physical mechanism causes most benefits in crop quality and yield improves in Si fertilized crops (Epstein 1999). (2) Silicon stimulates the activity of defense-related enzymes that are linked to disease resistance. This is a biochemical mechanism. (3) Silicon may regulate the plant’s responses to stressors by adapting the signaling pathways and balancing the phytohormones. Here Si regulates the systemic signals. (4) Via molecular mechanisms Si is involved in the interaction of the plant with the pathogen and activates the defense genes of host plants.

The age of the plant affects its Si concentration: older leaves contain significantly more Si (Henriet et al. 2006).

Tubaña and Heckman (2015) summarized that more than 210 million tons of Si are removed annually from the fields by various agricultural crops. Due to intensive cropping of high Si-accumulator plants, plant-available Si is drastically reduced in soils by the harvest of these crops.

Tubaña and Heckman (2015) gave an overview of critical values of plant-available Si concentration in soils for selected crops. Depending on soil type and extraction method, for rice the upper limit of deficiency lies between 19-207 mg/kg soil. They also looked at wheat, which is more relevant for the Austrian agriculture. For wheat the upper limit of deficiency ranges between 71-181 mg/kg. Due to different extraction methods the deficiency limits cannot be compared. For sugarcane Haysom and Chapman (1975) defined the upper limit of Si deficiency at 20 mg/kg when extracted by 0.01 M CaCl₂. Babu et al. (2016) found a critical soil Si concentration for rice between 37 and 110 mg/kg when extracted with 0.01 M CaCl₂. Narayanaswamy and Prakash (2009) defined it at 43 mg/kg for rice.

According to Landré et al. (2018), who developed a method to predict Si concentrations in soils, there are some maps about Si in European soils by De Vos et al. (2006) and Reimann et al. (2014). The maps are not available for the public. Landré et al. (2018) also criticize that soil Si concentrations are mainly measured in rice-growing areas but rarely in non-paddy regions, especially not in Europe.

1.4 Measurement of Silicon

To extract plant available Si fractions, different methods are known, however, none of them is universally accepted (Haynes 2014). A method primarily developed in Asia is the sodium acetate buffer method, which is recommended for the estimation of the Si availability in calcareous soils for wheat. An extraction method with 0.5 N acetic acid was developed in Florida and mainly used for organic and mineral soils of the region with typically low clay, Al and Fe contents (Rodrigues et al. 2003).

Another method, firstly used in Australia, is the extraction with 0.01 M CaCl₂ (Rodrigues et al. 2003). CaCl₂ is the weakest extractant after pure water and turned out to have the highest correlation to sugar cane yields (Sauer et al. 2006) in addition to a satisfying positive correlation in experiments with other plants (Babu et al. 2016). The ionic strength of the 0.01 M CaCl₂ is similar to that of the soil solution (Haynes 2014). That is why we chose to measure potentially plant available Si with a CaCl₂ extracting method, modified by Duboc et al. (2017), from Haysom and Chapman (1975).

Tubaña and Heckman (2015) refer to various authors stating that amorphous Si is best extracted at higher pH, because then its solubility increases. The extraction of amorphous Si using NaOH is a standard method already developed in the 1950s. Nonetheless, it must be said that there is a tendency to overestimate the amorphous Si when applying this method because the silicate minerals dissolve partially as well and eventually release Si.

Silicon colorimetric measurement is a method to measure Si in an extract: The Si filtrate is diluted with water and three different solutions are added to it in a given time. The last solution contains molybdenum, it gives the extract a blue colour. The amount of blue colour is measured with a photo spectrometer and tells about the Si concentration.

Monosilicic acid (H_4SiO_4) is the only form of Si reactive to molybdate. Other forms of Si have nearly no effect on the formation of a Si-molybdate complex. This Si-molybdate complex forms an intensive blue colour, the higher the concentration of monosilicic acid. Nevertheless they point out that because the molybdenum blue method is very sensitive, a high dilution of the sample is required which may lead to magnification of any measurement errors (Tubaña and Heckman 2015).

1.5 pH

The soil pH reflects the soil's development from parent material under the climatic conditions of the site and the current soil management. The soil reaction ranges from strongly acidic (pH < 4.6) to strongly alkaline (pH > 8.0). Most agriculturally used soils in Austria lie in the pH-range of 4.6 to 5.5 (acidic), 5.6 to 6.5 (slightly acidic), 6.6 to 7.2 (neutral) and 7.3 to 8.0 (alkaline). In the northeast of Austria, where precipitation is low and soil formation took place mainly on calcareous sediments like Loess, the pH-values are mostly stable in the alkaline range around 7.5. In more humid climates acidification takes place due to soil development and farming. This is primarily a natural process because more acidic protons are deposited than the soil can neutralize. Acidic protons are deposited through precipitation, soil processes such as the breathing of soil microorganisms, soil animals and plant roots as well as by fertilization with ammonium. Nutrients with an alkaline effect like Calcium and Magnesium are washed out and the soil buffer systems are increasingly exhausted. Through the acidification process the soil quality is reduced and plant growth is increasingly affected. Heavy metal mobility increases considerably in the acidic pH range. Nutrient availability is at its best in the slightly acidic to neutral pH range. Micronutrient availability is reduced in the alkaline pH range (Baumgartner et al. 2011).

1.6 Soil Organic Carbon

The first meter of soils store more carbon (C) than the atmosphere and the terrestrial vegetation combined. The amount of soil organic carbon (SOC) stored in the soil is the result of the amount of C entering the soil and the amount of C leaving the soil. SOC is one of the key properties associated with many soil function: it is a source of nutrients, therefore, a high SOC stock increases crop yields (especially in low-input degraded land) (Lefèvre et al. 2017). Soil organic carbon also plays a key role in the regulation of climate, water supplies, and biodiversity (Garcia et al. 2018).

The amount of C stored in the soil is mainly controlled by the amount and type of organic residues entering the soil (Lefèvre et al. 2017) and varies significantly between land use types (Clymans et al. 2011).

Soils with an optimal SOC concentration have a better water holding capacity and can create resilience against extreme weather conditions like storms, floods and droughts: They can absorb and store water during extensive rain and make it available under drought conditions (Lefèvre et al. 2017). Additionally, SOC improves the soil stability, primary production, C sequestration, biodiversity, nutrient cycles and soil fertility. Consequently SOC allows the provision of ecosystem services essential to human well-being (Masciandaro et al. 2018).

1.6.1 Soil Organic Carbon is a component of Soil Organic Matter

Soil organic carbon is the main component of Soil Organic Matter (SOM); SOM contains roughly 55-60% C. In many soils the C stock of the SOM is nearly the total C present in the soil, except for soils where inorganic C is present.

Organic residues, such as tissue from dead plants and animals, materials less than 2 mm big and soils organisms, in various stages of decomposition are summarized under the term Soil Organic Matter (SOM). The decomposition of SOM is mainly controlled by the soil temperature and water content.

Soil organic matter is crucial for the stabilization of the soil structure, the cycle of plant nutrients and the water holding capacity. The decomposition of SOM releases mineral nutrients and makes them available for plants. In this way SOM enhances plant growth and makes higher yields possible. (Lefèvre et al. 2017)

Soil organic matter is necessary for the formation of stable aggregates and a secondary pore system. This allows water movement into the soil profile, better aeration and soil moisture

retention. It also improves heat capacity, cation exchange capacity and soil buffering power (Garcia et al. 2018).

Soil organic matter can be divided into two pools:

- **Active pools** that turn over in months or a few years
- **Passive pools** that turn over in up to thousands of years

Long turn over times are explained not only by anaerobic conditions like in peat soils but also by the incorporation of SOM components into soil aggregates, the attachment of organic matter to protective mineral surfaces, the spatial disconnection between SOM and decomposers and the intrinsic biochemical properties of SOM (Lefèvre et al. 2017).

Soil Organic Carbon (SOC) is similarly to SOM divided into different pools according to its physical and chemical stability:

- **Fast pool** (labile or active pool) – Fresh organic carbon is added to the soil; within 1-2 years a large proportion of the initial biomass is lost through decomposition and emitted back into the atmosphere as CO₂
- **Intermediate pool** – consists of microbially processed organic carbon that has longer turnover times in the range of 10-100 years by stabilizing on mineral surfaces and/or protection within aggregates
- **Slow Pool** (refractory or stable pool) – highly stabilized SOC that turns over very slowly in 100 – 1.000 years

The labile carbon pool is described as an indicator of the key physical and chemical properties of the soil. The stable SOC pool mainly determines the soil's nutrient holding capacity (cation exchange capacity); because of its slow decomposition, it is also interesting for long term C sequestration. (Lefèvre et al. 2017)

Through mineralization of organic matter, soils can lose their C again as CO₂. Sustainable land management should prevent this development. In colder areas microbial activity is very low due to the low temperatures, therefore mineralization processes are very low and these soils are the greatest sinks for organic C worldwide. (Garcia et al. 2018)

1.6.2 Soil Organic Carbon Sequestration

Carbon from the atmosphere can be fixed via plants and organic residues and stored in the soil. This process is called soil organic carbon sequestration. Soil organic carbon sequestration has three stages: 1.) Plant photosynthesis removes CO₂ from the atmosphere; 2.) C is

transferred to plant biomass; 3.) C is transferred from the plant into the soil where it is stored in the most labile pool. To sequester C for a longer time it is important to find ways to catch C in the stable pool for long periods of time. Due to its resistance to change and irresponsiveness to management, C sequestration in the stable pool is difficult.

The maximum C stabilization capacity is reached when the soil has approached C saturation and no more soil C inputs can be stored. When C saturation is reached SOC sequestration comes to an end and the soil might turn from a net C sink to a net C source. Soil organic carbon sequestration has spatial and temporal limitations and is a reversible process. Most soils around the world are far from C saturation and have a great potential to sequester C (Lefèvre et al. 2017).

It is expected that cropland soils can sequester organic C for more than 20 years until an equilibrium is reached (Zomer et al. 2017). The „4 per 1000“ initiative, that was introduced at the Convention on Climate Change (COP 21) 2015 in Paris, aims to promote an annual increase of 0.4 % in SOC sequestration globally to mitigate the climate catastrophe. Schiefer et al. (2018) investigated this goal for Austrian soils and found out that the regarded Lower Austrian Chernozems from Marchfeld can, due to the soil age and its therefore much lower increase rate in OC stocks, not contribute to the 4 per 1000 goal on the middle and long term.

The largest spots of SOC are in wetlands and peatlands which occur mainly in permafrost and tropic regions (Lefèvre et al. 2017). Nevertheless around 12 percent of the world's total SOC are stored in crop land (Masciandaro et al. 2018).

Croplands are also estimated to be the biggest biospheric source of C. But the actual amount of C lost to the atmosphere by cropland remains very uncertain because literature doesn't draw a uniform picture and estimated fluxes vary a fair amount (Smith 2004).

To balance the C household, Lefèvre et al. (2017) recommend management practises that aim to increase photosynthetic and SOC sequestration potential (through afforestation, reforestation and cover cropping), decrease greenhouse gas emissions and SOC losses (through conservation/reduced tillage and organic farming); and increase food production by improving soil properties for better water, nutrient and pH buffering capacity (by adding organic complements such as compost and biochar).

Chernozems and Phaeozems are described by Lefèvre et al. (2017) as very productive and therefore also very intensively used soils. They are highly sensitive to soil degradation and SOC losses. To maintain their productive potential, they need to be managed carefully. In natural ecosystems the SOC concentration of Chernozems ranges between 2.9 and 3.5

percent in the upper 10 cm. Below the lower boundary of the chernic horizon the SOC concentration is still more than 1.2 percent.

1.7 Nitrogen

Nitrogen (N) is the most abundant gas in the air and also quantitatively the most important nutrient for plants and microorganisms. Nitrogen is essential for photosynthesis because it is an integral part of Rubisco, the enzyme that catalyses the photosynthesis (Amelung et al. 2018). One ha of soil can contain 3 000 kg to 20 000 kg of N. In the soil, N is mostly present in organic bonds (90-98%). The share of N in the organic substance is given as C/N ratio. Nitrogen rich soils have a C/N ratio of 6-10, N poor soils have C/N ratios above 25. Other than N in organic substance there is also microbial nitrogen. It changes a lot depending on the site and the season. Generally, between 100 and 400 kg microbial N are stored per ha. The mineral N pools fluctuate even more than the microbial pool. Through degradation of organic matter by microorganisms, Ammonium (NH_4^+) is produced; in biologically active, well aerated and not too acidic soils NH_4^+ is oxidized to Nitrite (NO_2^-) and then to Nitrate (NO_3^-). It can be detected that Ammonium is mainly found in very acidic and poorly aerated soils; in well aerated, slightly acidic to alkaline soils, Nitrate is mainly found. The mineralization of N increases in spring through warming and decreases throughout the vegetation period through the withdrawal of plants. The turnover rate of N is very high in comparison to the stocks and can reach up to 10%. In cropland N is added through fertilization (Stahr 2012).

1.8 Objective

The objectives of my present study were to (1) monitor the current status of plant available and amorphous Si fractions, the soil acidity (pH), organic carbon and nitrogen, as well as the temporal changes of these soil factors in the last 30 years. (2) To examine the influence of soil- and climate factors on the Si fractions. (3) To assess the soil quality or possible change of the soil quality based on the gathered data (Si availability in comparison to critical values of deficiency, C:N and pH in comparison to favourable ranges and OC in comparison to the saturation potential).

1.9 Hypotheses

- **Objective 1: Monitoring of the current status, registration of temporal changes and assessment of the soil quality:**

Hypothesis H1.a: The amount of soils with plant available Si concentrations under the critical level for optimal plant growth and stress resilience has increased in the last three decades and is substantially high.

Hypothesis H1.b: The amorphous Si concentrations in agricultural top soils has been decreasing in the last three decades due to Si removal with harvest and the use of crop residues.

Hypothesis H1.c: pH did not show substantial changes and is at a favourable level.

Hypothesis H1.d: Organic carbon concentrations have been increasing over the last 30 years.

Hypothesis H1.e: Soils contain enough Nitrogen and show favourable C/N ratios.

- **Objective 2: Examine the influence of soil- and climatic factors on the Si fractions**

Hypothesis 2: The Si concentration in soil is influenced by a variety of factors:

H2.a: pH: Higher soil pH levels increase Si solubility and are expected to lead to higher plant available Si concentrations. As weathering is usually higher in more acidic soil pH levels, higher amorphous Si concentrations are typically associated with lower soil pH.

- H2.b: C: High organic carbon concentration causes higher concentrations of amorphous Si because both are correlated with the input of organic matter and phytoliths.
- H2.c: Climate: Soils in areas with cold temperatures and low precipitation show slower weathering rates and, therefore, lower concentrations of amorphous Si.
- H2.d: Texture: Coarse soil texture is expected to enhance leaching, slow down the weathering rate and to provide less surface area for Si sorption. We expect the Si concentrations to be higher in soils with higher clay content and lower sand content.

2 Materials and Methods

2.1 Study design

For this research 99 topsoils in Lower Austria were resampled and different soil parameters were analyzed in the laboratory and compared with corresponding archived samples.

2.2 Soil sampling and preparation of the soils for the lab work

I focussed on “Tschernosem, Paratschernosem and Feuchtschwarzerde soils”, as classified by the Austrian soil classification system (Fink 1969), corresponding mainly to Chernozems and Phaeozems according to the “World Reference Base for Soil Resources 2014” (FAO 2014). The Digitale Bodenkarte (eBod 2000) provides detailed information about Austrian soil conditions.

The archive of Bundesamt für Wasserwirtschaft – Institut für Kulturtechnik in Petzenkirchen in Lower Austria stores soil samples from a soil mapping campaign of the 1980s and 1990s. Between November 15, 2016 and March 12, 2017, 99 of these soils were resampled. The coordinates provided in the Digitale Bodenkarte (eBod 2000) of Bundesforschungs- und Ausbildungszentrum für Wald, Naturgefahren und Landschaft were used to find the corresponding spots. The GPS data there is provided in Austrian Lambert. With the coordinate converting system epsg.io, the Lambert coordinates were translated to WGS84 coordinates, so google maps could be used for navigation.

The soil samples were taken in five soil mapping regions: Schwechat, Mödling, Retz, Laa and der Thaya Nord and Laa an der Thaya Süd.

Climate data, including mean annual temperature and precipitation, of the period between 1980 – 2010 was taken into consideration.

The temperature was obtained through the web service of Zentralanstalt für Meteorologie und Geodynamik (ZAMG) which provides climate data of more than 200 places in Austria. ZAMG does not have a meteorological station in Mödling, so data of the closest meteorological station, which is in Gumpoldskirchen, was taken into account (Ressler 6/5/2019).

The precipitation was calculated as an average of the available data from ZAMG and Bundesministerium für Nachhaltigkeit und Tourismus (BMNT). For Mödling, the value of ZAMG was again from Gumpoldskirchen.

Table 1 shows the mean annual temperature and precipitation in the sampling areas Schwechat, Mödling, Retz and Laa an der Thaya in the climatic period from 1981 – 2010 (ZAMG; BMNT).

Table 1 Mean annual temperature [°C] and mean annual precipitation [mm/m²] of the sampling areas

	Temperature [°C]	Precipitation [mm/m ²]
<i>Schwechat (n=16)</i>	9.9	568
<i>Mödling (n=20)</i>	10.3	636
<i>Retz (n=16)</i>	9.5	524
<i>Laa an der Thaya (n=47)</i>	9.6	510

The mean annual temperature differences in the sampling areas are maximum 0.8°C. This might seem very low, but putting 0.8°C in relation to the temperature variance in the Holocene brings 0.8°C into perspective: Since the beginning of the Holocene the global temperature only varied less than 1°C (ZAMG n.d.).

For some soils, only one soil sample was taken: The spade was put into the ground, max. 30 cm deep, the soil was then put into a plastic bag. For other soils, a sample was taken at the middle point (as given from the coordinates of the archived soils) and then nine further samples were taken in a radius of 10 meters around it, to get a mixed sample in the plastic bag. The soil samples were stored in the plastic bags in the university building in Tulln. After air drying for a few weeks the soil samples became very hard chunks. Mostly, the samples had to be chopped with a mallet in a big plastic box to be able to sieve them. All samples were sieved to a grain size of 2 mm with soil sieves and then put into plastic bags again. In between the handling of the samples, the plastic box and the sieve were cleaned with a broom. In the evening both were washed out with water and left to dry overnight. A part of every sieved sample was also milled with a Retsch ball mill to get very fine material. For easier handling in the laboratory, parts of the sieved samples and all the finely milled samples were put into separate small plastic bottles. The open bags with the sieved soil samples remained in the storage area. There, further drying could occur.

2.3 Determination of basic soil properties

The basic soil properties of the archived samples (soil texture, organic matter concentration and soil pH) were retrieved from the eBOD system (eBod 2000). They had been determined according to following procedures:

- Soil texture was determined through wet sieving, after destructing the soil micro aggregates with a dispersing agent (tetrasodium pyrophosphate) and shaking. The particle's diameter intervals were defined <0.002 mm for clay, 0.002 – 0.06 mm for silt and 0.06 – 2 mm for sand.
- Organic matter concentration (humus) was measured using the Walkley method. The fraction of organic substance (representing humus concentration) was oxidized through wet combustion.
- Soil pH measurement was conducted by mixing the soil fine fraction in a solution of 0.01 M CaCl₂, at a ratio of 1:2.5. pH was measured electrometrically with a glass-electrode.

Soil texture was assumed to be relatively stable since the initial sampling. Therefore, only soil pH and organic carbon were determined on the resampled soils.

2.4 Work in the laboratory

The laboratory work was done in the laboratories and greenhouse of the Institute of Soil Research of the University of Natural Resources and Life Science, Vienna. Mainly on the sites of Tulln, only the carbonate measurement (for the determination of OC) was done on Türkenschanze. The Total Carbon (TC) and nitrogen concentration was measured by Craig Jackson from the Division of Agronomy of BOKU in Tulln.

HQ (high quality) water ($\leq 0.055 \mu\text{S}/\text{cm}$, TKA-GenPure, Thermo Electron LED GmbH, Niederelbert, Germany) was used for laboratory procedures and preparation of extracts.

All extractions and measurements were conducted at room temperature. Like Haysom and Chapman (1975) did in their research, only PE plastic materials were used for Si measurements to avoid Si uptake from glassware. The PE plastic equipment was cleaned in the following procedure:

1. Wash equipment in dish washer
2. Acid wash by immersion in a 5% HNO₃ bath for at least six hours
3. Rinse the equipment three times with HQ water
4. Base wash by immersion in a 0.1 M NaOH bath for at least six hours
5. Rinse the equipment three times with HQ water
6. Allow to dry under a drying hood

All chemical reagents used in this work were of purest available grade supplied by Alfa Aesar (Karlsruhe, Germany), Sigma-Aldrich (Vienna, Austria), Merck (Vienna, Austria) or VWR (Vienna, Austria). All analytical instruments were checked for daily performance and calibrated regularly.

2.4.1 Silicon extractions

The amount of plant available Si is interesting because it can inform if the soil provides enough Si for optimal plant growth or if there might be the need for fertilization (Tubaña and Heckman 2015).

To determine potentially plant available Si, the samples were measured in two replicates: Air dried and sieved (< 2 mm) soil was used. 3 g of soil were weighed into 50 mL plastic centrifuge vials. A Sartorius CP 225 D balance was used. An inaccuracy of max. 0.015 g was accepted for the soil samples. Then 30 mL of 0.01 M CaCl₂ solution were added. When closing the vials, the vials were always shaken with the hand for a moment. The vials were then put on an overhead shaker (GFL 3040) for 16 hours at 5 rpm. After 16 hours the samples were taken off the shaker, shaken again with the hand and then filtered with plastic funnels and Munktell Ahlstrom folded filters into plastic vials. The contained plant available Si was measured in the filtrate, applying the Si colorimetric measurement described in 2.4.2.

To measure potentially amorphous Si a modified method of Georgiadis et al. (2015) was applied. The samples were measured in two replicates: Air dried, milled soil was used. 75 mg soil were weighted into 50-mL plastic centrifuge vials. A Sartorius CP 225 D balance was used. An inaccuracy of max. 0.84 mg was accepted for the soil samples. Then 30 mL of 0.2 M NaOH solution were added. When closing the vials, the vials were always shaken with the hand for a moment. The vials were then put on an overhead shaker for 120 hours at 5 rpm. After taking the samples off the shaker, the vials were shaken again with the hand and filtered with funnels and Munktell Ahlstrom folded filters into plastic vials. The Si concentration was afterwards measured in the filtrate, applying the Si colorimetric measurement described in 2.4.2. Sometimes it was not possible to measure the samples on the same day. In that case the

samples were put into the refrigerated storage room at 4°C and measured a few days to a few weeks later.

2.4.2 Silicon colorimetric measurement

To measure Si in the filtrates, the Si colorimetric measurement method was applied. It was adapted from our group members Duboc et al. (2017) according to Morrison and Wilson (1963) and Webber and Wilson (1964).

In preparation of the Si measurement the calibration standards were compounded (Duboc et al. 2017):

Standard Calibration:

The standards were prepared in a range of 0 – 16 mg/L Si in 0.2 M NaOH and were diluted 1:10 during colouring. This range was chosen to cover the typical Si concentration in the 0.01 M CaCl₂ or 0.1 M NaOH soil extracts.

The Si standard stock (1000 mg Si L⁻¹ in H₂O with tr. HNO₃, tr. HF; Density = 1.003, Inorganic Ventures) was diluted to 100 mg/L on the scale by mixing 2.508 g stock solution + 22.455 g HQ H₂O (corresponding to 2.5 mL + 22.5 mL = 25 mL).

0.4 M NaOH was used for the standard preparation. The standard solutions (45 mL each) were prepared on the scale using the data in grams (Table 2). The accuracy of weighing was taken care of until the third digit after the decimal point.

The calibration standards were stored in a refrigerator at 4°C and brought to room temperature before use.

Table 2 Preparation of calibration standards for colorimetric determination of Si concentrations; Blank, Std1, Std2, Std3, Std4, Std5, Std6 = label for Si standard solutions with Si concentrations ranging from 0 – 16 mg/L;

Si-std diluted = diluted Si standard stock

Densities of solutions		
Si work	0.4 M NaOH	H ₂ O
g/mL		
0.999	1.016	0.998

	Si. conc. mg/L	Si-std diluted (100 mg Si/L)		
		0.4 M NaOH	H ₂ O	
		mL		
Blank	0.00	0.000	22.500	22.500
Std 1	0.50	0.225	22.500	22.275
Std 2	3.00	1.350	22.500	21.150
Std 3	6.00	2.700	22.500	19.800
Std 4	9.00	4.050	22.500	18.450
Std 5	12.00	5.400	22.500	17.100
Std 6	16.00	7.200	22.500	15.300

	Si-std diluted (100 mg Si/L)			
	0.4 M NaOH	H ₂ O		Final weight
g				
Blank	0.000	22.858	22.455	45.313
Std 1	0.225	22.858	22.455	45.313
Std 2	1.350	22.858	22.455	45.313
Std 3	2.704	22.858	22.455	45.313
Std 4	4.056	22.858	22.455	45.313
Std 5	5.408	22.858	22.455	45.313
Std 6	7.211	22.858	22.455	45.313

Colouring and measurement:

The three reagent solutions were prepared:

- Acidified molybdate solution: To gain 250mL solution the dilution was made as follows: 22.25 g of ammonium molybdate ((NH₄)₆Mo₇O₂₄ · 4 H₂O) were dissolved in a PE volumetric flask with 200 mL HQ H₂O. 15.75 mL sulphuric acid (H₂SO₄ 98%) were diluted separately in a PE beaker by adding it cautiously to water, it was stirred and allowed to cool. The diluted acid was added to the molybdate solution and brought to the final volume of 250 mL with HQ water (Morrison and Wilson 1963).
- Tartaric acid solution: To gain 250 mL solution, 70 g of Tartaric acid powder were dissolved in HQ water and brought to 250 mL.
- Reducing Agent solution: To produce 100 mL solution, 1.2 g of Sodium sulphite (Na₂SO₃) and 0.2 g of 1-amino-2-naphthol-4-sulphonic acid were dissolved in about 70 mL HQ water in a PE volumetric flask. Then potassium metabisulphite (K₂S₂O₅) was added and shaken well until dissolved. HQ water was added to dilute the solution until a volume of 100 mL was reached.

The reducing agent was freshly prepared each week (Morrison and Wilson 1963). Both the acidified molybdate solution and the tartaric acid solution have been found to be adequately stable for at least 6 months (Webber and Wilson 1964). Volumes were always measured with Eppendorf pipettes.

For the colouring process the liquids were mixed in the following order in a 20 mL plastic vial:

- 1 mL of filtrated sample or calibration standard
- 7.75 mL HQ H₂O
- 0.5 mL acidified molybdate solution; mix immediately by hand vortexing; wait for 10 +/- 3 min
- 0.5 mL tartaric acid; mix immediatly by hand vortexing. Wait for 5 +/- 1 min
- 0.25 mL reducing agent; mix immediately by hand vortexing.

The measurement at 810 nm wavelength was carried out with a Varian DMS 200 UV visible spectrophotometer 1 – 24 hours later. The device was turned on at least half an hour before starting the measuring and set to 0 with blank HQ H₂O.

2.4.3 pH

pH needed to be measured only for the resampled soils. For the archived soils, the data was already provided from eBod (2000). The pH measurement was done according to ÖNORM L 1083-89: 10 g of air dried soil were weighed into 50 mL plastic bottles. A difference of up to 10 mg was accepted. 25 mL of 0.01 M CaCl₂ were added to the 10 g of soil to gain a soil to solution ratio of 1:2.5. The bottles were then shaken until completely mixed. After two hours the suspension was shaken again. The measurement started after the soil deposited on the ground of the plastic bottle. The electrode was put into the liquid phase and measured the pH in the 0.01 M CaCl₂ solution. The value on the display was accepted when stable. For every sample two replicates were made and the mean was taken as the result. A Hamilton Pro Lab 400 Schott Instruments pH meter was used to measure the pH.

2.4.4 Water content

The water content was measured to relate results of all analyses to air-dried soil.

To measure the water content of the resampled soils, around 10 g of air-dried soil were weighed into porcelain dishes. The mass of the porcelain dishes was also weighed. For both, a Sartorius GPA 3202-OCE balance was used. The samples were dried in a Memmert oven at 105°C for at least 24 hours. After 24 hours the samples were taken out and left in Duran exsiccators to cool down. When cool the porcelain dishes with the soil were weighed again. Later the percentage of soil water was calculated according to the following formula:

$$\frac{\text{wet soil} - \text{dry soil}}{\text{dry soil}} \times 100$$

The water content was measured for all resampled soils and for 11 archived samples. For the water content, no repetitions were made except for six resampled soils. Two of them were repeated because the water content was above 10%, the others were taken for control reasons. The soil water content was only considered for analysing the data. For the experiments air-dried soil was always used, never oven dried material.

2.4.5 Organic Carbon

The organic matter concentration (humus) of the archived soils was determined by the Walkley-Black method. To define the OC based on this information, the data was corrected: Humus (%) was divided by the van Bemmelen factor 1.724 to get the amount of C in humus (%). Depending on the result, the correction factor for wet oxidation according to Gerzabek et al. (2005) was used: Up to 3 % C, the results have to be multiplied with a correction factor of 1.13, between 3-7% with a factor of 1.20, between 7-9% with a factor of 1.24, between 9-12% with a factor of 1.3, between 12-14% with a factor of 1.35 and above 15% with a factor of 1.40. Like this, organic C determined by wet oxidation can be compared with results from dry oxidation.

For the resampled soils, the total C concentration was measured in an Elementar Vario Macro Cube. It determines the total C by dry combustion according to the ISO 10694 norm. As the aim was to find out the amount of organic C, the inorganic C concentration (carbonate) was measured using the Scheibler method, and later subtracted from the total C concentration.

The calcium carbonate equivalent was measured using the method of Scheibler according to ÖNORM L 1084, for all resampled soils with a pH > 7, and for soils with a pH between 6 and 7 that showed reaction with diluted HCl (18.5 % 1:1 with water) in a pre-test. The Scheibler equipment is depicted in Figure 2. Two replicates were made. The pressure and temperature in the laboratory were continuously measured. 0.5g – 2 g grounded soil were weighed into glass flasks. Then a vessel in the middle of the flask was filled with around 7-8 mL HCl (18.5% 1:1 with water). The glass flask was closed very densely with a stopper that was connected to a hose, to which the CO₂ could outgas. Henceforth the glass flask was shaken, so that the HCl could get in touch with the soil. The CO₂ displaces the green barrier liquid in the retort; in case of a big foamy reaction, the barrier liquid was let out with the compression bib to a bottle at the other side, to prevent overflow. After about 15 minutes of waiting time (or when no more

changes were observed) the volume of CO₂ in this sample was read from the scale on the retort.

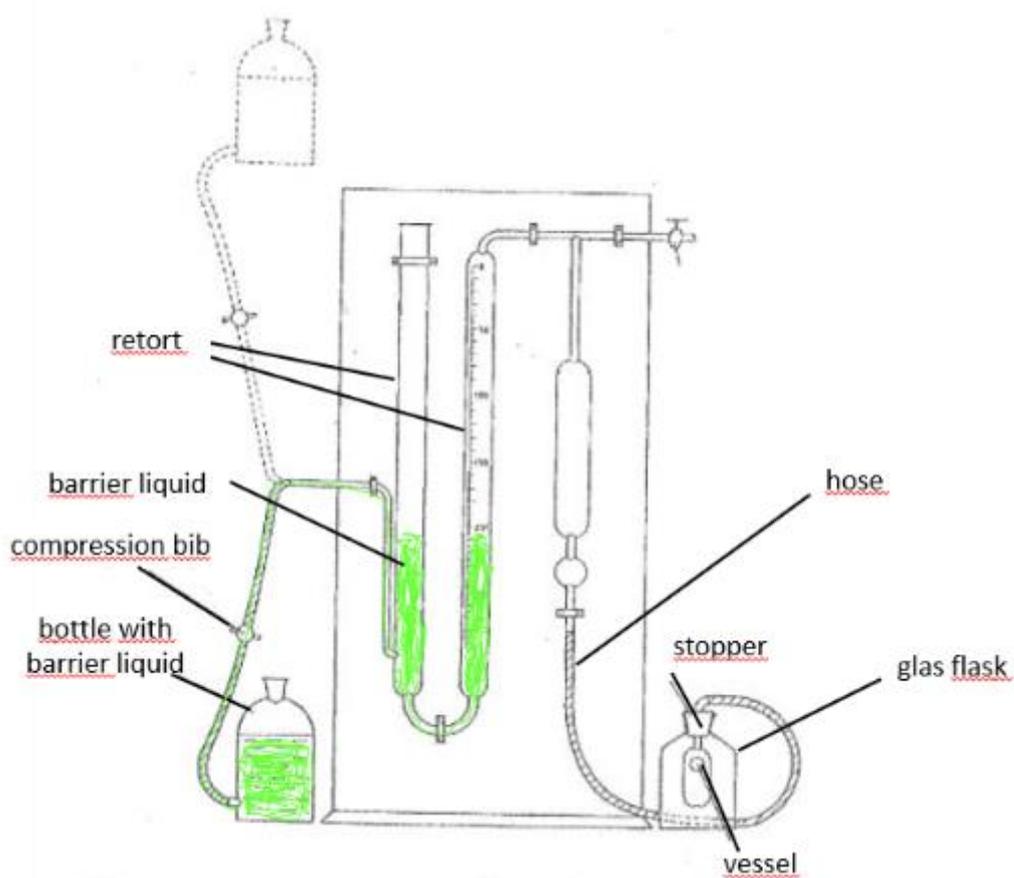


Figure 2 Scheibler equipment; edited after Neubert Glas

The mass fraction of the calcium carbonate equivalent in g/kg can then be calculated using the following formula:

$$w_{CaCO_3} = \frac{0,12120 \times V \times p}{m \times (T + 273,15)}$$

w CaCO ₃ [g/kg]	mass CaCO ₃ in the soil sample
V [mL]	the Volume of CO ₂ read on the scale
p [hPa]	atmospheric air pressure in the laboratory during reading the scale
m [g]	weighed solid mass of soil
T [°C]	temperature during the experiment

The calculation relies on the assumption that the whole released gas in the reaction flask is CO_2 and comes only from $(\text{CO}_3)^-$ and that lime was the only carbonate. To get the OC concentration of the soil sample, the Carbonate concentration was subtracted from the TC concentration.

2.4.6 Nitrogen

The total nitrogen concentration was determined in an Elementar Vario Macro Cube by dry combustion according to the UNE 77325:2003-04-11. It was only measured for the resampled soils.

2.5 Control experiments for method validation

To validate the soil sampling concept and to see if the methods in use are reliable two control experiments were made: One connected to the soil sampling on the fields and one connected to the Si extraction methods in the laboratory.

2.5.1 Soil sampling

The aim of this experiment was to find out how homogenous the soil on the fields was. The coordinates in eBod (2000) were only belatedly connected to the spots that were at the time of first soil sampling only marked in a map by hand. This might result in an inaccuracy of finding the exact same spot when resampling the soils. To know how much variation there might be on the field and consequently in the samples, this control experiment was conducted: One sample was taken at the exact spot that the coordinates indicated. Then four more bags were filled: each with soil from ten different spots that were taken in a radius of 10 m around the middle point. The samples were then also extracted with 0.01 M CaCl_2 and 0.2 M NaOH and tested for Si with the Si colorimetric measurement. This procedure was done for sample no. 1022 and for sample no. 213037.

Table 3 summarizes the general descriptive statistics of the control experiment for soil sampling.

Table 3 General descriptive statistics (minimum, maximum, mean, median, standard deviation, skewness, kurtosis and difference) of the control experiment for soil sampling

soil no.	1022		213037	
	0.01 M CaCl ₂ n=5 Si [mg/kg]	0.2 M NaOH n=5 Si [mg/kg]	0.01 M CaCl ₂ n=5 Si [mg/kg]	0.2 M NaOH n=5 Si [mg/kg]
Min	21.5	821	40.5	2120
Max	27.0	885	52.8	2180
Mean	23.8	843	48.7	2140
Median	23.5	837	52.4	2140
SD	2.2	24.6	5.6	22.5
Skewness	0.3	0.8	-0.5	0.5
Kurtosis	-1.8	-1.2	-1.9	-1.6
Difference min - max	5.4	64.3	12.3	56.9
Difference of mean in %	22.8	7.6	25.2	2.7

For soil no.1022 a maximum difference of the results to the mean of 22.8% could be observed for the CaCl₂-extractable Si, for the NaOH-extractable Si fraction it was 7.6%. For soil no. 213037 a maximum difference of the results to the mean of 25.2% could be observed for the CaCl₂-extractable Si fraction, for the NaOH-extractable Si fraction it was 2.7%. Note that the differences within the soil samples are higher for the CaCl₂-extractable Si fraction. The results vary up to 25%, which seems like quite a large difference, so the soil within one field cannot be assumed to be totally homogenous. This will be kept in mind for further interpretations.

2.5.2 Silicon extraction

To check the robustness of the Si extraction methods, two samples of previous analysis in our working group were chosen. One sample had a very high CaCl₂-extractable Si result (no. 32) and one had a very low result (no. 88) (Cocuzza 2017). These samples were extracted repeatedly with CaCl₂ and NaOH. This can inform about the robustness of the method but also about the variance within one soil sample.

Table 4 shows the general descriptive statistics of the control experiment for Si extractions. It shows the minimum, maximum, mean and median values as well as standard deviation (SD), skewness, kurtosis and difference between the minimum and maximum value, as well as percentage of this difference of the mean, additionally the mean of my colleague's measurement (Cocuzza 2017).

Table 4 General descriptive statistics (minimum, maximum, mean, median, standard deviation, skewness, kurtosis and difference) of the control experiment for Si extraction, additionally the mean of my colleague's measurement

soil no.	32	88	32	88
extraction method	0.01 M CaCl ₂ n=29 Si [mg/kg]	0.01 M CaCl ₂ n=29 Si [mg/kg]	0.2 M NaOH n=17 Si [mg/kg]	0.2 M NaOH n=13 Si [mg/kg]
Min	62	3.8	2980	4210
Max	68	7.4	6300	5250
Mean	65	6.3	5180	4560
mean of colleague's measurement n=3	64	4.7	6140	4830
Median	65	6.4	5500	4420
SD	1.47	0.99	1020	321
Skewness	0.02	-1.22	-1.38	1.19
Kurtosis	1.23	0.25	-0.07	-0.51
Difference min-max	5.3	3.6	3320	1040
Difference to mean in %	8	57	64	23

Soil no. 32 was extracted 29 times with 0.01 M CaCl₂. The results ranged from 62 mg/kg Si to 68 mg/kg. The difference between the maximum and the minimum result is 5.3 mg/kg which equals 8 % of the mean. The red line in Figure 3 represents soil no. 32.

Soil no. 88 was extracted 29 times with 0.01 M CaCl₂. The results ranged from 3.8 mg/kg Si to 7.4 mg/kg. The difference between the maximum and the minimum result is 3.6 mg/kg which equals 57 % of the mean. The blue line in Figure 3 represents soil no. 88.

The results of the control experiment with 0.01 M CaCl₂ stayed quite constant. The maximum difference in Si concentrations between the samples of soil no. 32 was 5.3 mg/kg and for the samples of soil no. 88 it was 3.6 mg/kg. It might be an indication that the extraction method and also the photo-spectrometric measurement are very robust. Three g soil used per sample is also quite a large amount of soil so some of the variance within the sample is already taken in account by this amount.

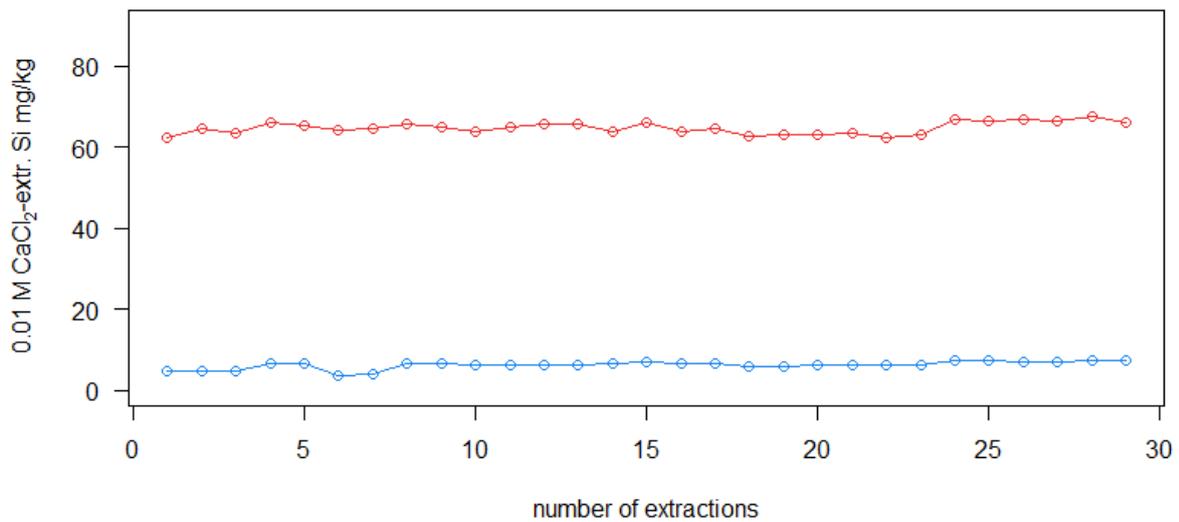


Figure 3 Results of the control experiment with CaCl₂ extracted Si. in red = soil no. 32, in blue = soil no. 88, n=29

Soil 32 was extracted 17 times with 0.2 M NaOH. The results ranged from 2980 mg/kg Si to 6300 mg/kg. The difference between the maximum and the minimum result is 3320 mg/kg which equals 64 % of the mean (Table 4). The red line in Figure 4 represents soil no. 32.

Soil 88 was extracted 13 times with 0.2 M NaOH. The results ranged from 4210 mg/kg Si to 5250 mg/kg. The difference between the maximum and the minimum result is 1040 mg/kg which equals 23 % of the mean (Table 4). The blue line in Figure 4 represents soil no. 88.

For the extraction with NaOH, the results of the control experiments showed bigger differences. The maximum difference between the samples of soil no. 32 was 3320 Si mg/kg. The maximum difference between the samples of soil no. 88 is 1040 Si mg/kg. Of course, these big differences also occur because the 0.2 M NaOH-extractable Si concentration is generally higher. But especially the samples of soil no. 32 have 4 samples with quite low results. The last two are caused by high blank values. The other two just showed very low results already at the photo spectrometer. I do not have an explanation for this, and I also cannot repeat this measurement (as it was a control experiment) but it shows how the lab work has its mistakes. Another explanation might be that the method of extracting 0.2 M NaOH-extractable Si is not so robust because only a very low amount of 75 mg soil is used for extracting it.

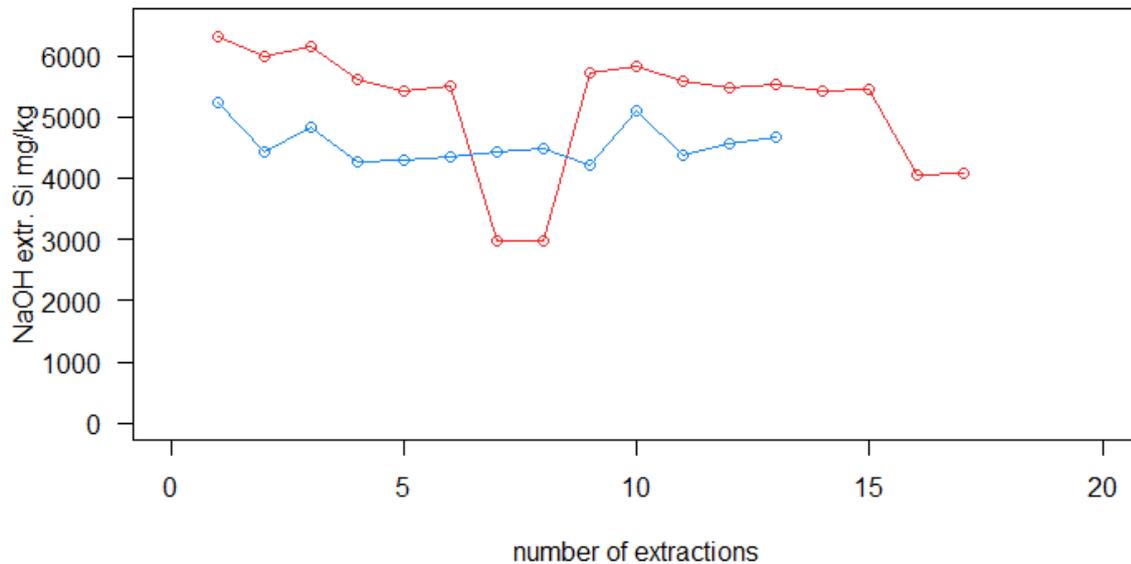


Figure 4 Results of the control experiment with NaOH-extracted Si. In red = soil no. 32 (n=17), in blue = soil no. 88 (n=13)

2.6 Calculation of the results

All results were collected in Microsoft Excel Files.

The statistical analysis was performed with Rstudio Version 1.1.463. All plots and graphs were produced with R. The figure of the Si fractions was drawn in Microsoft Power Point. All data was tested on normal distribution with the Shapiro Wilk test. If normality was refused, the significance was tested with the Wilcoxon test, a non-parametric test. To test the influence of the soil and climatic parameters on the concentration of the Si fractions, multiple linear regressions were performed.

3 Results and Discussion

3.1 Objective 1: Monitoring of the current status, registration of temporal changes and assessment of the soil quality

Data about soil parameters provided by the Bundesanstalt für Bodenwirtschaft (1994) of the Bodenzustandsinventur (BZI) of Lower Austria in the years of 1990-1992 and soil data obtained by AGES - Agentur für Gesundheit und Ernährungssicherheit (2010) in the years 1991-2009 give an idea of the overall condition and development of key soil parameters in Lower Austria. The method of the examinations differs decisively from the present study. In this study the soil samples were taken at the exact spot as given in the soil map of the first sampling. The period between the samplings is up to 30 years. Further information about the soils was already given in the soil map of eBod (2000), so the soil samples could be chosen very attentively to focus mainly on Chernozems.

The BZI has been carried out once until now. AGES is monitoring the Austrian soils more frequently but is dependent on the goodwill of the farmers. The soil samples considered for the analysis differ greatly in the amount and also in their origins because the samples are solely connected with the place of residence of the farmer.

As the administrative borders often do not apply to the natural circumstances, Bundesanstalt für Agrarwirtschaft divided Austria in agricultural production areas (Landwirtschaftliche Haupt- und Kleinproduktionsgebiete) and AGES provides the data according to this system. The area „Nordöstliches Flach- und Hügelland“ applies to all sampling areas of this study, and also for the subgroups of the production areas, data of the sampling areas could be found (in Baden-Gumpoldskirchner Gebiet for Mödling, Wiener Boden for Schwechat, westliches Weinviertel for Retz and Mistelbach/Laaer Bucht for Laa an der Thaya). BZI provides the data based on the judicial districts.

In spite of all the methodological differences, the available data of the two surveys is highly valuable for the present study, especially since the data can, if not absolutely precise, at least be assigned to the sampling areas Mödling, Schwechat, Retz and Laa an der Thaya of this study. Therefore, a comparison of the means is attempted. For the BZI data, only the results of cropland topsoils were considered.

3.1.1 CaCl₂-extractable Si

Table 5 summarizes the general descriptive statistics of the 0.01 M CaCl₂-extractable Si. The mean of the archived soils is 42.4 mg/kg which is slightly lower than the mean of the resampled soils (44.0 mg/kg). The 0.01 CaCl₂-extractable Si concentration ranges between 13.3 and 110 mg/kg for the archived soils and between 8.4 and 123 mg/kg for the resampled soils.

Table 5 General descriptive statistics (minimum, maximum, mean, median, standard deviation, skewness and kurtosis) of CaCl₂-extractable Si concentrations [mg/kg] of archived and resampled soils.

<i>CaCl₂-ext</i>	Archived soils (n=99) [mg/kg]	Resampled soils (n=99) [mg/kg]
<i>Min</i>	13.3	8.4
<i>Max</i>	110	123
<i>Mean</i>	42.4	44.0
<i>Median</i>	40.8	43.9
<i>SD</i>	16.1	18.3
<i>Skewness</i>	1.3	1.3
<i>Kurtosis</i>	3.4	3.4

The Shapiro Wilk Test performed on the archived and resampled 0.01 M CaCl₂-extracted soils shows that the data is not normally distributed (archived soils: $p=3.143e-06$, resampled soil: $p=5.768e-06$). The Wilcoxon test shows that there is no significant difference in the 0.01 M CaCl₂-extractable Si concentration between the archived and the resampled soils ($p = 0.3752$). The boxplots in Figure 5 also show that the CaCl₂-extractable Si concentration stayed very constant over the past 30 years.

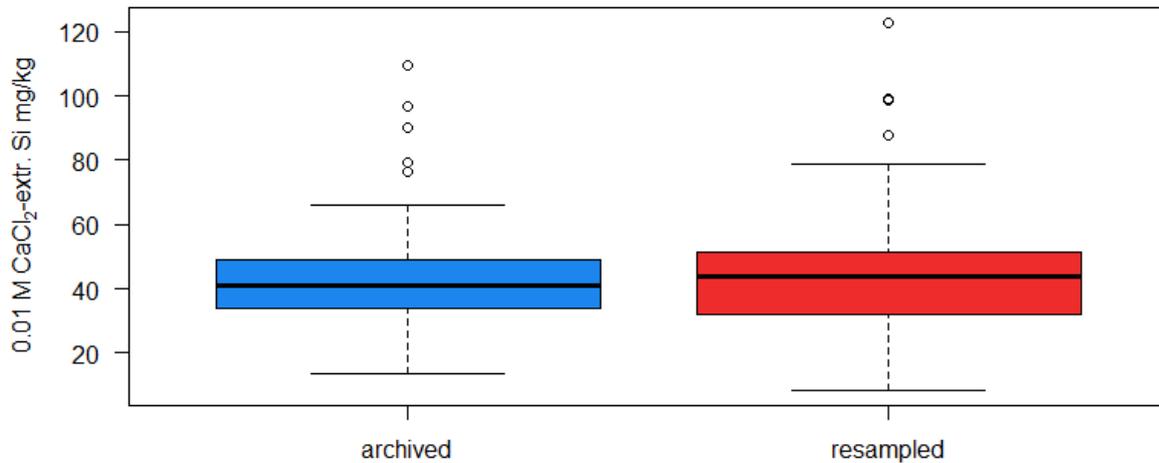


Figure 5 Boxplots of CaCl_2 -extractable Si mg/kg in archived and resampled soils, $n=99$

Examination of H1.a: The amount of soils with plant available Si concentrations under the critical level for optimal plant growth and stress resilience has increased in the last three decades and is substantially high.

The results of this research show, that the plant available Si concentration in the regarded soils did not change significantly over the last three decades. Furthermore, the amount of soils with plant available Si concentration under the upper limit of Si deficiency for optimal plant growth and stress resilience did not change significantly (Table 4).

Depending on which limit one applies, the Si deficiency concerns less than 10% of the soils (< 20 mg for sugarcane), or up to 50% if the upper limit of < 43 mg/kg for rice is applied. Lower Austrian Chernozems cannot generally be described as Si deficient. Yet calibration of an upper limit of deficiency of 0.01 CaCl_2 -extractable Si is needed for Si-accumulating crops grown in Austria like wheat, sugar beet, tomatoes or barley.

Figure 6 visualizes the amount of resampled soils below or above the upper limits of plant available Si deficiency.

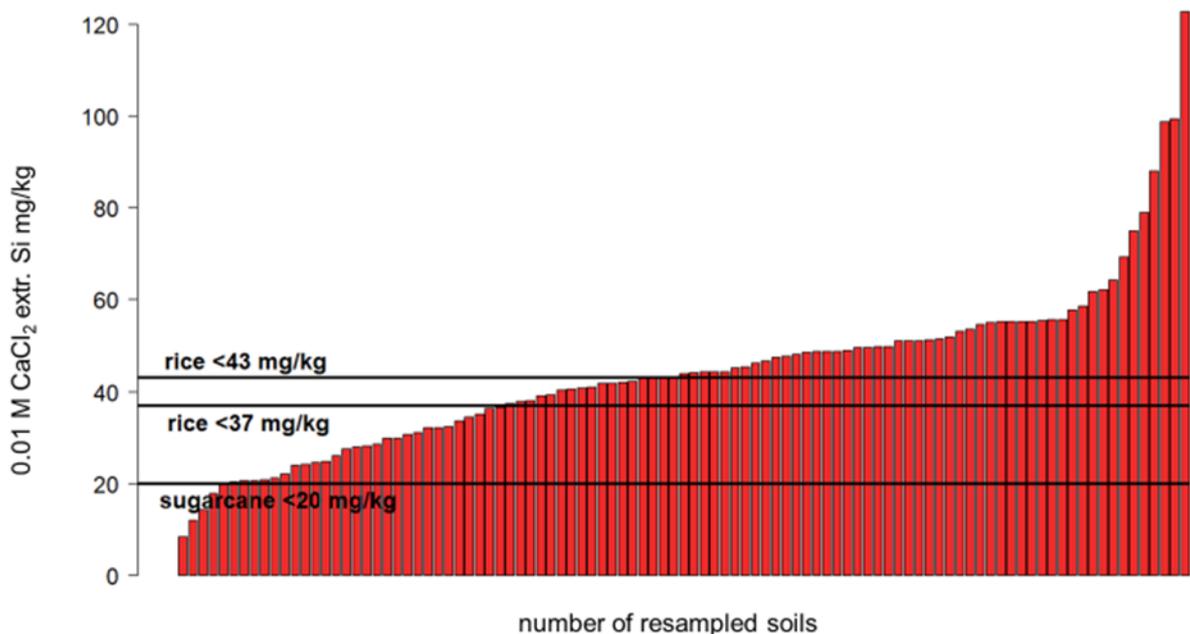


Figure 6 Barplot of the resampled soils with lines at upper limits of deficiency for 0.01 M CaCl₂ extracted Si concentrations < 20 mg/kg for sugarcane (Haysom and Chapman 1975), <37 mg/kg for rice (Babu et al. 2016), < 43 mg/kg for rice (Narayanaswamy and Prakash 2009), n=99

According to Szulc et al. (2016), soils having pH between six and seven are usually sufficient in plant available Si, while those with pH below six may be deficient in Si depending on texture. As shown in chapter 3.1.3 the regarded soils of this study have pH in the neutral to alkaline range and were, therefore, maybe not eminently prone to Si deficiency in the first place.

3.1.2 NaOH-extractable Silicon

Table 6 summarizes the general descriptive statistics of the 0.2 M NaOH-extractable Si. The mean of the archived soils is 2334 mg/kg which is lower than the mean of the resampled soils (2556 mg/kg). The NaOH-extractable Si concentration ranges between 299 and 8960 mg/kg for the archived soils and between 253 and 12300 mg/kg for the resampled soils.

Table 6 General descriptive statistics (minimum, maximum, mean, median, standard deviation, skewness and kurtosis) of NaOH extractable Si concentrations [mg/kg] of archived and resampled soils.

<i>NaOH-extr. Si</i>	Archived soils (n=99) [mg/kg]	Resampled soils (n=99) [mg/kg]
<i>Min</i>	299	253
<i>Max</i>	8960	12300
<i>Mean</i>	2330	2560
<i>Median</i>	2290	2510
<i>SD</i>	1310	1460
<i>Skewness</i>	1.6	3.0
<i>Kurtosis</i>	5.6	18.1

The Shapiro Wilk test shows no normal distribution for the archived and resampled NaOH-extractable Si concentration (archived soils: $p=7.597e-07$, resampled soils: $p=3.868e-11$). The Wilcoxon test shows no significant difference between the two collecting periods ($p = 0.1334$). The boxplot of the NaOH-extractable Si in Figure 7 shows that the high maximum value of the resampled NaOH-extractable Si is only an outlier.

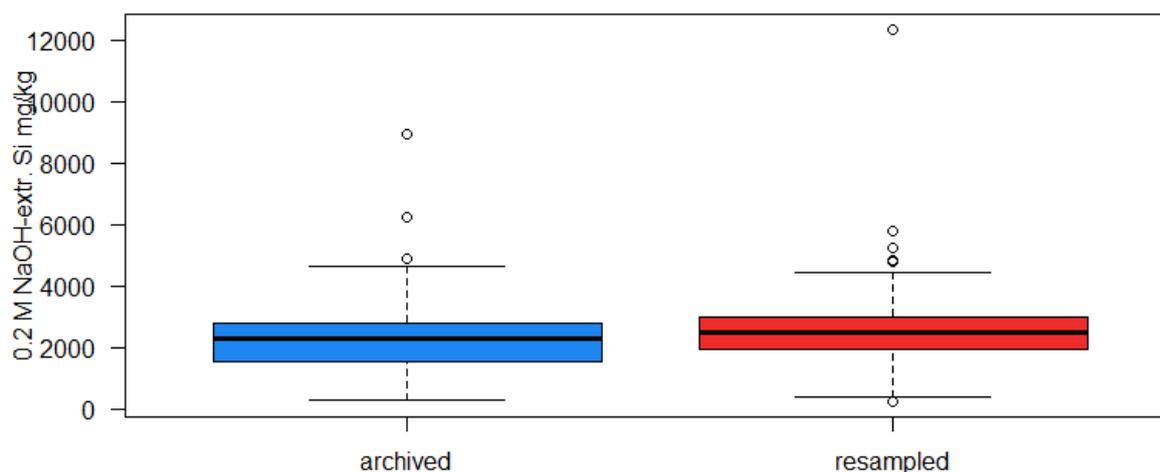


Figure 7 Boxplots of NaOH-extractable Si mg/kg in archived and resampled soils, $n=99$

Examination of H1.b: The amorphous Si concentrations in agricultural top soils was decreasing in the last three decades due to Si removal with harvest and the use of crop residues

The research did not show a significant change of the amorphous Si concentration in Lower Austrian top soils. The concentrations were rising but not significantly (p -value = 0.1334). H1.b has to be falsified.

3.1.3 pH

Table 7 summarizes the general descriptive statistics of the pH. The pH ranges from 5.3 to 8.1 for the archived soils and from 4.5 to 7.8 for the resampled soils. The mean is the same with 7.2.

Table 7 General descriptive statistics (minimum, maximum, mean, median, standard deviation, skewness and kurtosis) of the pH of archived and resampled soils.

<i>pH</i>	Archived soils (n=99)	Resampled soils (n=99)
<i>Min</i>	5.3	4.5
<i>Max</i>	8.1	7.8
<i>Mean</i>	7.2	7.2
<i>Median</i>	7.4	7.5
<i>SD</i>	0.6	0.6
<i>Skewness</i>	-1.27	-2.01
<i>Kurtosis</i>	0.89	4.51

The Shapiro Wilk test shows that the pH values are not normally distributed (archived soils: $p=1.612e-08$, resampled soils: $p=3.697e-11$). The Wilcoxon test shows no significant difference of the pH of the archived and resampled soils ($p=0.5192$). The boxplots in Figure 8 visualize the consistency of the pH values of the archived and resampled soils.

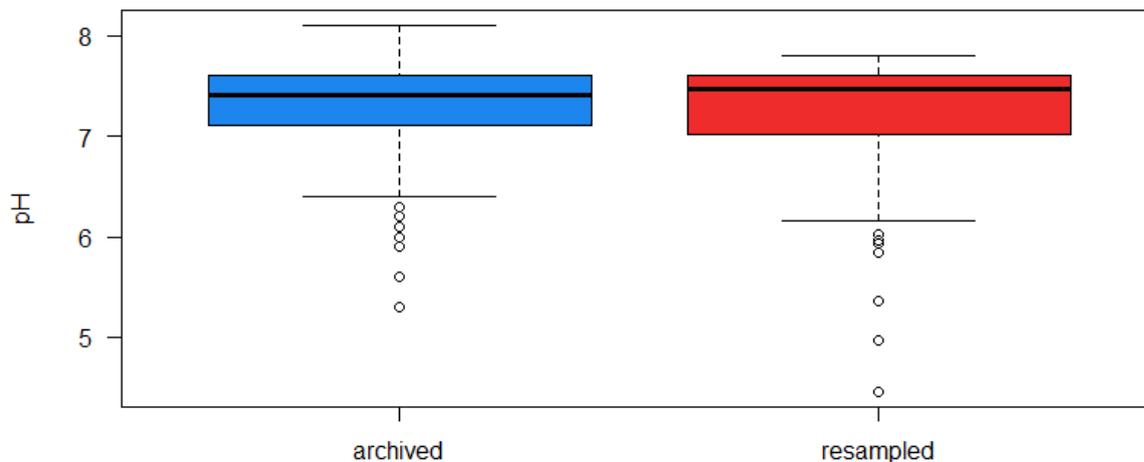


Figure 8 Boxplots of the soil pH in archived and resampled soils, n=99

Examination of H1.c: pH did not show substantial changes.

The regarded soils of this study showed constant pH values in the neutral to slightly alkaline range with only a few outliers in the acidic range. Hypothesis H1.c can therefore be confirmed. The results also fit in with the pH values determined by the BZI and AGES:

According to the BZI, the mean pH value numbered 7.2 in cropland topsoils in Mödling, Schwechat, Retz and Laa an der Thaya in 1990-1992.

AGES also analyzed the pH of Lower Austrian croplands:

In Laa an der Thaya more than 85% of the soils showed an alkaline soil reaction, the rest had a neutral pH value. No changes could be observed between 1991 and 2009.

In the area of Retz 70-75% of the soils showed a slightly alkaline pH. The rest was neutral or slightly acidic. In the years from 1991 to 2009 no big changes took place.

In the area of Schwechat and Mödling the pH of 95 % of the soils lay consistently around 7.5. Slightly acidic soils were not present between 1991 and 2009.

In all sampling areas of this study, AGES found that more than 80% of the soils showed an alkaline soil reaction between 2001 and 2009 and more than 11-12 % were neutral.

Egger recommends treating cropland soils with lime when pH is below 6 to increase it. The regarded soils mainly do not need to be treated to increase their pH.

3.1.4 Organic Carbon

Table 8 summarizes the general descriptive statistics of the organic carbon. It ranges from 7.2 g/kg to 74.5 g/kg in the archived soils and from 9.8 to 78.1 g/kg in the resampled soils. Although the range between minimum and maximum values did not expand much, the mean soil OC raised from 19.6 to 29.3, which is a significant increase of nearly 40% (p-value = 1.606e-08).

Table 8 General descriptive statistics (minimum, maximum, mean, median, standard deviation, skewness and kurtosis) of organic carbon concentrations [g/kg] of archived and resampled soils

<i>org. C</i>	Archived soils (n=99) [g/kg]	Resampled soils (n=99) [g/kg]
<i>Min</i>	7.2	9.8
<i>Max</i>	74.5	78.1
<i>Mean</i>	19.6	29.3
<i>Median</i>	16.4	22.9
<i>SD</i>	12.1	16.8
<i>Skewness</i>	2.59	1.37
<i>Kurtosis</i>	7.46	0.91

The Shapiro Wilk test shows that the organic carbon concentration is not normally distributed (archived soils: p=9.283e-13, resampled soils: p=1.475e-09). The Wilcoxon test confirms that there is a significant difference in the organic carbon concentration between the archived and the resampled soils (p = 1.606e-08). The boxplots in Figure 9 illustrate this difference. One can observe that the range of the organic C marked by the outliers stayed the same however the box itself shifted decisively.

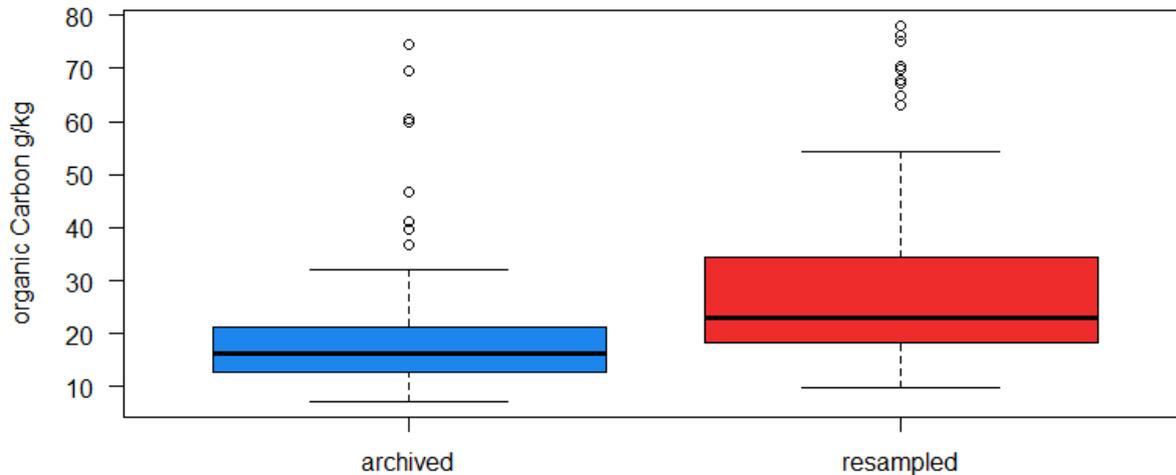


Figure 9 Boxplots of organic carbon concentrations in archived and resampled soils, n=99

Examination of H1.d: Organic carbon concentrations have been increasing over the last 30 years

The organic carbon concentrations of the regarded soils in this study showed a substantial increase of nearly 50% from 19.6 to 29.3 g/kg. H1.d can therefore be accepted.

The mean SOC concentration in the resampled soils of 29.3 g/kg corresponds to 2.9 percent. Lefèvre et al. (2017) described the SOC of Chernozems in natural ecosystems between 2.9 and 3.5 percent in the upper 10 cm, below this line it is 1.2 percent. This might be an indication that the regarded soils are reaching a SOC saturation level. Through suitable management measures, the SOC concentration could probably still be increased and because cropland is already intensively cultivated, the measures can be implemented fairly easy (Zomer et al. 2017).

Previous soil surveys of AGES also show rising organic carbon concentrations.

In the period between 1991 and 2009 the humus concentration in “Nordöstliches Flach- und Hügelland” showed a rise and with that also the organic carbon concentration. The mean increased from 3.02% to 3.28% corresponding to an organic carbon rise from 19.8 g/kg to 21.5 g/kg. AGES (2015) recommends a humus content of 2-3% for croplands. The share of low humus sites with amounts lower than 2% was halved from 20% to 10%. The relevant changes in farming were especially the ÖPUL measures for enhancing the organic carbon

concentration such as the construction of greenery, mulch drilling and no till farming / direct seed. Around “Nordöstliches Flach- und Hügelland” the burning of straw was a very common practise and is only prohibited since 1993. Since the straw is left on the fields now, more organic material is available for the sequestration of organic carbon.

Baumgartner et al. (2011) determined that according to the humus balance of 2007, organic farming and the abandonment of N fertilizers and certain pesticides had a positive influence on the humus content.

The data of BZI (1990-1992) showed that the mean humus content in Lower Austrian topsoils (0-20cm) was 3.5%. The humus content in Tschernosem, Paratschernosem and Feuchtschwarzerde lay between 1.7 and 2.5 %, corresponding to organic carbon concentrations between 11.1 to 16.4 g/kg. This value lies below the mean organic carbon concentration of the archived soil samples of this study. The mean organic carbon concentration of the BZI survey of only cropland topsoils in Schwechat, Mödling, Retz and Laa an der Thaya is 16.8 g/kg.

The comparison with the other soil surveys shows that the soils of the present study showed a higher rise in soil organic carbon and generally higher values. Reasons might be the very long observation period, that the second sampling took place only recently (as organic carbon sequestration is a slow process) and that the exact same soils were analysed.

Schiefer (2019) conducted a soil survey very similar to this master thesis. More than half of Schiefer’s soils were grassland soils and furthermore the research focused mainly on Cambisols. The mean organic carbon concentration numbered 37.7 g/kg in the resampled soils which is much higher than the OC results observed in the Chernozems of this study. An explanation might be that the conversion of natural ecosystems to agro-ecosystems and especially to cropland depletes the SOC pool because of a) lower return of biomass-C, b) higher losses of SOC by erosion, mineralization and leaching and c) stronger variations in soil temperature and moisture regimes (Lal et al. 2015).

3.1.5 Nitrogen

Table 9 shows the general descriptive statistic of the nitrogen concentration in the resampled soils. It ranges from 0.91 g/kg to 6.68 g/kg. The mean is 2.52 g/kg.

Table 9 General descriptive statistics (minimum, maximum, mean, median, standard deviation, skewness and kurtosis) of nitrogen concentrations [g/kg] of archived and resampled soils

<i>N</i>	Resampled soils (n=99) [g/kg]
<i>Min</i>	0.91
<i>Max</i>	6.68
<i>Mean</i>	2.52
<i>Median</i>	2.13
<i>SD</i>	1.18
<i>Skewness</i>	1.45
<i>Kurtosis</i>	1.83

Examination of H1.e: Soils contain enough Nitrogen and show favourable C/N ratios.

The single time observation of N showed a mean of 2.52 g/kg and can be compared to results of the BZI that showed N concentrations (determined from Kjeldahl ÖNORM L 1082) in Tschernosem, Paratschernosem and Feuchtschwarzerde soils between 0.1 and 0.2 % (corresponding to 1-2 g/kg) in the years 1990-1992.

The C/N ratio of the soils can put the N concentration of the regarded soils into perspective: The C/N ratio of the means of the resampled soils is 11.4. Soils with a C/N ratio between 6 and 10 are classified as N rich and above 25 as N poor. Hence the regarded soils lie in the middle range. H1.e can therefore be accepted, the soils contain enough N and also the C/N ratio is favourable. Moreover the soil samples were taken between November and March. As the mineral and microbial N pool (which can make up to 10% of the N pool) is very season-dependent (Stahr 2012) and furthermore fertilization with N is mostly prohibited between October and the middle of February (AMA 2015), the N concentrations of the regarded soils might be higher in summer.

3.2 Objective 2: Examine the influence of soil- and climatic factors on the Si fractions

This chapter shows the influence of different soil and climatic factors on the Si concentrations in the soils. Various multiple linear regressions were run to count the influence of the factors:

The archived soils were tested with the soil factors (S): pH, OC, clay, sand and with the soil and climatic factors (S+C): pH, OC, clay, sand, mean annual temperature, mean annual precipitation.

The resampled soils were tested with the soil factors (S): pH, OC and additionally with the soil and climatic factors (S+C): pH, OC, mean annual temperature, mean annual precipitation.

Table 10 shows the p-values of the significant factors of the multiple linear regressions. It also shows the direction of the slope estimates of the individual models.

Table 10 Overview of significant p-values of the multiple linear regression models on CaCl₂-extractable Si and NaOH-extractable Si with soil factors (S) and soil + climatic factors (S+C). For archived soils: S=pH, OC, clay, sand;

S+C = pH, OC, clay, sand, mean annual temperature, mean annual precipitation.

For resampled soils: S=pH, OC; S+C=pH, OC, mean annual temperature, mean annual precipitation.

Significance codes: '***' = 0.001; '**' =0.01; '*' =0.05

'+' positive slope estimate, '--' negative slope estimate

	0.01 CaCl ₂ -extractable Si				0.2 M NaOH-extractable Si			
	Archived		Resampled		Archived		Resampled	
	S	S+C	S	S+C	S	S+C	S	S+C
pH	-	-	-	-	0.000121 *** --	0.004911 ** --	-	-
OC	0.000143 *** --	0.00469 ** --	0.000349 *** --	0.000349 *** --	0.000678 *** --	0.007288 ** --	9.53E-06 *** --	3.02E-03 ** --
Clay	6.02E-05 *** +	1.05E-05 *** +	-	-	7.62E-05 *** +	5.17E-09 *** +	-	-
Sand	-	-	-	-	0.038 * --	-	-	-
Temp.	-	5.22E-05 *** --	-	-	-	0.000388 *** --	-	0.01006 * --
Precip.	-	-	-	-	-	0.00256 ** +	-	0.02417 * +
R²	0.2309	0.3532	0.1241	0.1241	0.4479	0.5153	0.1838	0.244
adj. R²	0.2148	0.3327	0.115	0.115	0.4244	0.4892	0.1754	0.2201

0.01 M CaCl₂-extractable Si in archived soils:

The regression model testing soil factors on 0.01 M CaCl₂-extractable Si contained pH, OC, clay and sand. pH and sand were not significant and, therefore, removed from the model.

The following equation explains the 0.01 M CaCl₂-extractable Si concentration in archived soils by soil factors.

$$0.01 \text{ M CaCl}_2\text{-extr. Si} = 33.59 + \text{OC} * (-0.48) + \text{clay} * 0.63$$

Organic carbon (p=0.000143) and clay (p=6.02e-05) show a significant influence on the 0.01 M CaCl₂-extractable Si concentration in the archived soils (R² = 0.23, adj. R²= 0.22).

The model testing soil and climatic factors on 0.01 M CaCl₂-extractable Si contained pH, OC, clay, sand, mean annual temperature and mean annual precipitation. Only OC (p=0.00469), clay (p=1.05e-05) and mean annual temperature (p=5.22e-05) showed a significant effect on the 0.01 M CaCl₂-extractable Si. The other factors were removed from the model. The following equation explains the 0.01M CaCl₂-extractable Si by soil and climatic factors.

$$0.01 \text{ M CaCl}_2\text{-extr. Si} = 227.21 + \text{OC} * (-0.34) + \text{clay} * 0.64 + \text{temp.} * (-20.14)$$

0.01 M CaCl₂-extractable Si in resampled soils:

The regression model testing soil factors on 0.01 M CaCl₂-extractable Si for resampled soils contained pH and organic carbon. pH showed no significant influence and was therefore removed from the model. The following equation was obtained from the multiple regression:

$$0.01 \text{ M CaCl}_2\text{-extr. Si} = 55.26 + \text{OC} * (-0.38)$$

Organic carbon (p=0.000349) shows a significant influence on the 0.01 M CaCl₂-extractable Si concentration in resampled soils (R²=0.1241, adj. R²=0.115).

The model testing soil and climatic factors on 0.01 M CaCl₂-extractable Si for resampled soils contained pH, organic carbon, mean annual temperature and mean annual precipitation. pH, temperature and precipitation showed no significant influence and were therefore removed from the model. The following equation shows the effect of organic carbon on 0.01 M CaCl₂-extractable Si:

$$0.01 \text{ M CaCl}_2\text{-extr. Si} = 55.26 + \text{OC} * (-0.38)$$

Organic carbon (p=0.00401) shows a significant influence on the 0.01 M CaCl₂-extractable Si concentration in resampled soils (R²=0.1241, adj. R²=0.115).

Research of Schiefer (2019) and Cocuzza (2017) shows that land use and soil type play a crucial role for the 0.01 M CaCl₂-extractable Si concentration, as well. These factors were not tested in these models because all soils were cropland soils and the objective was limited to test only Chernozems. Cambisols showed mean 0.01 M CaCl₂-extractable Si concentrations of 25.4 mg/kg in resampled soils (Schiefer 2019); the Chernozems of this study showed 0.01 M CaCl₂-extractable Si concentrations of 44 mg/kg. Furthermore, arable soils (30.6 mg/kg) have nearly 50% higher mean 0.01 M CaCl₂-extractable Si concentrations than grasslands (15.7 mg/kg) (Cocuzza 2017).

0.2 M NaOH-extractable Si in archived soils:

The following equation was obtained through the regression model for testing soil factors influencing the archived soils. It includes pH, organic carbon, clay and sand.

$$0.2 \text{ M NaOH-extr. Si} = 7606.75 + \text{pH} * (-797.85) + \text{OC} * (-33.07) + \text{clay} * 55.42 + \text{sand} * (-17.64)$$

All these factors showed a significant influence: pH (p=0.000121), OC (p=0.000678), clay (p=7.62e-05), sand (p=0.038048). The R² is 0.45, the adjusted R² is 0.42.

The following equation shows the influence of the soil and climatic factors on the 0.2 M NaOH-extractable Si for archived soils.

$$0.2 \text{ M NaOH-extr. Si} = 43668.34 + \text{pH} * (-522.83) + \text{OC} * (-23.87) + \text{clay} * 65.44 + \text{temp.} * (-5547.74) + \text{precip.} * 27.87$$

The regression model contained pH, organic carbon, clay, sand, mean annual temperature and mean annual precipitation. Sand and precipitation showed no significant influence and were therefore removed from the model. pH (p=0.004911), organic carbon (p=0.007288), clay (5.17e-09), temperature (p=0.000388) and precipitation (p=0.002560) had a significant influence on the archived 0.2 M NaOH-extractable Si (R²= 0.52, adj. R²=0.4892).

0.2M NaOH-extractable Si in resampled soils:

The following equation was obtained through the multiple regression testing soil factors on 0.2 M NaOH-extractable Si in resampled soils.

$$0.2 \text{ M NaOH-extr. Si} = 3649.66 + \text{OC} * (-37.28)$$

The model included pH and organic carbon. pH was not significant and therefore removed from the model. Organic carbon (p=9.53e-06) showed a highly significant influence on the 0.2 M NaOH-extractable Si (R²=0.18, adj. R²=0.18).

The following equation was obtained through the multiple regression testing soil and climatic factors on 0.2 M NaOH-extractable Si in resampled soils.

$$0.2 \text{ M NaOH-extr. Si} = 40209.48 + \text{OC} * (-30.43) + \text{temp.} * (-5321.85) + \text{precip.} * 27.72$$

The model included pH, organic carbon, mean annual temperature and mean annual precipitation. pH was not significant and therefore removed from the model. Organic carbon ($p=0.00302$), temperature ($p=0.01006$) and precipitation ($p=0.02417$) showed a significant influence on the 0.2 M NaOH-extractable Si concentration in resampled soils ($R^2=0.24$, adj. $R^2=0.22$).

Examination of Hypothesis 2: The Si concentration in soil is influenced by a variety of factors:

The multiple linear regression analysis identified OC, clay and mean annual temperature as the main determining factors of Si fractions in Lower Austrian Chernozem and Phaeozem soils (Table 11). Nevertheless, in some of the observations the R^2 and the multiple R^2 is quite low, so there are presumably also other factors influencing the soil Si fractions.

Examination of H2.a: Higher soil pH levels increase Si solubility and are expected to lead to higher plant available Si concentrations. As weathering is usually higher in more acidic soil pH levels, the amorphous Si concentration is typically associated with lower soil pH.

pH showed no correlation with the 0.01 M CaCl_2 -extractable Si. pH showed negative correlations with 0.2 M NaOH-extractable Si of the archived soil samples; here H2.a can be confirmed. There was no correlation with the 0.2 M NaOH-extractable Si concentration in the resampled soils. pH of the regarded soils did not show significant changes and only covers a very limited window of neutral to slightly alkaline soils. So, a big influence of soil pH on the Si concentrations might be merely expected at lower pH levels. Yanai et al. (2016) found a significant influence of pH on the plant available Si concentrations but the majority of their observed soils had pH levels in the range between 4 and 7.

Examination of H2.b: High organic carbon concentration causes higher concentrations of amorphous Si because both are correlated with the input of organic matter and phytoliths.

Organic carbon had a significant effect on all Si fractions (Table 11). It might be expected that amorphous Si fractions are higher in soils with higher organic carbon concentration because silica is mainly returned to the soil in plant litter and during the decomposition of silica the organic matter is released. Due to this similar recycling process the distribution of silica in the soil profile is typically similar to that of organic carbon (Haynes 2014). Still my results do not support this theory. The OC had a significantly reducing effect on all Si fractions, the H2.b must therefore be refused. Liang et al. (2015) summarize Chinese literature that states that, even though most authors agree that Si concentrations are positively correlated with soil organic matter, others believe that there might even be a negative relationship which could be ascribed to the differences of soil types investigated.

Examination of H2.c: Climate: Soils in areas with cold temperatures and low precipitation show slower weathering rates and therefore lower concentrations of amorphous Si.

The climatic factors, mean annual temperature and mean annual precipitation only partially showed significant effects on the Si fractions. Overall, higher mean annual temperature is contrary to recent studies, significantly decreasing Si concentrations in soils (except for the resampled 0.01 M CaCl₂-extractable Si). Precipitation showed, in line with hypothesis H2.c, an increasing effect on the 0.2 M NaOH-extractable Si fractions. Cornelis and Delvaux (2016) support this result; they described the dissolution of different Si fractions through mineral weathering accelerated by precipitation water. They also found out that Si uptake by plants is related to mean annual precipitation.

Examination of H2.d: Texture: Coarse soil texture is expected to enhance leaching, slow down the weathering rate and to provide less surface area for Si sorption. We expect the Si concentrations to be higher in soils with higher clay content and lower sand content.

Only the archived soils were tested on the influence of texture on the Si fractions. In line with the hypothesis, higher clay contents were significantly related to higher Si concentrations. For sand, such a clear picture could not be drawn: Only the archived amorphous Si (in the model where the climate was not included) was decreased by higher sand contents. The results are in line with the hypothesis that soils with sandy texture are usually Si deficient and those with a more clayey texture are Si sufficient (Liang et al. 2015; Liang et al. 1994).

4 Conclusion

Soil monitoring takes place on European and Austrian level in various forms. Monitoring networks are, in general, quite rough. Increasing attention is put on the use of the same analysis methods and on European level, on monitoring of the exact same locations (in the LUCAS project).

For Austria, monitoring networks that examine soils from the same locations with the same methods in reasonable intervals are lacking. Soil surveys on the territory of Austria either date back up to 30 years or are only conducted to control conditions for certain subventions and are therefore not exactly attributable to locations.

The present study contributes to the monitoring of soil quality in Austria.

Lower Austrian Chernozems and Phaeozems show pH levels in the neutral to alkaline range and stayed stable over the 30 years monitoring period. Organic carbon concentrations increased substantially: The mean rose from 19.6 to 29.3 g/kg which is an increase of nearly 40%. This increase can be attributed to ÖPUL measures like organic farming, no till farming, mulch seed and the ban of straw burning.

Although the data of this work shows that the cropland soils have been sequestering substantial amounts of SOC during the past few decades, sequestration of SOC is a riskier long-term strategy for climate change mitigation than direct reduction of C emissions (Insam et al. 2018). Therefore, efforts to avert the climate catastrophe have to be taken on various

paths; for example finally ending the tax exemption on kerosene, ending other tax reliefs like on diesel that are harmful to the climate (Kletzan-Slamanig et al. 2016) and instead introducing a CO₂-tax. Sequestering SOC can only be a part of the solution to avoid the climate catastrophe.

Mean nitrogen concentrations of 2.52 g/kg lead to a C/N ratio of around 11 which shows a middle supply of nitrogen in Lower Austrian Chernozems and Phaeozems.

Si concentrations did not show a significant temporal change over the monitoring period between 1982 and 2017.

Mean 0.01 M CaCl₂-extractable Si was at 44 mg/kg in resampled soils. As main influencing factors for the 0.01 M CaCl₂-extractable Si concentrations, organic carbon could be determined as a reducing factor and clay as an increasing factor, furthermore temperature showed a reducing effect on the archived samples. Only five soils out of 99 show plant available Si concentration under the upper limit of deficiency of 20 mg/kg for sugarcane. This shows that Lower Austrian Chernozems and Phaeozems are well supplied with 0.01 M CaCl₂-extractable Si. Satisfactory statements can still only be made when Si requirements for Si accumulator crops grown in Austria, such as wheat, sugar beet, maize and barley are available.

0.2 M NaOH-extractable Si had a mean of 2560 mg/kg in resampled soils. Regression analysis showed that it is mainly influenced by the reducing effect of organic carbon and the increasing effect of clay. Temperature showed a reducing effect and precipitation an increasing effect. pH was a reducing factor only for the archived soil samples.

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5.3 List of Results

Archived soil sample's data

mapping area	ID no.	mean annual temperature	mean annual precipitation	pH	organic matter	organic carbon (calculated)				0.01 M CaCl ₂ -extractable Si	0.2 M NaOH-extractable Si
		°C	mm/m ²		%	g/kg	sand	silt	clay	mg/kg	mg/kg
1	22	9.9	568	7.7	4.3	28.18	32	53	15	19.81	600.96
1	23	9.9	568	7.4	3.2	20.97	19	61	20	40.33	2149.72
1	25	9.9	568	7.4	4.2	27.53	29	45	26	35.04	1244.89
1	33	9.9	568	7.8	8.6	59.86	19	58	23	54.84	1596.47
1	36	9.9	568	7.3	5.3	36.89	10	33	57	32.36	2790.50
1	38	9.9	568	7.7	3.1	20.32	12	57	30	21.78	831.43
1	39	9.9	568	7.1	2.6	17.04	23	55	22	42.28	2673.35
1	41	9.9	568	7.3	3.1	20.32	10	65	25	38.38	2484.94
1	43	9.9	568	7.9	4.9	32.12	13	60	27	27.23	806.35
1	45	9.9	568	7.5	5.9	41.07	16	62	22	25.05	883.14
1	47	9.9	568	7.8	6.7	46.64	15	55	30	25.03	1265.87
1	48	9.9	568	7.4	3	19.66	14	53	33	34.33	1827.08
1	51	9.9	568	8	10	69.61	9	70	21	15.03	593.18
1	52	9.9	568	7.9	10.7	74.48	5	61	34	19.68	944.13
1	53	9.9	568	7.8	8.7	60.56	8	63	29	16.86	471.69
1	57	9.9	568	7.7	4	26.22	20	34	46	46.62	3832.62
26	10	10.3	636	7.5	2.8	18.35	42	36	22	40.88	1820.50
26	11	10.3	636	7.7	3.4	22.29	21	51	28	18.47	505.45
26	12	10.3	636	7.4	2.4	15.73	19	49	32	39.17	2462.31
26	13	10.3	636	7.6	2.5	16.39	40	41	19	33.92	1230.78
26	14	10.3	636	7.4	1.9	12.45	33	45	22	40.23	1941.54

Archived soil sample's data

mapping area	ID no.	mean annual temperature	mean annual precipitation	pH	organic matter	organic carbon (calculated)				0.01 M CaCl ₂ -extractable Si	0.2 M NaOH-extractable Si
		°C	mm/m ²		%	g/kg	sand	silt	clay	mg/kg	mg/kg
26	15	10.3	636	7.6	3.5	22.94	19	58	23	24.72	806.10
26	17	10.3	636	7.7	3.6	23.60	26	60	14	15.94	298.94
26	19	10.3	636	7.5	3.1	20.32	14	60	26	36.12	2189.06
26	20	10.3	636	7.1	2.9	19.01	10	54	36	50.40	4909.82
26	21	10.3	636	6.8	1.6	10.49	7	55	38	47.99	4235.27
26	22	10.3	636	7.5	1.4	9.18	26	38	36	32.04	2438.01
26	23	10.3	636	7.6	3.3	21.63	15	23	62	25.61	704.68
26	24	10.3	636	7.5	4.7	30.81	13	56	31	13.30	309.12
26	26	10.3	636	7.1	2.6	17.04	13	52	35	53.01	3622.85
26	27	10.3	636	7.4	3.6	23.60	33	37	30	29.75	1637.80
26	28	10.3	636	7.4	2.4	15.73	13	50	37	38.03	2144.28
26	32	10.3	636	7.4	2.5	16.39	12	57	31	49.35	2437.82
26	37	10.3	636	7.7	4.4	28.84	22	55	23	31.95	981.46
26	38	10.3	636	7.6	5.7	39.68	13	57	30	23.09	537.45
26	39	10.3	636	7.6	3.3	21.63	19	38	43	37.77	2311.63
177	12	9.5	524	7.5	2.6	17.04	5	67	28	44.51	2769.66
177	13	9.5	524	7.7	4	26.22	5	56	39	33.91	3011.89
177	15	9.5	524	7.5	2.8	18.35	12	53	35	34.11	2799.39
177	17	9.5	524	7.6	2.3	15.08	9	60	31	44.88	2716.47
177	19	9.5	524	6.5	1.6	10.49	25	45	30	48.16	3510.68
177	21	9.5	524	7.5	1.5	9.83	20	48	32	46.83	2895.78
177	23	9.5	524	7.2	2.1	13.76	43	37	20	46.52	2336.63
177	26	9.5	524	7.3	2	13.11	22	45	33	44.28	3429.59
177	27	9.5	524	6	1.5	9.83	22	44	34	64.83	4330.26
177	29	9.5	524	6.5	4.3	28.18	12	34	54	79.38	4662.79

Archived soil sample's data

mapping area	ID no.	mean annual temperature	mean annual precipitation	pH	organic matter	organic carbon (calculated)				0.01 M CaCl ₂ -extractable Si	0.2 M NaOH-extractable Si
		°C	mm/m ²		%	g/kg	sand %	silt %	clay %	mg/kg	mg/kg
177	30	9.5	524	7.4	1.7	11.14	13	63	24	39.46	2477.18
177	31	9.5	524	5.3	1.6	10.49	36	42	22	24.67	2813.39
177	32	9.5	524	7.5	2.7	17.70	11	45	44	76.57	4330.94
177	34	9.5	524	6.4	3.2	20.97	5	43	52	96.65	6254.80
177	66	9.5	524	7.4	1.6	10.49	47	36	17	39.51	1926.82
177	67	9.5	524	7.2	3.1	20.32	9	51	40	109.71	8954.67
212	24	9.6	510	7.4	1.8	11.80	36	41	23	44.05	2189.35
212	25	9.6	510	7.6	1.5	9.83	21	54	25	60.16	2539.32
212	26	9.6	510	7.5	1.7	11.14	11	64	25	43.95	2389.55
212	27	9.6	510	7.4	1.6	10.49	17	59	24	44.43	2202.25
212	28	9.6	510	7.6	1.4	9.18	31	46	23	32.39	1850.59
212	31	9.6	510	7.5	2.6	17.04	32	37	31	43.21	2787.31
212	32	9.6	510	7.2	1.7	11.14	62	19	19	48.30	1912.41
212	33	9.6	510	7.3	3	19.66	21	32	47	90.08	4868.16
212	35	9.6	510	6.6	1.8	11.80	67	15	18	36.94	1949.58
212	37	9.6	510	6.7	2.8	18.35	21	51	28	50.36	3306.84
212	38	9.6	510	7	2.5	16.39	6	63	31	52.36	3244.05
212	39	9.6	510	5.9	1.9	12.45	43	35	22	40.31	2815.61
212	41	9.6	510	6.5	2.7	17.70	32	32	36	57.59	3590.77
212	43	9.6	510	6	2.4	15.73	58	22	20	27.37	2568.75
212	44	9.6	510	7.1	2.2	14.42	34	34	32	45.53	3375.59
212	45	9.6	510	7.6	2.3	15.08	13	58	29	49.10	2279.91
212	46	9.6	510	7.6	3.2	20.97	56	28	16	60.81	1661.42
212	53	9.6	510	6.1	2.1	13.76	52	25	23	41.50	2570.43
212	54	9.6	510	6.8	1.3	8.52	54	29	17	40.76	2340.94

Archived soil sample's data

mapping area	ID no.	mean annual temperature	mean annual precipitation	pH	organic matter	organic carbon (calculated)				0.01 M CaCl ₂ -extractable Si	0.2 M NaOH-extractable Si
		°C	mm/m ²		%	g/kg	sand %	silt %	clay %	mg/kg	mg/kg
212	58	9.6	510	8	2.2	14.42	42	32	26	52.24	2286.13
212	61	9.6	510	8.1	2.9	19.01	21	48	31	36.44	2069.75
212	63	9.6	510	7.6	3.6	23.60	19	37	44	39.77	3149.51
212	66	9.6	510	6.5	2.6	17.04	65	20	15	30.77	1882.58
212	69	9.6	510	5.9	2.1	13.76	57	20	23	40.41	2602.49
212	70	9.6	510	7.1	2.1	13.76	58	22	20	48.38	2263.75
213	11	9.6	510	7.3	1.9	12.45	44	36	20	38.64	2142.08
213	13	9.6	510	7.5	1.8	11.80	13	59	28	38.94	2678.75
213	14	9.6	510	7.4	2.1	13.76	26	47	27	51.55	2642.56
213	16	9.6	510	7.4	2.2	14.42	22	46	32	46.22	3169.55
213	18	9.6	510	7.5	2.3	15.08	9	49	42	40.00	3235.01
213	19	9.6	510	7.2	2.3	15.08	54	24	22	65.97	2590.80
213	21	9.6	510	7.2	1.8	11.80	55	27	18	53.33	2531.26
213	22	9.6	510	5.9	2.3	15.08	6	65	29	46.15	3293.89
213	23	9.6	510	6.2	2.1	13.76	44	34	22	48.31	1454.53
213	24	9.6	510	7.4	1.5	9.83	47	32	21	21.23	1300.52
213	25	9.6	510	5.9	1.7	11.14	64	16	20	46.10	1124.07
213	26	9.6	510	6.5	2.2	14.42	29	40	31	51.95	2250.00
213	29	9.6	510	7.5	2.6	17.04	14	57	29	50.07	1022.71
213	30	9.6	510	7.6	2	13.11	44	36	20	48.96	550.56
213	32	9.6	510	5.6	1.1	7.21	75	14	11	22.52	2250.95
213	33	9.6	510	6.3	2.3	15.08	36	39	25	39.73	1759.35
213	34	9.6	510	7	1.4	9.18	66	17	17	54.90	942.71

Archived soil sample's data

mapping area	ID no.	mean annual temperature	mean annual precipitation	pH	organic matter	organic carbon (calculated)				0.01 M CaCl ₂ -extractable Si	0.2 M NaOH-extractable Si
		°C	mm/m ²		%	g/kg	sand	silt	clay	mg/kg	mg/kg
213	35	9.6	510	7.5	3.5	22.94	23	41	36	38.82	1230.20
213	37	9.6	510	7.6	2.3	15.08	42	31	27	48.00	902.35
213	38	9.6	510	7.6	2.4	15.73	22	35	43	37.63	2516.17
213	39	9.6	510	6.7	3.9	25.56	14	40	46	53.66	3130.92
213	41	9.6	510	7.4	2.2	14.42	18	44	38	49.04	1883.76

Resampled soil sample's data

mapping area	ID no.	mean annual temperature	mean annual precipitation	water content	pH	organic Carbon	Nitrogen	0.01 M CaCl ₂ -extractable Si	0.2 M NaOH-extractable Si
		°C	mm/m ²	%		g/kg	g/kg	mg/kg	mg/kg
1	22 m	9.9	568	2.56	7.58	49.64	3.48	22.27	831.96
1	22 I	9.9	568	2.56	7.59	46.51	3.63	21.53	842.93
1	22 II	9.9	568	2.25	7.53	48.26	3.46	24.88	836.69
1	22 III	9.9	568	12.98	7.49	42.30	3.15	26.96	820.71
1	22 IV	9.9	568	2.46	7.55	48.83	3.71	23.52	884.95
1	23	9.9	568	3.09	7.40	24.55	2.41	36.37	1915.73
1	25	9.9	568	4.17	7.68	46.31	3.35	24.77	1115.05
1	33	9.9	568	3.20	7.63	76.37	5.26	55.64	1768.90
1	36	9.9	568	6.16	7.42	45.54	4.65	32.43	2939.55
1	38	9.9	568	1.93	7.59	46.89	2.61	24.49	902.57
1	39	9.9	568	2.99	6.16	17.67	1.92	40.79	2877.36
1	41	9.9	568	2.77	7.50	17.75	1.96	30.98	2165.22
1	43	9.9	568	3.09	7.80	53.91	3.76	27.86	760.35
1	45	9.9	568	3.95	7.67	64.84	5.12	34.99	866.81
1	47	9.9	568	4.71	7.58	53.18	5.01	20.53	1165.43
1	48	9.9	568	4.06	7.60	34.91	2.78	28.06	2139.74
1	51	9.9	568	3.73	7.68	69.79	5.13	25.96	637.66
1	52	9.9	568	12.22	7.38	75.07	6.68	11.97	810.25
1	53	9.9	568	5.70	7.73	70.36	4.65	17.90	553.90
1	57	9.9	568	6.26	7.52	33.87	2.97	41.92	4463.11
26	10	10.3	636	2.56	7.45	41.82	3.53	46.54	1667.15
26	11	10.3	636	2.67	7.74	53.93	3.44	19.90	616.88
26	12	10.3	636	4.93	7.40	36.33	3.41	48.05	2682.29
26	13	10.3	636	1.73	7.70	32.30	2.03	24.16	907.35
26	14	10.3	636	3.73	7.53	31.14	2.71	28.52	2348.12

Resampled soil sample's data

mapping area	ID no.	mean annual temperature	mean annual precipitation	water content	pH	organic Carbon	Nitrogen	0.01 M CaCl ₂ -extractable Si	0.2 M NaOH-extractable Si
		°C	mm/m ²	%		g/kg	g/kg	mg/kg	mg/kg
26	15	10.3	636	3.20	7.41	78.06	6.40	29.87	850.64
26	17	10.3	636	3.41	7.43	67.23	5.57	20.57	373.67
26	19	10.3	636	3.95	7.46	31.30	3.15	45.12	2224.40
26	20	10.3	636	4.82	7.19	29.98	3.05	48.78	3697.90
26	21	10.3	636	4.16	7.13	24.19	2.50	48.85	4179.46
26	22	10.3	636	4.71	7.49	23.43	1.93	40.35	2468.65
26	23	10.3	636	1.83	7.73	50.79	2.57	20.29	616.84
26	24	10.3	636	4.38	7.79	67.85	4.59	8.37	253.31
26	26	10.3	636	3.95	7.50	26.88	2.77	46.32	3546.94
26	27	10.3	636	4.49	7.51	40.56	3.38	49.58	2768.85
26	28	10.3	636	3.41	7.46	38.34	3.32	55.13	2208.11
26	32	10.3	636	3.73	7.42	30.88	2.83	64.37	2528.06
26	37	10.3	636	3.84	7.72	54.26	3.99	29.79	980.66
26	38	10.3	636	2.88	7.67	63.13	4.43	22.09	517.14
26	39	10.3	636	3.31	7.50	42.80	3.10	55.21	2223.27
177	12	9.5	524	3.31	7.53	20.31	2.06	32.15	2569.37
177	13	9.5	524	7.06	7.74	30.35	3.28	21.20	2867.08
177	15	9.5	524	3.41	7.60	23.58	1.97	33.60	2765.38
177	17	9.5	524	5.81	7.63	18.87	1.77	44.26	2703.86
177	19	9.5	524	2.67	7.18	14.86	1.59	55.42	2545.26
177	21	9.5	524	8.58	7.64	13.14	1.08	34.42	2198.12
177	23	9.5	524	2.04	6.39	15.25	1.45	43.25	2061.81
177	26	9.5	524	4.52	6.99	20.31	2.13	47.42	3485.54
177	27	9.5	524	3.84	6.66	18.50	2.00	44.41	3147.52

Resampled soil sample's data

mapping area	ID no.	mean annual temperature	mean annual precipitation	water content	pH	organic Carbon	Nitrogen	0.01 M CaCl ₂ -extractable Si	0.2 M NaOH-extractable Si
		°C	mm/m ²	%		g/kg	g/kg	mg/kg	mg/kg
177	29	9.5	524	5.70	6.92	39.60	3.15	87.98	4831.80
177	30	9.5	524	5.47	7.57	18.17	1.91	41.86	2841.98
177	31	9.5	524	2.45	4.97	11.83	1.27	20.85	2727.52
177	32	9.5	524	5.15	7.70	23.20	2.15	74.94	4030.73
177	34	9.5	524	8.69	6.75	24.81	2.36	99.37	5805.45
177	66	9.5	524	1.63	7.42	15.78	1.50	55.59	1922.56
177	67	9.5	524	5.26	7.43	22.80	2.44	122.85	12338.39
212	24	9.6	510	2.35	7.34	18.47	1.81	42.15	2412.68
212	25	9.6	510	6.27	7.65	15.56	1.50	44.05	2425.20
212	26	9.6	510	2.99	7.49	18.21	1.78	45.39	2469.30
212	27	9.6	510	2.46	7.60	15.26	1.43	41.90	2347.32
212	28	9.6	510	2.04	7.67	15.37	1.41	32.05	1641.15
212	31	9.6	510	3.30	7.57	22.92	2.18	43.85	2768.96
212	32	9.6	510	1.93	6.65	14.34	1.52	47.61	2308.77
212	33	9.6	510	8.34	7.07	29.78	2.81	98.88	5231.76
212	35	9.6	510	1.52	7.16	12.12	1.16	30.62	1732.02
212	37	9.6	510	3.09	6.42	21.58	2.04	61.79	3177.68
212	38	9.6	510	3.09	6.74	20.26	1.93	51.50	3279.00
212	39	9.6	510	2.35	6.67	16.00	1.54	49.55	2955.61
212	41	9.6	510	4.38	7.05	26.48	2.39	58.63	3367.32
212	43	9.6	510	4.60	5.84	22.33	1.97	37.90	3044.62
212	44	9.6	510	2.77	6.23	26.69	2.10	69.38	3577.33
212	45	9.6	510	2.99	7.72	20.43	1.73	43.00	2151.07
212	46	9.6	510	3.41	7.80	16.86	1.48	37.31	1495.80

Resampled soil sample's data

mapping area	ID no.	mean annual temperature	mean annual precipitation	water content	pH	organic Carbon	Nitrogen	0.01 M CaCl ₂ -extractable Si	0.2 M NaOH-extractable Si
		°C	mm/m ²	%		g/kg	g/kg	mg/kg	mg/kg
212	53	9.6	510	2.45	7.50	19.31	1.99	53.50	2199.22
212	54	9.6	510	1.93	6.43	10.27	1.05	42.78	2342.96
212	58	9.6	510	2.67	7.61	19.01	1.68	51.12	1863.55
212	61	9.6	510	3.62	7.46	24.99	2.34	39.35	2714.28
212	63	9.6	510	6.82	7.67	23.67	2.15	40.54	3253.60
212	66	9.6	510	1.42	6.67	19.05	1.74	48.52	2091.60
212	69	9.6	510	1.62	5.94	17.27	1.52	44.25	2560.54
212	70	9.6	510	2.24	6.92	19.52	1.76	51.23	2493.76
213	11	9.6	510	3.95	7.21	19.25	1.81	41.04	2769.12
213	13	9.6	510	3.41	7.52	21.39	2.13	49.88	2832.22
213	14	9.6	510	3.19	7.34	21.23	2.11	54.64	2511.34
213	16	9.6	510	3.62	7.49	21.22	2.16	48.89	3225.72
213	18	9.6	510	5.59	7.72	28.68	2.33	55.18	2998.77
213	19	9.6	510	4.49	6.85	22.90	2.05	78.94	3552.91
213	21	9.6	510	2.04	6.97	13.97	1.50	42.97	2822.38
213	22	9.6	510	2.67	7.20	18.15	1.96	49.85	3043.26
213	23	9.6	510	2.35	7.23	16.89	1.65	53.12	2620.81
213	24	9.6	510	2.04	6.85	14.42	1.44	55.31	2938.37
213	25	9.6	510	2.35	6.87	14.71	1.56	55.23	2328.93
213	26	9.6	510	4.71	6.02	25.06	2.17	62.21	3902.34
213	29	9.6	510	3.09	7.73	22.11	1.74	37.98	2086.76
213	30	9.6	510	2.56	7.60	19.05	1.75	51.02	1973.65
213	32	9.6	510	1.01	4.46	9.77	0.91	14.22	2927.14
213	33	9.6	510	2.35	5.97	15.48	1.58	57.82	2982.01

Resampled soil sample's data

mapping area	ID no.	mean annual temperature	mean annual precipitation	water content	pH	organic Carbon	Nitrogen	0.01 M CaCl ₂ -extractable Si	0.2 M NaOH-extractable Si
		°C	mm/m ²	%		g/kg	g/kg	mg/kg	mg/kg
213	34	9.6	510	2.14	5.36	14.92	1.33	27.57	2414.61
213	35	9.6	510	4.26	7.65	27.76	2.66	36.62	3032.38
213	37 m	9.6	510	4.70	7.57	20.33	1.95	40.53	2151.15
213	37 I	9.6	510	3.40	7.53	21.42	2.11	52.78	2138.54
213	37 II	9.6	510	2.35	7.48	22.56	2.13	52.35	2127.97
213	37 III	9.6	510	4.17	7.58	21.57	2.06	45.07	2121.73
213	37 IV	9.6	510	2.46	7.47	22.38	2.14	52.74	2178.59
213	38	9.6	510	3.63	7.12	25.87	2.41	51.87	3555.09
213	39	9.6	510	5.71	7.17	28.11	2.51	39.04	4804.08
213	41	9.6	510	3.41	7.47	20.16	1.97	51.06	3256.58

5.4 List of soils

List of soils

mapping area	ID no.	coordinates WGS 84	collection years	Austrian soil classification	WRB Classification
1	22	48.0346764°, 16.4249279°	1994-1997	Tschernosem (ehemals Feuchtschwarzerde)	Calcaric Skeletic Chernic Phaeozem (Aric)
1	23	48.1002216°, 16.6232902°	1994-1997	Tschernosem	Skeletic Phaeozem (Aric)
1	25	48.0781247°, 16.4209233°	1994-1997	Tschernosem (ehemals Feuchtschwarzerde)	Calcaric Skeletic Chernic Phaeozem (Aric)
1	33	48.0097754°, 16.4503809°	1994-1997	Tschernosem (ehemals Feuchtschwarzerde)	Calcaric Chernic Phaeozem (Aric)
1	36	48.072164°, 16.4067068°	1994-1997	Tschernosem	Calcaric Skeletic Chernic Phaeozem (Aric)
1	38	48.0276002°, 16.4440911°	1994-1997	vergleyter Tschernosem	Calcaric Regosol (Aric, Humic)
1	39	48.0969367°, 16.6206901°	1994-1997	entkalkter Tschernosem	Skeletic Chernic Phaeozem (Aric)
1	41	48.0956353°, 16.6518583°	1994-1997	schwach vergleyter, entkalkter Tschernosem	Endocalcaric Chernic Phaeozem (Aric, Pachic)
1	43	48.0035476°, 16.4240759°	1994-1997	Tschernosem (ehemals Feuchtschwarzerde)	Calcic Chernozem (Aric)
1	45	48.093082°, 16.4383533°	1994-1997	Tschernosem (ehemals Feuchtschwarzerde)	Calcic Chernozem (Aric, Pachic)
1	47	48.0399957°, 16.4297139°	1994-1997	kalkhaltige Feuchtschwarzerde	Calcic Chernozem (Aric, Pachic)
1	48	48.0982261°, 16.4446142°	1994-1997	kalkhaltige Feuchtschwarzerde	Calcaric Gleyic Regosol (Aric, Drainic, Humic)
1	51	47.9944536°, 16.4442745°	1994-1997	versalzte, kalkhaltige Feuchtschwarzerde	Calcaric Gleyic Chernic Phaeozem (Aric, Hyperhumic, Pachic)
1	52	47.9920181°, 16.4474557°	1994-1997	versalzte, kalkhaltige Feuchtschwarzerde	Calcaric Protocalcaric Chernic Gleysol (Humic)
1	53	48.0013759°, 16.4443251°	1994-1997	versalzte, kalkhaltige Feuchtschwarzerde	Calcaric Chernic Gleysol (Aric, Humic)
1	57	48.0267636°, 16.4507656°	1994-1997	kalkhaltige Feuchtschwarzerde	Calcic Chernozem (Aric, Pachic)
26	10	48.0094229°, 16.3926789°	1988-1994	Tschernosem	Calcaric Skeletic Regosol (Aric)
26	11	48.0147593°, 16.4114692°	1988-1994	Tschernosem	Calcaric Regosol (Aric)
26	12	48.1338357°, 16.3340259°	1988-1994	Tschernosem	Calcaric Chernic Phaeozem (Aric)
26	13	48.0088489°, 16.395664°	1988-1994	Tschernosem	Calcaric Skeletic Regosol (Aric, Humic)

List of soils

mapping area	ID no.	coordinates	collection years	Austrian soil classification	WRB Classification
		WGS 84			
26	14	48.1321654°, 16.3495029°	1988-1994	Tschernosem	Calcaric Skeletic Chernic Phaeozem (Aricc)
26	15	48.0358737°, 16.2822385°	1988-1994	Tschernosem	Calcaric Skeletic Regosol (Aric, Humic)
26	17	48.0348468°, 16.2861536°	1988-1994	Tschernosem	Calcaric Chernic Phaeozoem (Aric, Pachic)
26	19	48.1253175°, 16.3749238°	1988-1994	Tschernosem	Calcaric Chernic Phaeozoem (Aric)
26	20	48.1227443°, 16.2968812°	1988-1994	entkalkter Tschernosem	Skeletic Chernic Phaeozem (Aric)
26	21	48.1153503°, 16.3299624°	1988-1994	entkalkter Tschernosem	Haplic Kastanozem (Aric)
26	22	48.0557065°, 16.2893093°	1988-1994	versalzter Tschernosem	Calcaric Skeletic Phaeozem (Aric)
26	23	48.0210472°, 16.408284°	1988-1994	versalzter Tschernosem	Calcaric Regosol (Aric, Endosalic, Humic)
26	24	48.023353°, 16.409601°	1988-1994	versalzter Tschernosem	Calcaric Regosol (Aric, Endosalic, Humic)
26	26	48.1105038°, 16.3398327°	1988-1994	versalzter, entkalkter Tschernosem	Skeletic Chernic Phaeozem (Aric, Endosalic)
26	27	48.0523197°, 16.377069°	1988-1994	Tschernosem (ehemalige Feuchtschwarzerde)	Calcaric Skeletic Chernic Phaeozem (Aric)
26	28	48.1196997°, 16.3497352°	1988-1994	kalkhaltige Feuchtschwarzerde	Calcaric Gleysol (Aric, Humic)
26	32	48.0934191°, 16.3598238°	1988-1994	versalzte, kalkhaltige Feuchtschwarzerde	Eutric Regosol (Aric, Humic)
26	37	48.013922°, 16.403664°	1988-1994	aggradierte, kalkhaltige Feuchtschwarzerde	Calcic Chernozem (Aric)
26	38	48.020617°, 16.4116002°	1988-1994	aggradierte, kalkhaltige Feuchtschwarzerde	Calcaric Regosol (Aric, Humic)
26	39	48.0623826°, 16.3475186°	1988-1994	aggradierte, versalzte, kalkhaltige Feuchtschwarzerde	Calcaric Skeletic Regsol (Aric)
177	12	48.6835514°, 15.8934756°	1982-1987	Tschernosem	Calcaric Chernic Phaeozem (Aric, Pachic)
177	13	48.7232545°, 15.9630725°	1982-1987	Tschernosem, kolluvial beeinflusst	Haplic Chernozem (Aric, Colluvic, Pachic)
177	15	48.7466242°, 16.0497334°	1982-1987	Tschernosem	Calcaric Chernic Phaeozem (Aric)

List of soils

mapping area	ID no.	coordinates	collection years	Austrian soil classification	WRB Classification
		WGS 84			
177	17	48.7043288°, 15.967163°	1982-1987	Tschernosem	Calcaric Chernic Phaeozem (Aric, Pachic)
177	19	48.722782°, 15.8695197°	1982-1987	entkalkter Tschernosem	Haplic Phaeozem (Aric, Pachic)
177	21	48.7714977°, 15.9985535°	1982-1987	Tschernosem	Calcaric Phaeozem (Aric)
177	23	48.6948832°, 15.8962412°	1982-1987	Tschernosem	Skeletal Phaeozem (Aric, Pachic)
177	26	48.6622561°, 15.9721164°	1982-1987	Tschernosem	Chernic Phaeozem (Aric, Pachic)
177	27	48.7469775°, 15.9035316°	1982-1987	entkalkter Tschernosem	Haplic Phaeozem (Aric, Pachic)
177	29	48.6744988°, 16.0021886°	1982-1987	entkalkter Tschernosem	(Gleyic) Chernic Phaeozem (Aric, Pachic)
177	30	48.6883424°, 15.8783969°	1982-1987	brauner Tschernosem	Calcaric Cambic Phaeozem (Aric, Pachic)
177	31	48.775547°, 15.9726098°	1982-1987	Paratschernosem	Haplic Umbrisol (Aric, Pachic)
177	32	48.6898916°, 15.9868937°	1982-1987	kalkhaltige Feuchtschwarzerde	Calcaric Chernic Phaeozem (Aric, Pachic)
177	34	48.7089244°, 15.9800977°	1982-1987	entkalkte Feuchtschwarzerde	Chernic Phaeozem (Aric, Pachic)
177	66	48.7385782°, 15.9465645°	1982-1987	kalkhaltiges Tschernosemkolluvium	Calcaric Phaeozem (Aric, Colluvic, Pachic)
177	67	48.7024667°, 15.9767474°	1982-1987	kalkhaltiges Tschernosemkolluvium	Haplic Phaeozem (Aric, Colluvic, Pachic)
212	24	48.6891861°, 16.2655464°	1988-2000	Tschernosem	Calcic Chernozem (Aric, Pachic)
212	25	48.7565716°, 16.5398252°	1988-2000	Tschernosem	Haplic Kastanozem (Aric)
212	26	48.7343774°, 16.2371573°	1988-2000	Tschernosem	Haplic Kastanozem (Aric)
212	27	48.7293424°, 16.2409679°	1988-2000	Tschernosem, kolluvial beeinflusst	Haplic Kastanozem (Aric, Pachic)

List of soils

mapping area	ID no.	coordinates	collection years	Austrian soil classification	WRB Classification
		WGS 84			
212	28	48.6536721°, 16.2289263°	1988-2000	Tschernosem	Calcaric Gleyic Regosol (Aric, Protocalcic)
212	31	48.7723765°, 16.5156604°	1988-2000	Tschernosem	Haplic Chernozem (Aric, Pachic)
212	32	48.6983828°, 16.4008921°	1988-2000	Tschernosem, kolluvial beeinflusst	Haplic Phaeozem (Aric, Colluvic, Pachic)
212	33	48.7119493°, 16.4628903°	1988-2000	Tschernosem	Haplic Chernozem (Aric)
212	35	48.6962151°, 16.3866772°	1988-2000	entkalkter Tschernosem	Chernic Phaeozem (Aric, Pachic)
212	37	48.7367482°, 16.2410056°	1988-2000	entkalkter Tschernosem	Haplic Chernozem (Aric, Pachic)
212	38	48.7349178°, 16.2261947°	1988-2000	Tschernosem, kolluvial beeinflusst	Haplic Chernozem (Aric, Colluvic)
212	39	48.7866648°, 16.5291179°	1988-2000	entkalkter Tschernosem, kolluvial beeinflusst	Chernic Phaeozem (Aric, Colluvic, Pachic)
212	41	48.792716°, 16.5223834°	1988-2000	entkalkter Tschernosem	Chernic Phaeozem (Aric, Pachic)
212	43	48.8010144°, 16.5273677°	1988-2000	entkalkter Tschernosem, kolluvial beeinflusst	Chernic Phaeozem (Aric, Colluvic, Pachic)
212	44	48.7951935°, 16.5236271°	1988-2000	entkalkter Tschernosem, kolluvial beeinflusst	Chernic Phaeozem (Aric, Colluvic)
212	45	48.6548023°, 16.2104203°	1988-2000	vergleyter Tschernosem	Gleyic Kastanozem (Aric)
212	46	48.7135103°, 16.3906258°	1988-2000	entwässerter Tschernosem	Calcaric Gleyic Chernic Phaeozem (Aric, Drainic)
212	53	48.7512998°, 16.529478°	1988-2000	Paratschernosem	Chernic Phaeozem (Aric, Pachic)
212	54	48.6728296°, 16.2646013°	1988-2000	Paratschernosem	Eutric Regosol (Aric)
212	58	48.7518732°, 16.5083201°	1988-2000	kalkhaltige Feuchtschwarzerde	Gleyic Chernic Phaeozem (Aric, Pachic)
212	61	48.6825937°, 16.2184974°	1988-2000	versalzte, kalkhaltige Feuchtschwarzerde	Calcaric Gleyic Chernic Phaeozem (Aric, Endogypsiric, Endosalic)
212	63	48.6840357°, 16.4046859°	1988-2000	versalzte, kalkhaltige Feuchtschwarzerde	Gleyic Chernozem (Aric, Endosalic)
212	66	48.7247714°, 16.4484747°	1988-2000	entkalkte Feuchtschwarzerde	Skeletal Chernic Phaeozem (Aric, Pachic)
212	69	48.7787007°, 16.5409613°	1988-2000	entkalkte Feuchtschwarzerde	Gleyic Chernic Phaeozem (Aric, Pachic)
212	70	48.7809069°, 16.5230531°	1988-2000	entkalkte Feuchtschwarzerde	Gleyic Chernic Phaeozem (Aric, Pachic)

List of soils

mapping area	ID no.	coordinates WGS 84	collection years	Austrian soil classification	WRB Classification
213	11	48.6653082°, 16.2698934°	1985-1988	Tschernosem	Haplic Chernozem (Aric, Pachic)
213	13	48.6386311°, 16.2612705°	1985-1988	Tschernosem	Haplic Chernozem (Aric)
213	14	48.6692845°, 16.4446282°	1985-1988	Tschernosem, kolluvial beeinflusst	Eutric Colluvic Regosol (Aric, Protocalcic, Humic)
213	16	48.6866484°, 16.4659059°	1985-1988	Tschernosem	Haplic Chernozem (Aric)
213	18	48.6708481°, 16.4474407°	1985-1988	Tschernosem	Calcic Chernozem (Aric)
213	19	48.694864°, 16.4848292°	1985-1988	Tschernosem	Haplic Chernozem (Aric, Pachic)
213	21	48.6821585°, 16.3608742°	1985-1988	kalkarmer Tschernosem	Chernic Phaeozem (Aric)
213	22	48.6653253°, 16.4231232°	1985-1988	entkalkter Tschernosem	Haplic Chernozem (Aric, Pachic)
213	23	48.675218°, 16.3113101°	1985-1988	entkalkter Tschernosem	Haplic Chernozem (Aric, Pachic)
213	24	48.6676757°, 16.3699694°	1985-1988	entkalkter Tschernosem, kolluvial beeinflusst	Haplic Kastanozem (Aric, Pachic)
213	25	48.6938761°, 16.4773588°	1985-1988	entkalkter Tschernosem	Haplic Kastanozem (Aric)
213	26	48.6938967°, 16.4427852°	1985-1988	entkalkter Tschernosem	Haplic Chernozem (Aric, Pachic)
213	29	48.6512418°, 16.2673392°	1985-1988	schwach vergleyter Tschernosem	Calcic Chernozem (Aric)
213	30	48.6873079°, 16.4546628°	1985-1988	schwach vergleyter Tschernosem	Haplic Chernozem (Aric)
213	32	48.6949013°, 16.4817587°	1985-1988	Paratschernosem	Skeletal Umbrisol (Aric)
213	33	48.6723784°, 16.3719004°	1985-1988	Paratschernosem	Skeletal Chernic Phaeozem (Aric, Pachic)
213	34	48.6960028°, 16.4936961°	1985-1988	Paratschernosem	Haplic Phaeozem (Aric)
213	35	48.6693912°, 16.2775592°	1985-1988	entwässerte, kalkhaltige Feuchtschwarzerde	(Gleyic) Chernic Phaeozem (Aric, Pachic)
213	37	48.6891201°, 16.4317841°	1985-1988	kalkhaltige Feuchtschwarzerde	Calcaric Chernic Phaeozem (Aric, Pachic)
213	38	48.6899919°, 16.4403469°	1985-1988	kalkhaltige Feuchtschwarzerde	Gleyic Chernic Phaeozem (Aric)
213	39	48.6831571°, 16.334251°	1985-1988	vergleyte, kalkhaltige Feuchtschwarzerde	Gleyic Calcic Chernozem (Aric, Pachic)
213	41	48.6560275, 16.3092495°	1985-1988	kalkhaltige Feuchtschwarzerde, kolluvial beeinflusst	Eutric Gleyic Chernic Phaeozem (Aric, Anocalcaric, Pachic)

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