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Comparison of two-year and immediate effect of biochar application on soil hydrophysical properties of haplic cambisol

Diploma Thesis

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Declaration:

I declare that I wrote this Diploma Thesis titled “Comparison of two-year and immediate effect of biochar application on soil hydrophysical properties of haplic cambisol” under control of my supervisor. Used literatures and informations are cited and referenced at the end of the thesis.

Prague, April 13, 2018

Signature: _______________

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It would not be possible without you. Thank you!

Summary

Biochar is solid material obtained from thermochemical conversion of biomass in an oxygen-limited environment. Biochar can be used for range of application as an agent for soil improvement, improved resource use efficiency, remediation and protection against particular environmental pollution and as avenue for greenhouse gas mitigation.

Biochar improves almost any soil, especially areas with low rainfall or nutrient-poor soils will most likely see the largest impact from addition of the biochar. However, long-term effect of biochar is not studied well in the Czech Republic. The aim of the study was to compare immediate and long-term effect of biochar on soil hydrophysical properties of haplic cambisol. The thesis was based on laboratory experiments, which were carried out in laboratory of the Department of Water Resources on repacked soil core samples with the volume of 250 cm^3. Haplic cambisol was taken at the experimental site of Research Institute for Soil and Water Conservation in Prague-Zbraslav in Třebsín, where biochar was applied two years ago, approx. 12 t/ha. . Three variants of biochar application were studied as follows: (1) no biochar admixture (control variant), (2) biochar admixture of 1% by mass, which was added to the soil in lab before the measurements, and (3) about 0.6% of biochar applied to the field two years ago. In addition, pure biochar was studied as well. Soil hydrophysical properties; saturated soil hydraulic conductivity (Ks) and soil water retention curve (SWRC) were measured both at the same sample by employing falling head method and evaporation method, respectively, with at least three replicates. Constant dry bulk density (BD) was maintained during the measurements, however, two BD values were tested.

From the obtained results for Ks, it was seen that BD affects the Ks value much more than biochar particles. Therefore, samples prepared with lower BD (1.2 g/cm^3) showed significantly higher Ks values. Samples with higher BD (1.4 g/cm^3) showed statistically significantly higher Ks for the variant (3) compared to (2) while there was no significant difference between (1) and (3).

SWRC is affected in the part close to saturation up to pF 1.5. Results showed that there is no much difference between (1) and (2); however, variant (2) has insignificantly higher water retention. On the other hand, increase in (3) (field application) was considerable.

Keywords: biochar, cambisol, saturated hydraulic conductivity, soil water retention curve

Table of Contents

List of Figures

List of Tables

1 Introduction

Biochar is charred organic material that contains great amount of carbon in a stable form which can be held for very long time in soil. There is no difference between biochar and charcoal except in its utilitarian intention; purpose of charcoal production is different (heating, barbeque, etc.) than biochar. However, if we consider it by chemical point of view, they are essentially the same materials. Biochar is stable carbon compound, is created by biomass (feedstock, organic agricultural wastes, etc.) in temperatures between 300 and 1000^{0}C, under low (near to zero) oxygen concentration. The process of production biochar in low temperature is called "torrefaction". Although after torrefaction biomass still contains some organic compounds (e.g. volatile organic compounds) which are original compounds in biomass, it is very much like fossil coal and is considered as carbon neutral fuel. Objective of biochar concept in soil is decline-enhanced greenhouse effect by sequestering, while improving soil quality.

Addition of biochar changes physicochemical properties of amended soil (Wong et al., 2016; Wong et al., 2017) and its hydraulic properties, for example, water permeability, soil water retention curve, etc. However, knowledge about effect of biochar on saturated hydraulic conductivity is not well known. It was concluded that biochar can increase (Asai et al., 2009; Lei and Zhang, 2013; Oguntunde et al., 2008) or decrease (Devereux et al., 2012; Ibrahim et al., 2013) or may not even have significant effects (Laird et al., 2010) on soil hydraulic conductivity.

The objective of this thesis is to investigate and compare the long-term (two-year) effect of biochar applied to the soil and immediate effect of biochar on the soil that biochar applied in laboratory on particular type of soil.

2 Scientific Hypothesis and Objectives

Hypothesis:

The application of biochar changes soil structure and porosity and thus affects soil hydrophysical properties such as saturated hydraulic conductivity and soil water retention. The long-term application will cause more significant changes in soil hydrophysical properties than immediate application.

Objectives of the thesis:

The aim of the thesis is to study in laboratory using homogeneous repacked soil core samples the influence of biochar admixture on soil hydrophysical properties of haplic cambisol both directly after mixing and after two years of field application.

3 Literature review

3.1 Biochar and its history

Biochar has very porous structure, allowing an unlimited flow of oxygen, the ability to retain water and at the same time maintain low bulk density. Therefore, addition of biochar to the soil gives space for health and strong growth of roots. The porous media even tends to suck water with nutrients from surrounding land and hold them. In addition to these, it serves to reproduction of microorganisms, maintaining their development and upbringing health development of plants.

High amount carbon contained and enriched with charcoal man-made soil (Anthrosols) was found close to both current and historic human settlements throughout Amazonia which takes place of a total area of 6000 – 18000 km^2 (Sombroek, 1966). After many researches, scientists have concluded that these layers of soil were created by indigenous people, as far back as 10000 years before present (Woods et al., 2009), with a depth about 1 m.

Soil enriched with organic material from peatlands and heathlands, have been arranged 3000 years before present in Europe, in particular, on the German island of Sylt (Blume and Leinweber, 2004). The largest area, about 3500 km^2 total area of man-made soils (Plaggic Anthrosols), was made in Middle Ages, from nutrient poor, dry sandy soil (Arenosols) of the Netherlands, northern Belgium and north-western Germany (Fig. 1), with similar depth as Anthrosols found in Amazonia. Although European and Amazonian anthrosols were enriched to increase their agricultural performance, there is crucial difference between Anthrosols of Europe and Hortic Anthrosols of Amazonia.

Word of Plaggic came from Dutch, “Plag” means cut out section of organic top soil layer, includes vegetation while Hortic Anthrosols is translated as “kitchen soil”. These names are expression of their composition, for example, Plaggic Anthrosols were created by adding organic topsoil components and peat and mixed with manure while Hortic Anthrosols were made by various type of mineral materials, animal bones as well as charcoal and pottery fragments. What separates Terra Preta from other Hortic Anthrosols is high concentration of charcoal as assumed that charcoal was designedly created for application to soil.

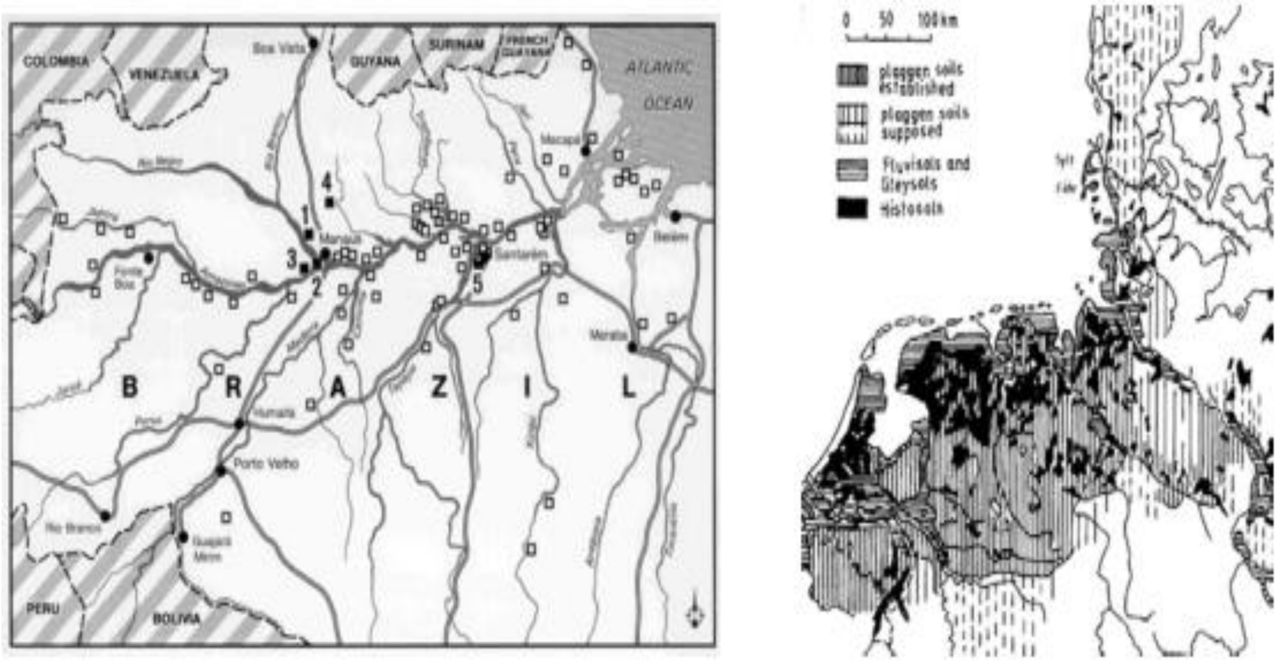

Figure 1. Distribution of Anthrosols in Amazonia (left, Glaser et al., 2001) and in Europe (right, Blume and Leinweber, 2004).

Terra Preta, as it is known in this area of Brazil, remains highly fertile until today, even with no application of fertilizers. Terra Preta was found mainly along the major rivers of the Amazon basin. It is anthropogenic, or man-made soil with high amount of microorganisms and useful nutrients like nitrogen, potassium, phosphorus, calcium, magnesium, and especially carbon. This type of soil has very dark color, because it contains high level of stable soil organic matter, on average three times higher than non-anthrosols of Amazonia. Its pH is rather neutral if you compare it to surrounding soil, which is mostly acidic, with range of 5.2 to 6.4. Because of these chemical features, soil contains and retains plant available nutrients. High content of stable soil organic matter also improves soil physical properties as organic matter plays a role in changing porosity of background soil matrix, resulting in soil that is better able to hold water. This feature might seem inappropriate for tropical rainforest zone, but the fact is that many areas of Amazon basin, particularly central Brazilian Amazon, encounters strong dry season influence on non-irrigated agricultural lands. Also, parent materials of non-anthrosols in the region are often either of high clay content resulting in periods of excessive moisture, or exhibit sand-sized aggregates that results in rapid flow-through and poor water retention.

In 2006, World Congress of Soil Science, was held in Philadelphia, Pennsylvania, USA, there was held workshop to discuss the potential of generating terra preta like soil conditioners.

Inspired by terra preta, scientists and academics formed organization that was known later as the International Biochar Initiative (IBI) (IBI, 2018).

3.1.1 Biochar in the attention

In worldwide, concept of biochar has come increasingly into attention in both political and academic areas. Several countries (e.g. the United Kingdom, New Zealand, the U.S.A) established biochar research centers. In media, it is often represented as miracle cure. The illustration is given by comparing search volumes “biochar”, “terra preta” and “black earth” from 2004 to 2009, testifying the recent increase in attention and exposure of biochar (Fig. 2) (Verheijen et al., 2010).

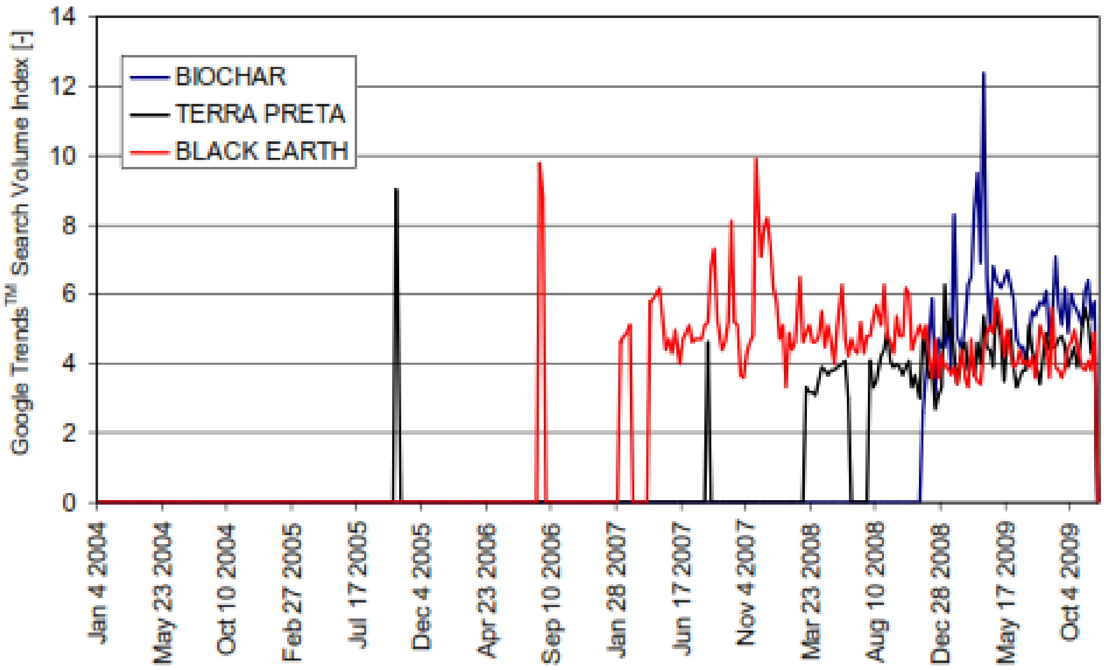

Figure 2. Google Trends result of “biochar”, “terra preta”, and “black earth”. The scale was based on average worldwide traffic of biochar from January 2004 until January 2009. (Verheijen et al., 2010).

3.2 Biochar Production

Biochar is the solid product of biomass pyrolysis. Pyrolysis is the thermochemical decomposition of fuel at elevated temperatures and without adding external oxygen (Weber and Quicker, 2018). The process should be started by drying of biomass. After that, biomass is further heated and volatile matter released from the solid particle. These volatile compounds can be converted to permanent gases (e.g. CO_2, CO, CH_4, and H_2). Further reactions in gas phase include cracking and polymerization and therefore can change the entire product spectrum. Three different groups can be classified: permanent gases, one or more liquid phrases (water and tar) and solid particle. Ways of reaction these different products compete partially and the product distribution can be influenced by the conditions of the process, mainly by the process temperature and residence time. Depending on the desired product process, some general guidelines can maximize the profitability of a certain product group.

The target of the flash pyrolysis is production of liquid oil. Condensable volatile products, which are discharged from the solid particles, should quickly be cooled down in order to avoid cracking gases or polymerization into char. The yield of the liquid might be up to 75% of dry matter of the feedstock (Quicker and Weber, 2016).

However, in the production of biochars, the main interest is carbon solid product. Evaporation of water and release of volatile substances lead to an increase in the relative fixed carbon content in solid. The polymerization of organic compounds in vapors and gases leads to the formation of secondary coal and increase the solid yield. The reaction pathways to these different products are partly competing and the product distribution can be influenced by the process conditions, mainly process temperature and residence time. In the traditional way of charcoal production (charcoal pit), it may take several weeks before the completion of the carbonization. Typical temperatures for slow pyrolysis is about 500 °C, but ultimately depends on the desired product properties. A very high carbon content of more than 95% can require treatment temperatures close to 1000 °C which can be achieved for wood raw materials, but create problems for agricultural waste and other materials with a low melting temperature of ash. Therefore, pyrolysis does not run beyond 700°C. If temperature range is between 200-300°C, this type of pyrolysis is referred to as torrefaction. Primary goal is to preserve and concentrate most of the energy content in solid, and visibly increase mechanical properties of biomass (e.g. grindability), which can otherwise limit to some applications.

3.3 Carbon sequestration potential

As global estimations, soil is able to hold more organic carbon (1100 Gt) than the atmosphere (750 Gt) and terrestrial biosphere (560 Gt) (Post et al., 1990; Sundquist, 1993). In Kyoto Protocol on Climate Change of 1997, which was adopted in United Nations Framework Convention on Climate Change, article 3.4 allows organic carbon stored in arable soil to be included in calculations of net carbon emissions. It talks about the possibility of subtracting the amounts of CO_2 removed from the atmosphere in agricultural sinks, from designated targeted reductions for individual countries. Soil organic carbon (SOC) sequestration into arable land has been studied (Smith et al., 2000; Freibauer et al., 2002; West and Post, 2002; Sleutel et al., 2003; Janzen, 2004; King et al., 2004; Lal, 2004) against background of organic carbon credit trading schemes (Jonson and Heinen, 2004).

Principle that using biochar in carbon sequestration is connected to the role of soil in carbon cycle (Fig. 3). In Figure 3, global flux of CO_2 is demonstrated. According to figure, CO_2 from the soil to the atmosphere is in the region of 60 Gt of C per year. The main part of this CO_2 is made up by microbial respiration within the soil systems as the soil organic matters (SOM) are decomposed by microbes. Apparently, biochar components are more recalcitrant than SOM and decomposition time takes much more time if we compare to SOM, over time frame which can be measured in thousands of years. That means biochar allows carbon input in increased amount into soil compared to carbon output through soil microbial respiration, and this is the basis behind possible carbon negativity of biochar, therefore its potential for climate change mitigation.

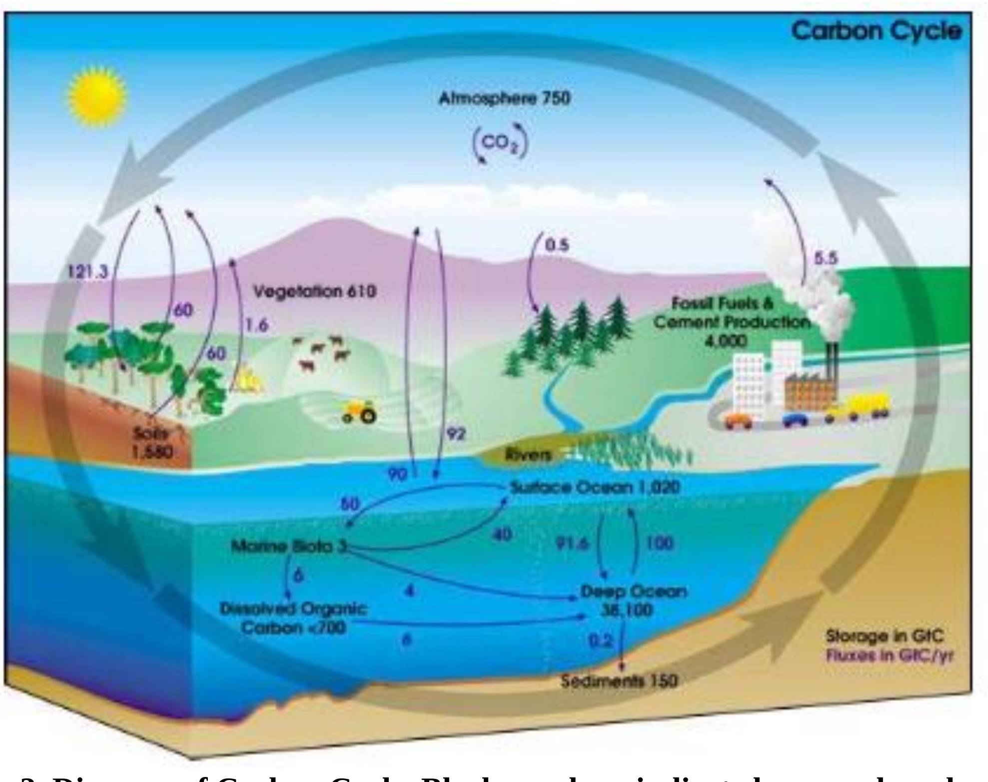

Figure 3. Diagram of Carbon Cycle. Black numbers indicate how much carbon is stored in different reservoirs in Gigatons. The purple numbers show how much carbon moves each year between reservoirs (NASA, 2008).

In Figure 3, we can see simplification of C-cycle, however, numbers are well established (NASA, 2008). Calculation of the fluxes while being more “black envelope” calculation, than precise mathematics, is highly demonstrative of the anthropogenic influence on atmospheric

CO_2. If we add all sinks together, total amount of sink is 213.35 Gt per year. On the other hand, when all carbon that emitted to atmosphere from non-anthropogenic sources was calculated, it was in total 211.6 Gt per year, with net loss of carbon from the atmosphere of 1.75 Gt C. That is why such small amount anthropogenic sources (5.5 Gt per year) play crucial role in C cycle. Overall, net gain of C is 3.75 Gt per year in atmosphere.

Lehmann et al. (2006) estimated potential global C-sequestration of 0.16 Gt /year using the current forestry and agriculture wastes, such as forest residues, mill residues, field crop and urban wastes for biochar creation. As estimation of the same authors, using projections of renewable fuels by 2100, sequestration to reach potential range of 5.5-9.5 Gt/year, thereby exceeding current fossil fuel emissions.

3.4 Effect of the biochar on plant growth

Literatures show that addition of biochar effects significantly on growth of the plant as well as composting materials. Studies have proven that biochar, in both climate conditions, improves the rate of plant growth, microbial activity and water retention, while reduces leaching of nutrients (Hunt et al., 2010). In 2005 Major et al. reported that, as the result of research on Hawaiian native soil proved that biomass of the plant increased 189% when biochar was applied at rate of 23.2 t/ha. Similar situation occurred in Brazil, when biochar was introduced to the soil native plant species increased by 63%. However, some studies showed that plant growth may decrease due to nutrient imbalances associated with the temporary pH levels of fresh biochar, volatile or mobile matter, which was created by tars, and other short-lived substances that remain on biochar surface after it was made (McClellan et al., 2007). Value of pH of new made biochar is basic that shows strong positive effect on acidic soil. Despite this advantage, if soil becomes too alkaline, nutrient transfer may break. Within time, microbial activities may decompose mobile matters and made nutrient for the plant, however, this process requires nitrogen and soil elements, making nutrients temporarily unreachable for plant to uptake (McClellan et al., 2007). But, all these inconveniences will disappear after decaying mobile matters, pH neutralizes, and nutrient distribution reorganizes. Most of studies have shown that useful effects of biochar on plant growth increases overtime after it has been applied to soil (Cheng et al., 2006; Major et al., 2010).

3.5 Effects of application of biochar to soil

3.5.1 Effect on physicochemical properties of soil

Once biochar applied to soil, its physical and chemical features completely changes. In review by Joseph et al. (2010) and Lehmann et al. (2011) possible reactions were shown. If we add biochar with high concentration of soluble minerals and organic molecules on their surface to wet soil (or after addition rain follows) there is change in pH, EC, and Eh (redox potential) through particles, approximately within a first week, as minerals are dissolved and ions are exchanged on the surface of surrounding clay particles.

As the result of raining, colloidal soil particles can migrate into the pores of the biochar, react with carbon surface and end up as biochar organomineral complex (Fig. 4). Very limited information is available indicate that, type of reactions taking place and steadiness of compounds retained on the surface depend on type of biochar and conditions under which it was produced (Spokas and Reicosky, 2009).

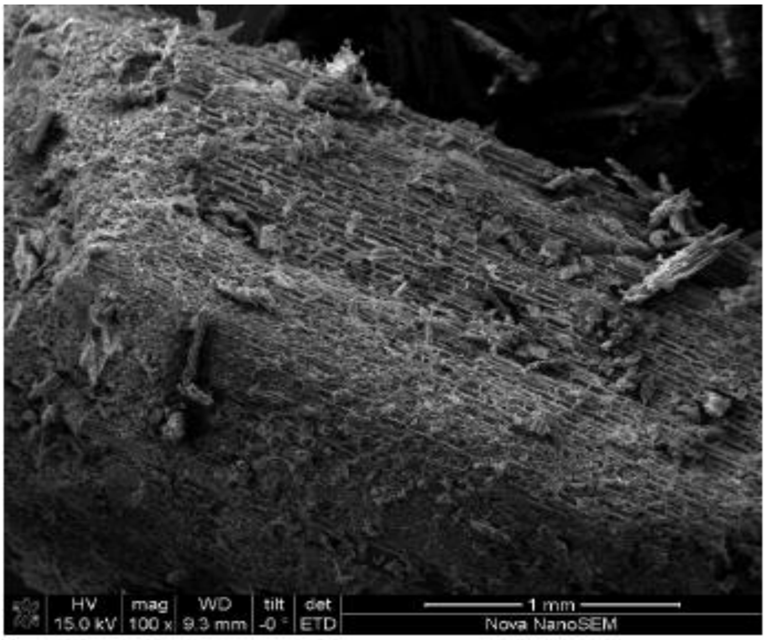

Figure 4. Wood biochar extracted from the soil. Organomineral compounds evident on the surface. Source: Electron microscopy unit (EMU), University of New South Wales.

When biochar, that made at low temperature, is added to wet soil, large amount of soluble organics can be released to the soil solution. Some easily breakable organics can increase seed germination, fungi growth, nutrient uptake and reduction in pathogens (Graber et al., 2010, Dixon, 1998, Light et al., 2009).

During the first month of biochar addition, enhanced CO_2 emission can be observed. These enhanced emissions are partly attributed to biochar surface oxidation that has both chemical and biological basis. It is possible, that mineral matters in biochar and water-soluble organics on internal and external surface provide nutrients for microorganisms in order to grow fast and catalyzing the breakdown organic matter (Amonette et al., 2006).

Biochar surface oxidation improves the potential for hydrophilic interactions with the range of soil inorganic and organic compounds. This indicator is significantly high in mineral rich ash biochars (Lima and Marshall, 2005). Greater reactivity of biochar with mineral matter could further promote physical protection of biochar and labile organic matter and thus long term stability (Brodowski et al., 2006). When roots and especially, their root hairs, interact with biochar, wider range of reactions can happen, during the uptake of nutrients by plants, and release of root residue. Over the period of time, physical disturbances interactions with microflora and microfauna and complex reactions with soil constituents, will break larger piece of biochar particles into smaller ones and establishment of organomineral agrregates (Joseph et al., 2010).

3.5.2 Soil bulk density

Density of biochar is much lower than mineral soil's density, therefore application of biochar can decrease the total bulk density of the soil, although increase in bulk density is also possible (Verheijen et al., 2010). If we apply 100 t/ha of biochar with bulk density 0.4 g/cm^3, to top 20 cm of soil with bulk density 1.3 g/cm^3, and biochar particles do not fill up exist soil pore space, then soil surface will increase to 2.5 cm with overall bulk density reduction (assuming homogeneous mixing) of 0.1 g/cm^3 to 1.2 g/cm^3. However, applied biochar has low mechanical strength and decomposes relatively quickly into small particles, thereafter it fills up existing pore spaces in that soil, and then soil dry bulk density increases.

In agriculture, even small differences in bulk density can bring good results in agronomic benefits. Conventionally, i.e. without biochar additions, lower bulk density is associated with higher soil organic matter content leading to nutrient release and retention and lower soil compaction due to better soil management (potentially leading to improved seed germination and cost saving for tillage and cultivation). Biochar application to soil by itself might also increase nutrient retention directly, but nutrient release is mostly very small (except for some biochars, especially ash rich biochars, in the first year) and biochar application with heavy machinery may compact the subsoil, depending on application method and timing (Verheijen et al., 2010).

3.5.3 Water and nutrient retention

The mechanism leading to biochar–provided potential improvements in water retention is relatively straightforward. Adding biochar to soil can affect directly or indirectly on soil water retention, which can be long or short-lived. Water retention of soil is determined by the distribution and connectivity of pores in soil porous system which is largely regulated by soil particle size distribution, combined with structural characteristics and soil organic matter content.

The direct effect of biochar application is based on large inner surface area of biochar. In 1985 Kishimoto and Sugiura evaluated charcoal inner surface area that formed between 400 and 1000°C to range between 200 and 400 m^2/g. Van Zwieten et al. (2009) determined the surface area of biochar, that was created from paper mill waste by slow pyrolysis, is 115 m^2/g.

The hypothesis about indirect effect of biochar on soil water retention is improvement in aggregation or structure. Biochar can affect on soil aggregation due to interaction with soil organic matter, microorganisms and minerals. Characteristics of the surface charge and their development over time determine the long term effect on soil aggregation. Older biochars will generally have higher cation exchange capacity, improving its potential to act as binding agent of minerals and organics. Mbagwu and Piccolo (1997) reported macro aggregate stability increases from 20 to 130% with application rates of coal derived humic acids between 1.5 t/ha and 200 t/ha and also an indication was found that black carbon acts as binding agent in microaggregates in soil under forest, grassland and arable land use, in Germany (Brodowski et al., 2006).

Tseng and Tseng (2006) reported that activated biochar held about 95 % of micropores, with diameter <2 nm. We know porosity of biochar is highly related to micropores, therefore actual amount of additional plant amount of water will depend on biochar feedstock as well as the texture of soil it's applied to. Glaser et al. (2001) said that Anthrosols rich in charcoal with surface areas three times higher than those of surrounding soils had an increased field capacity of 18%. Tryon (1948) studied the effect of charcoal on the percentage of available moisture in soils with different textures. In sandy soil addition of charcoal increased the available moisture by 18% after adding 45% of biochar by volume, while no changes were observed in loamy soil, in clayey soil water availability decreased when addition of biochar to the soil increased.

3.5.4 Effect of biochar on soil water retention

The soil water retention is one of the vital factors of the soil. Soil water retention characteristics is the relationship between amount of water held in soil and the forces holding it. Soil water retention is important hydraulic property related to overall porosity and depending on soil structure and its organic matter content (Tuller and Or, 2003). The graph giving the information about relation between soil water potential and soil water content is called soil water retentioncurve (SWRC) or soil water characteristic curve. From the SWRC:

a) We can determine the index of the available water in soil and classify them according to purposes (e.g. irrigation, construction etc.).
b) We can identify drainable pore space (effective pore space, effective porosity, specific yield) to design drainage system.
c) We can check changes in structure of soil (caused by tillage, mixing of soil layers, etc.).
d) We can use it to ascertain relation between soil water potential and other physical properties of the soil (capillary conductivity, thermal conductivity, clay and other matters content).

The main forces that determine water content of the soil are two;

1) Positive forces (adhesion and cohesion) for amplifying ability of the soil to retain water.
2) Negative forces (gravity, evaporation etc.) which help to pump out water from the soil (Lal and Shukla, 2004).

In many researches C-rich content of biochar and charcoal have demonstrated to increase soil water retention (Lehmann et al., 2006; Laird et al., 2010; Spokas et al., 2010). The potential co-benefits or negative externalities of the use of biochar in irrigated agricultural system are not well learned. Hypothetically, if water-holding capacity of the soil is increased it should reduce irrigation volume and frequency. Nevertheless, potential susceptibility of disintegrated biochar to cement or clog the soil may also result in increased runoff and lower infiltration rates.

In 1980, van Genuchten represented hypothetically illustration of soil water retention curve and Verheijen et al. (2010) hypothesised effect of the addition of biochar to this soil (Fig. 5). Notice that in this conceptual example most of the water that is stored additionally in the soil will not be freely available for plant water uptake since it occurs at tensions superior to the range wherein plant roots are able to take up water. In this representation this is mainly due to pore size distribution of the biochar which largely consist of very small pores and only very little pores in a range relevant for plant water uptake. Although it is hypothetical consideration; it highlights the need for the further understanding of the direct effects of biochar addition on soil water retention, and its longevity.

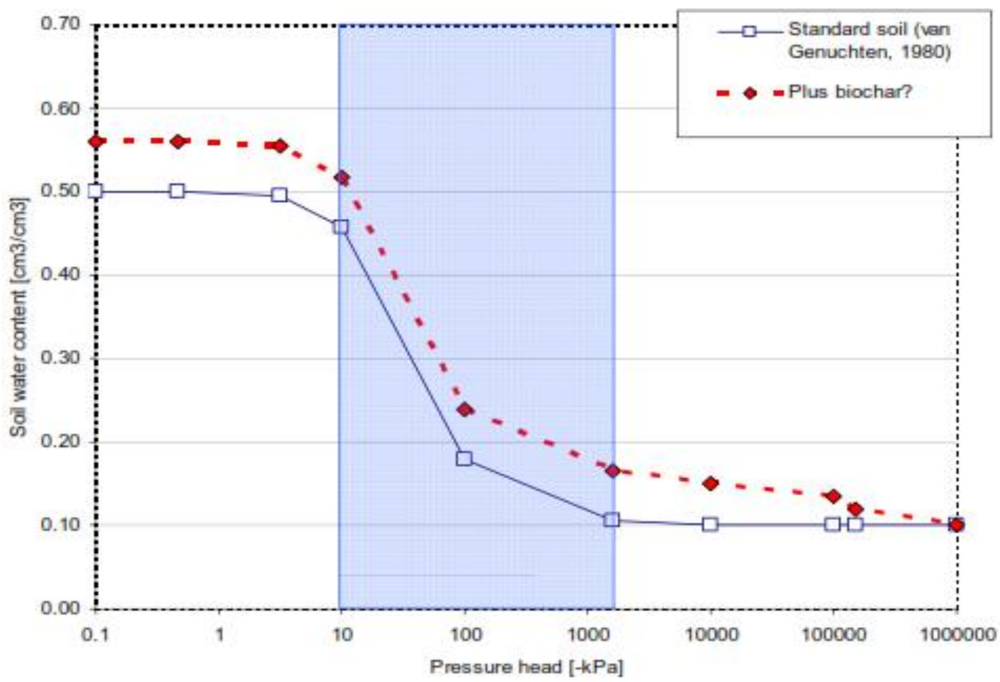

Figure 5. Typical representation of soil water retention curve as provided by van Genuchten (1980) and the hypothesized effect of biochar addition to the soil (Verheijen, 2010).

Bayabil et al. (2014) studied effect of charcoal and biochar on soil water retention in Ethiopian highland soils. Biochar that made up from different materials has various effect on the same soil (Abel et al., 2013; Enders et al., 2012). Therefore, samples were tested to evaluate the effect of incorporation of two biochars (prepared from corn stover and oak) and three wood charcoals (*Eucalyptus camaladulensis*, *Acacia abyssinica*, and *Croton macrostachyus*) compared to non-amendment control (Bayabil et al., 2014). Adjusted amount (0.5% by weight) was randomly added to columns in a randomized complete block design. Analysis of soil water retention data (Fig. 6) shows that for all biochar and charcoal amendment, except of corn biochar, soil water retention decreased when most tensions considered (tension is absolute value of soil matric potential). However, significant differences were seen only at 10 and 30 kPa. At 10 kPa, soil water retention of biochar applied soil and control soil was significantly higher than three charcoal applied soils (acacia, croton and eucalyptus). At 30 kPa, significant low water retention belonged onlyto croton. Surprisingly, neither charcoal nor biochar could affect available water content (AWC).

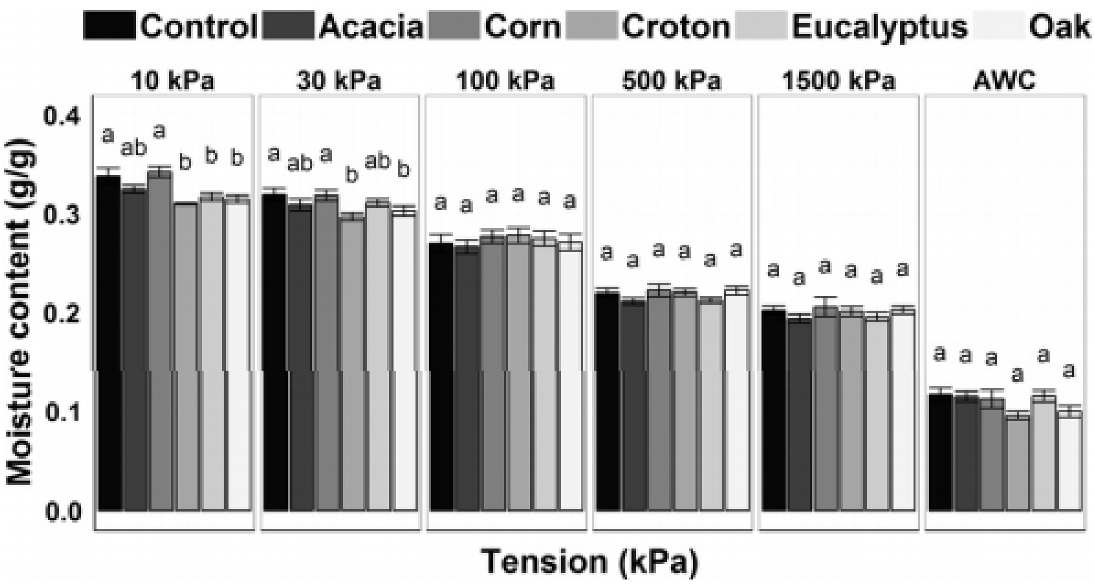

Figure 6. Treatment effect on moisture retention at the different tensions. Different latters indicate difference at p< 0.05. Acacia, croton, eucalyptus are wood charcoals, and corn and oak are biochars.

Moreover, Ma et al. (2016) also studied soil hydraulic properties after three years of field application in representative Chinese Mollisols. Four treatment as follows: control sample (with no fertilizers), application of inorganic fertilizers, combined application of inorganic fertilizers with maize straw and addition of biochar with inorganic fertilizers. Various treatments with fertilizers did not have any significant change in wilting point. Mixture biochar with inorganic fertilizers increased field capacity and plant available water noticeably when compared to others. There was no significant difference between control sample and inorganic fertilizers applied sample.

3.5.5 Saturated Hydraulic Conductivity in Biochar treated Soil

Hydraulic conductivity, (symbolically as K) is the property of the soil that fluid (usually water) can go through pore spaces or fractures. It is affected by permeability of the material, degree of saturation as well as density and viscosity of the fluid. Saturated hydraulic conductivity (Ks) is water movement through saturated media. Biochar addition to the soil alerts the saturated hydraulic conductivity of the soil. The increase in saturated hydraulic conductivity was shown in many researches (Asai et al., 2009; Lei and Zhang, 2013; Oguntunde et al., 2008). However, biochar addition can also decrease it (Devereux et al., 2012; Ibrahim et al., 2013). In 2014 Barns et al. reported that biochar application to sandy soil will decrease saturated hydraulic conductivity up to 92 %, on the other hand, will increase 300% in clay soil.

An experiment done by Ouyang et al. (2013) showed how admixture of biochar effects on soil hydraulic properties as well as aggregate structure. Main goal of this research was learning behavior of biochar with different soil structures. Two types of soil were chosen for the experiment; silty clay loam and sandy loam. To both soil samples were added two percent (by mass) biochar sieved on 2 mm sieve. The result they obtained showed that biochar admixture increased Ks in both soils and decreased residual water content, and showed significant change in function of water retention curve. In addition, biochar amendment promoted formation of macro aggregate structures in both soils. However, increase in silty-clay loam was significantly higher than in the sandy loam. In their opinion, improvement in soil structure would have greater influence on Ks if higher concentration of biochar was applied to the soil. Soil water retention also depends on structure of the soil, such as larger pore size and soil aggregates (Hillel, 1982).

Wong et al. (2017), in kaolin clay, studied effect of higher concentration of biochar. Biochar amendment was made by mixing 0 (control), 5 and 20 % (by dry mass) of air dry biochar with kaolin clay. To this amendment, de-ionized water was added to optimum gravimetric water content. The optimum gravimetric water content of clay, biochar amended clay (BAC) 5% and BAC 20% were 36, 39, 41% respectively (Wong, 2017). Then, wet BAC was sieved on 2 mm sieve to break down clay clods that have significant effect on soil hydraulic properties.

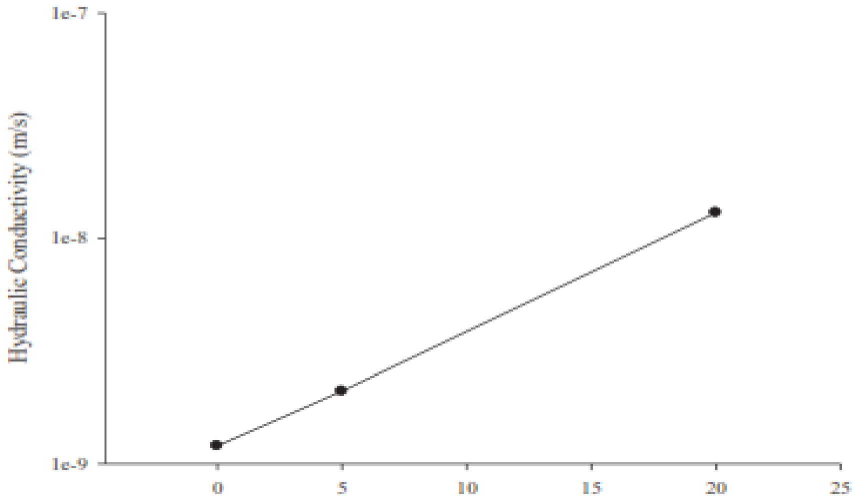

Figure 7. The biochar effect on hydraulic conductivity of compacted clay (Wong et al., 2017).

In the result they reported, adding 5, 10 and 20% of the biochar increased hydraulic conductivity from 1.2 . 10^{-9} to 2,1 . 10^{-9} and 1.3 . 10^{-8} respectively. Their research showed that there is linear relationship between biochar addition and increase in hydraulic conductivity. Improvement in Ks was due to the shift in pore size distribution of compacted BAC. Adding 20% of biochar shifted pores diameter to between 0.1 and 4 µm (micropores).

3.5.6 Effect of biochar addition on particle and pore size distribution

Initially, particle size distribution in biochar is influenced by nature of the biomass feedstock and the pyrolysis condition (Cetin et al., 2004). Shrinkage and attrition of the organic material are seen during processing, thus generating a range of particle sizes of the final product. The exertions of such processes are dependent on condition of the pyrolysis and technology (Cetin et al., 2004). Particle size distribution in biochar is one of the attributes that has implications on determining the suitability of the each biochar product for specific application (Downie et al., 2009). And to choose the most sufficient application method. In addition, health issues that may occur in handling and transportation are also determined by its particle size distribution.

Sohi et al. (2009) studied how different type of feedstocks effect on biochar particle size distribution and how this biochar will influence soil. As they reported, wood based on feedstocks create coarser and predominantly xylemic nature biochars, while, biochars from crop residues (e.g. rye or maize) and manures finer or more brittle structure.

Soil pore network can be affected by biochar's inherent porosity as well as its other characteristics in several ways. Biochar particle size and pore size distribution and connectivity, the mechanical strength of the biochar particles in the soil are all determining factors that will lead to different outcomes in different soil-climate-management combinations. These all factors can be reason why overall porosity of the soil increases or decreases following biochar incorporation into soils.

Chan et al. (2007) studied how biochar application effects overall net surface area of the soil and they received positive result. This increase in surface area may improve soil water retention (Downie et al., 2009). In addition smallest particle size fraction of the biochar may partially or totally block soil pores and decrease water infiltration rate. However, there are not enough evidences of such mechanism, therefore any effects of pore size distribution of biochar on soil properties and functions is still uncertain.

3.6 Measurements of Saturated Hydraulic Conductivity and Soil Water Potential

3.6.1 Laboratory Measurements of Saturated Hydraulic Conductivity

As standard, there are two main and inexpensive methods of measuring saturated hydraulic conductivity (Ks) in laboratory: constant head and falling head methods. These methods are quite accurate and reproducible, also lab samples are relatively small compared to aquifer as a whole. However, always some degree of disturbance of samples accompanies their collection. Klute and Dirksen (1986) reviewed laboratory measurement methods of saturated hydraulic conductivity. It is good if undisturbed core samples are used for measuring, however, samples can be made up with dry or fragmented soils but must be packed into flow cells in a standard manner (McIntyre, 1958).

Both methods (constant head ad falling head) are based on Darcy's Law, only difference is in maintaining pressure in constant head while decreasing pressure in falling head. We should always take note that Darcy's law only applicable for laminar flow, in other words where there is a non-turbulent displacement of adjacent layers of fluid relative to other (Hillel, 1998).

- **Constant head method**

  The constant head method is usually used for granular soil, or non-cohesive sediments like sand. This procedure allows movement of the water through soil under steady state head condition while volume of the water that is going through the sample is measured over the time. By knowing quantity of measured water (Q), length of the specimen (L), and cross sectional area of the specimen (A), time required for water flow (t), and difference in pressure head (H), the saturated hydraulic conductivity can be calculated according to eq. (1). Figure 8 demonstrates the constant head apparatus.

$$K_s = \frac{\mathrm{QL}}{\mathrm{AHt}} \qquad \text{(eq.1)}$$

- **Falling head method**

  In falling head method, first sample is saturated under certain head condition. Then water is allowed to move through the sample without adding any water, therefore pressure head of water decreases as the water passes through the sample. The advantage of this method is that it can be used for coarse-grain as well as fine-grain soils. Head of the water in certain tube radius falls from H_0 to H_1 in measured time duration. Figure 9 shows falling head apparatus.

  With solving for various cross sectional area of the sample (πr_s^2) and the cross sectional area of the tube (πr^2), and the time (t) for which the water flows from H_0 to H_1, the following basic equation (2) was created for the calculation of Ks.

$$K_s = \frac{r^2 L}{r_s^2 t} \ln \frac{H_0}{H_1} \qquad \text{(eq.2)}$$

Where: r – radius pf the tube (m) ;r_s – radius of the sample (m); L – height of the sample (m); t – time (s); H_0 – initial water level (m); H_1 – final water level (m).

3.6.2 Field Measurement of Saturated Hydraulic Conductivity

There are many methods of measuring saturated hydraulic conductivity (Ks) of the soil, it is because this property is one of the most crucial factor of the soil to evaluate. In 1974, Bouwer and Jackson have explained some small-scale in situ methods for estimation of Ks. These methods are separated into two groups; methods that determine Ks above the water table and methods that determine Ks values below the water table. Above the water table methods are for not saturated soil. For measuring saturated hydraulic conductivity sufficient water amount must be applied to get near saturated condition. These methods are called “infiltration methods” and to estimate use relationship between measured infiltration rate and hydraulic head.

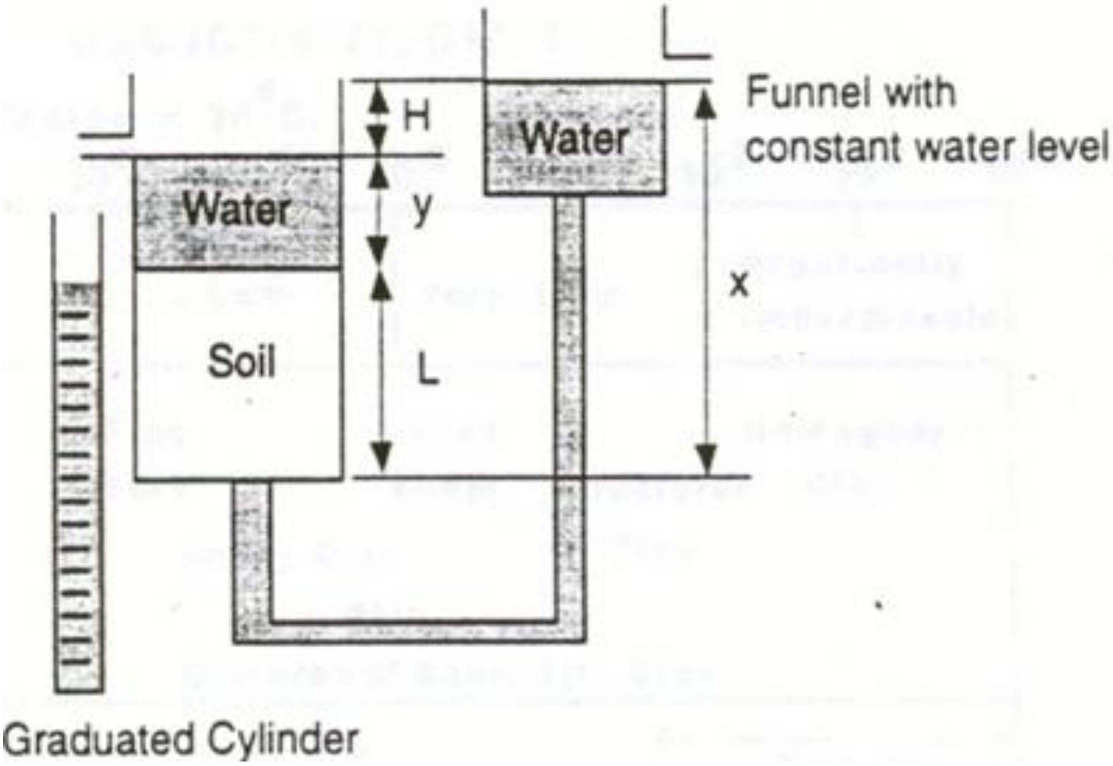

Figure 8. Constant head apparatus (source: http://slideplayer.com/slide/10105610/).

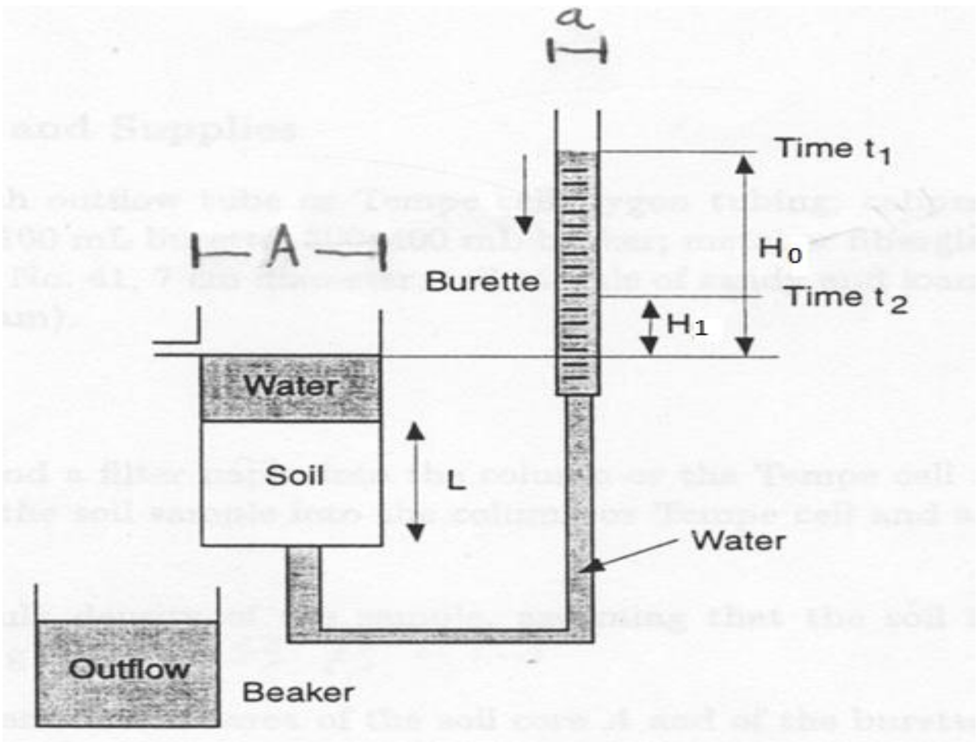

Figure 9. Falling head apparatus (source: http://slideplayer.com/slide/10105610/).

However, most common methods are available, such as, auger hole method (Hooghoudt, 1936; Ernst, 1950), double ring infiltrometer (Parr and Bertrand, 1960; Matula and Dirksen, 1989), and pressure infiltrometer (Matula and Kozakova, 1997). All these methods are carried out at original position or near to the surface of the soil. There is no single perfect in situ way of determining soil hydraulic conductivity, every method has certain limitation and was selected based on project budget, soil type, availability, and time.

3.6.3 Measurement of soil water potential

Various field and laboratory methods are available; however, there are two fundamental and highly precise ways. Those are tensiometer and vapor pressure. Water potential is a measure of difference in potential energy between water in a sample water and in reference pool of free water. The tensiometers are actualization of this definition. Nowadays technology can measure precisely full water potential in laboratory but it requires skilled users and excellent methods (UMS, 2015).

3.6.4 Tensiometer

Tensiometers are relatively cheap and simple devices but proper installation and maintenance is required. Tensiometers are probably the oldest type of water potential measuring instrument (the initial concept dates at least to Livingston in 1908), but they can be quite useful. In fact, in wet range, high quality tensiometers, used skillfully can have excellent accuracy. Tensiometers used to consist of ceramic porous cup and mercury manometer attached to water filled cup through water reservoir tube (Fig. 10). The ceramic cup has high conductivity, low response time and air entry pressure of about 1 bar. When the cup is placed in soil and equilibrated, water tends to move out of the cup under suction exerted by soil. In a result, vacuum pressure develops in the cup and make up this mercury rises in the manometric tube attached to water reservoir tube. Modern tensiometer use pressure transducer and automatic reading system, i.e. see Fig. 10. Vacuum in a porous cup is a matric potential of the soil water. Tensiometer shows that the amount of water, which was held in soil, is not actually water content. Relationship between soil water potential and soil water content is called soil water retention curve.

Figure 10. Tensiometer T5 (producer Meter Group Inc.; source: https://www.metergroup.com/environment/products/t5-tensiometer-water-potential/)

3.6.5 Evaporation Method and HYPROP Device

The evaporation method, which was developed by Wind (1966), is simple and fast technique to determine SWRC of soil samples in standard 250 cm^3 soil-sampling rings. Actually, unsaturated hydraulic conductivity also can be determined by measuring soil water tension with miniature tensiometers (as on Figure 10) in two levels inside the sample, and correlated to the soil water tension or water content.

In mid-sixties evaporation method was created by Wind and in that time 5 tensiometers were put in soil sample. But in 1980 Schindler simplified this method. He only used two tensiometers and simplified evaluation procedure. The method was tested several times and proven by scientific analyses (Wendroth et al., 1993; Peters and Durner, 2008; Peters et al., 2015). HYPROP device works based on this method.

HYPROP (HYdraulic PROPerty analyser) is measuring and evaluation system that works fully automatically and determines hydraulic properties of the soil sample (UMS, 2015). It measures tension of the water at two levels by using two tensiometer shafts. If the soil hydraulic conductivity is small, upper layer dries out first while lower layers are still wet. Therefore, upper tensio shafts measures quite drier tensions than the lower ones.

Figure 11. HYPROP device (UMS, 2015).

If conductivity is good, water will easily be evaporated from the whole sample and both tensions are almost the same. The water content of pF/SWRC curve is determined based on weight loss of the sample. Range of the microtensiometers in HYPROP device between +100 kPa (water pressure) and -85 kPa (water tension). The common distributed microtensiometer sizes are 2.5 cm for the small one, and 5 cm for the bigger one. Tensiometer shafts are very sensitive part of the tensimeter so manipulation with this part should be rather gentle.

4 Materials and Methods

4.1 Information about locality and soil

The area where soil samples were taken is near to Trebsin village which is located about 40 km far from the Prague in southeast direction (Fig. 12, Fig. 13). Research area is operated by Research Institute for Soil and Water Conservation in Prague-Zbraslav (RISWC Prague). The location of area belongs to mildly warm region; the annual mean precipitation is 517 mm, average temperature is 6.5^{0}C and altitude is 340-350 m a.s.l. The natural soil composition is originally a gneiss substrate and is mostly of Haplic Cambisol type (IUSS Working Group WRB, 2015) with a texture class silty loam (Kovar et al., 2012).

Biochar influence on the soil was studied previously on this experimental locality by Huislova and Cechmankova (2017). Two parcels were investigated: blank control and with biochar which was applied to the soil in spring 2015 in amount corresponding to the application rate 12 t/ha and ploughed into the surface layer of 15 cm. For the purpose of the current study, both parcels were sampled in early summer 2017.

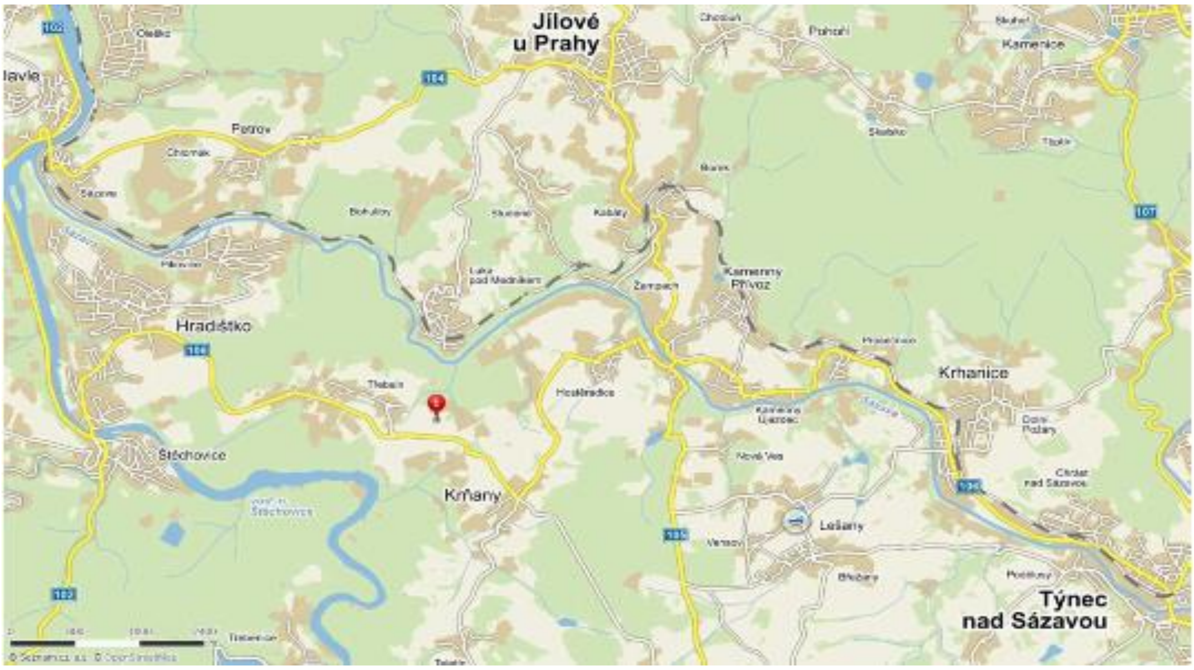

Figure 12. Location of the study area (Huislova and Cechmankova, 2017).

Figure 13. Trebsin experimental area (source: Google Earth Pro).

4.2 Biochar properties

Manufacturer BIOUHEL.CZ s.r.o biochars were used for carrying out lab experiments. The biochar was made from mixture of silage maize resting in a biogas station and wheat straw, at ratio of about 1:1. Low temperature pyrolysis was used for biochar production and underwent at 460^{0}C for about 18 minutes without access of air. The biochar was produced based on KARBOTECH technology. The advantage of KARBOTECH technology is utilization of flue gases from external source, that is why it is possible to process biomass with a low content of combustible substance (such as biowaste) and higher water content. At the same time, the technology has higher processing capacity (Table 1). Water content of the fresh biochar used to be 0.84 g/g (Kidane, 2016), and it was kept in room temperature away from any alterations.

Table 1. KARBOTECH technology properties. (source: http://www.biouhel.cz)

Processing capacity	400-800 kg per hour
Water content in biomass	< 70%
Biochar production	200 – 400 kg per hour
Electric power	30 kW

The biochar has received certification as additional soil supplement from the Central Institute for Supervising and Testing in Agriculture. Its commercial name is "agrouhel". The basic properties of the biochar was given in Table 2.

Table 2. Basic characteristics of the biochar. (Source: http://www.agrouhel.eu/?page_id=8)

characteristics	value
Burnable matter in a dry matter (%)	min. 45.0
Dry matter %	min. 60.0
Total carbon content as C in dry matter	min. 45.0
Total nitrogen content as N in dry matter	min. 1.0
Total phosphorus content as P_2O_5 in dry matter	16
Total potassium content as K_2O in dry matter (%)	17
Calcium content as CaO in dry matter (%)	56.3
Magnesium content as MgO in dry matter (%)	6.6
pH	9 – 11.0
Particles <2 mm (%)	min. 40.0
Particles >10 mm (%)	max. 10.0

4.3 Samples Repacking and Labeling

Disturbed soil samples were brought from the study area and artificially repacked for measuring saturated hydraulic conductivity and soil water retention curve, both properties on the same sample. These hydraulic properties are most commonly determined on natural undisturbed soil samples. However, the repacked samples were chosen in order to reduce natural variability of the soil by maintaining the same dry bulk density, in order to better observe the effect of biochar admixture rather than natural soil heterogeneity. In addition, other physical soil properties were determined as well, such as particle size distribution curve, particle density, initial water content, saturated water content and dry bulk density.

After bringing samples, big pieces of soil were gently crumbed, plant, animal residues and big stones were removed. After that, soil was sieved through 8 mm sieve, and led to air drying for few days. The reason why soil samples were crumbed and sieved is undoing heterogeneity of natural soil. For measurement of the SWRC and Ks soil core samples of volume 250 cm^3 were required. To avoid the various problems that artificially prepared samples may encounter, repacking procedure is important. Useful method of repacking was chosen based on previous studies (Dziadula, 2017).

Knowing natural dry bulk density of the soil is necessary to estimate how much soil will be used for preparing the repacked core sample. Used value of dry bulk density (BD) was chosen based on values obtained in situ method by previous researches (1.18 – 1.42 g/cm^3). Biochar does not have perceptible effect on bulk density during repacking, therefore the same value was used for all variants. Firstly, BD = 1.2 g/cm^3 was chosen. Four samples were prepared with 1.2 g/cm^3 at the beginning of research. But during measurement of hydraulic properties was found, that the samples were too loose and seriously destructed after Ks determination. Thus, the remaining samples were prepared with BD = 1.4 g/cm^3. However, all samples were evaluated later on, they are denoted as 1.2 or 1.4 when necessary. The amount of soil was calculated according to eq. 3.

$$m = V \,.\, BD = 250 \,.\, 1.4 = 350\ g \qquad \text{(eq. 3)}$$

where m is the required amount of soil and V is volume of the core sample. Assumed amount of air dry soil was weighted and spread into a thin layer on plastic sheet, after that water sprayed until it became thoroughly wet. In the process, natural wetness was tried to be achieved as nuch as possible, therefore the soil was left for about one hour to air dry so water can redistribute into soil pores (Fig. 14 a).

Figure 14. Control sample was left to air dry after spraying water (a) and repacked into Kopecky ring (b).

After that, soil was ready to be gently packed into Kopecky ring (Fig. 14b). This method was used for all variants.

In total, three variants of the soil were investigated; 1) control variant (pure soil); 2) soil into which the biochar was applied two years ago (field application); 3) soil into which the biochar was applied in lab directly before experiments (lab application). Each variant was measured at least three times; therefore, labeling system was made to keep track of the running results. Soil was labeled as TR. Thus, ring of the control sample group labeled as 0TR (e.g. 0TR1 for sample number one etc.), 1TR – for field-application samples; and 2TR – for the samples into which biochar was applied in lab. During the Ks measurement, each ring was measured at least three times. As the result of that for control sample 1 data appears as follows: 0TR1_1, 0TR1_2, 0TR1_3, other samples were labeled in a similar manner.

4.4 Biochar concentrations and water content

In this study soil sample cores were subject to addition of 0% or no biochar addition (control sample, labeled as 0TR), by mass 0.6% (roughly estimated) biochar applied to the soil in field two years ago (labeled as 1TR), and 1% of dry biochar by mass mixed in lab (labeled as 2TR). To better observe differentiation of long term and immediate effect of biochar on soil, near concentration was chosen in lab too. In a Figure 15, application of biochar on field was shown.

Figure 15. Application of biochar to the Trebsin soil (Huislova and Cechmankova, 2017).

In fact, field applied biochar concentration was estimated to be between 0.5 and 1%. About 1.2 kg/m^2 of biochar was applied and mixed depth of the soil was 15 cm. With these data can be calculate precise concentration of applied biochar, but small errancy in physical factors (e.g. bulk density and especially the water content of the biochar.) may affect hugely. Therefore, the nearest value 0.6% was taken as concentration of applied biochar.

Water content of air dry soil was about 3% by mass which was neglected during sample preparation. However, biochar concentration is related to dry matter of the biochar, as it may contain not negligible amount of water. The stored biochar contains 55% water by mass. Knowing that biochar had 55% water content biochar weight had to be recalculated considering only dry mass of biochar. For 1 kg of soil 1% of dry biochar was calculated as 10 + 10 . 0.55 = 15.5 g; So 15.5 g of air dry biochar was added to each 1 kg of soil.

4.5 Particle size distribution analysis with Pario device

Particle size distribution analysis is one of the most important soil properties, thus it should be determined for each tested soil. The gradation of soils affects water and nutrient holding and drainage capabilities.

Soil consists of assembly of ultimate soil particles of various shapes and sizes. The object of the particle size analyses is to group these particles into separate ranges of sizes and determine the relative proportion by weight of each size range. This method is based on sieving and sedimentation of soil, water and dispersant suspension to separate the particles. The hydrometer technique employs application of Stokes' law to soil/water suspension and periodic measurement of the density of the suspension (Durner et al., 2017).

As a modern alternative to the standard hydrometer method, Pario device (Meter Group, Inc.) was employed in this study. Preparation process is generally the same as for hydrometer method, air-dried soil was sieved on 2 mm sieve and 35 g soil was taken for measurement. At the same time, small amount of soil was taken to determine water content of air-dry soil, which will be used to determine hygroscopic correction factor. Sodium hexametaphosphate was used for making dispersion. The ratio of soil, hexametaphosphate and distilled water was 1:1:0.5 which means to 35 g soil added 35 ml of sodium hexametaphosphate of concentration 40 g/l and 17.5 ml distilled water. The sample was shaken and put into one room with Pario device and bottle of distilled water overnight to keep temperature the same. Next day, some more distilled water was added to the suspension and mechanically dispersed with high velocity mixer machine for 20 min. Then, sample was sieved on wet basis on 0.063 mm sieve to separate sand particles. During the sieving, it is necessary not to lose any amount of sample; all clay particles should be washed carefully through the sieve. Ready sieved suspension was carefully transferred into one-liter cylinder and filled up with room tempered distilled water to the mark. Another cylinder also should be filled up with room-tempered water in order to cap the Pario device.

In Fig. 16 Pario device is demonstrated. Pario derives the particle size distribution from the pressure decrease at measuring depth in suspension. The theory of the method was shown by Durner et al. (2017). Pario is controlled by computer and it requires to install Pario Control software. Used Pario device was connected to computer via USB cable and software was started. The device should flash white, otherwise should be reconnected again. On software following parameters should be entered: “particle density”, “sample name”, “volume of suspension”, “mass of particles” and “mass of dispersing agent”. After entering required informations, we can start “start” button. This initializes the Countdown for mixing.

Figure 16. Pario device (Meter Group, 2017).

Countdown is set to 60 sec. During countdown, suspension should be mixed thoroughly. Then, we should take Pario device carefully and insert it into suspension, however, time from the ending mixing until the final insertion of the Pario should not exceed 30 s.

From the time Pario is connected Pario Control software measures three types of data (time, pressure and temperature) in each 10 s. and shows recorded data graphically. For the operation, there is nothing to do until the end of the measurement.

4.6 Soil saturated hydraulic conductivity measurement with KSAT device

Measurement of soil saturated hydraulic conductivity and soil water retention curve were carried out always at the same sample. Firstly, soil saturated hydraulic conductivity was determined with KSAT device (UMS GmbH., Germany, now Meter Group, Inc.). KSAT device can be used for both falling head and constant head methods. In this study, falling head method was employed.

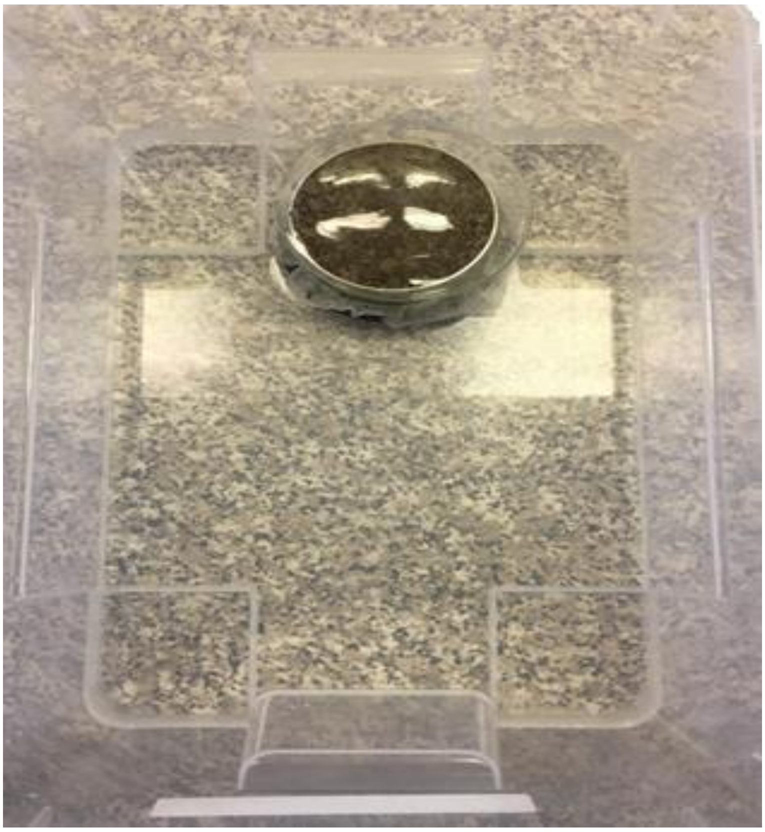

Figure 17. Sample was left for saturation.

Before measuring saturation process is necessary. After packing soil into the ring (Fig. 14 b), the sample was placed on porous plate. Afterwards, all the samples rings were put into trough and trough was filled in 2 cm of tap water (to the bottom of the samples). Soils were left to saturate by capillary forces overnight (Fig. 17). Then, water level was increased to the top of the sample as required by the operation manual, for about 30 min to complete saturation and not to destroy artificial soil structure.

When soil sample is ready, saturated hydraulic conductivity was measured with KSAT device. The device is connected to computer via USB and measurement are operated with special software (UMS GmbH, 2013). The software calculates Ks value automatically according to eq.2. Each sample was measured at least three times and result was average of these values.

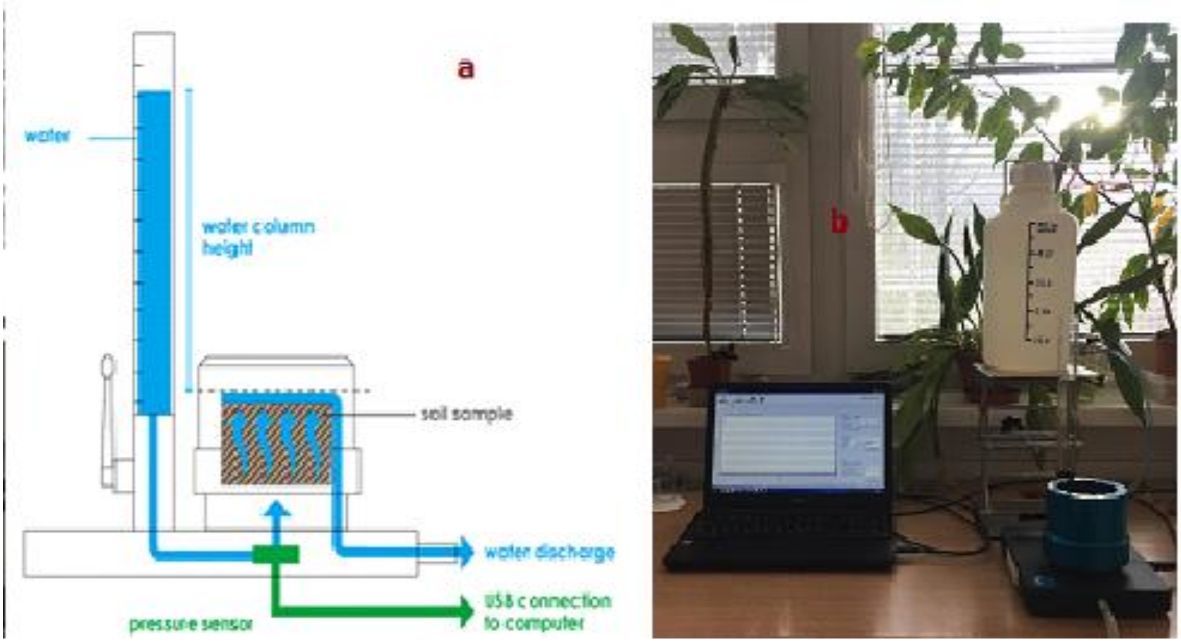

Figure 18. Schematic illustration of KSAT device (a), and KSAT ready for measurement (b).

When determining soil saturated hydraulic conductivity it is important that there is no any gap or crack in sample along the direction of percolation. One of the biggest problem is edge gaps. If the soil samples were tilted during the sampling they likely to have such problem. Dirksen reported (1999) that accuracy of the measurement is not major challenge but quality and representativeness of the soil samples in the determination of the saturated hydraulic conductivity.

4.6.1 The effect of temperature on changing value of Ks

Hydraulic conductivity is he property used to describe the attributes of both soil as porous media and water as the transmitted liquid. Soil characteristics affecting Ks are total porosity, distribution of pores, and tortuosity. Fluid attributes that affect Ks are density and viscosity (Hillel, 1998). These factors are dependent on temperature. Theoretically Ks may be separated into two factors: intrinsic permeability of the soil k and fluidity of the permeating liquid f. since fluidity is directly related to density and inversely to viscosity the formula for permeability of soil matrix is as follows (eq 4):

$$k = Ks \frac{\eta}{pg} \qquad \text{(eq.4)}$$

Where k – intrinsic permeability (m^2); η - is dynamic viscosity ($N.s/m^2$); ρ – is the fluid density (kg/m^3). Despite there are some natural changes in pressure at surface of the earth, density of the liquid remains generally constant. Small changes may occur in density of the liquid but it is because of temperature changes, solute concentrations, and primarily from changes in viscosity (Hillel, 1998). Therefore, temperature in which lab measurement readings were taken became very relevant and temperature always had to take count. KSAT device registers the temperature and recalculates the resulting Ks to the set temperature according to the above formula. Results of this study were recalculated to the 20°C.

4.7 Soil water retention curves measurement with Hyprop device

For the measurement of SWRC Hyprop device (UMS, 2015), which employs the evaporation method, was used. This method also requires the complete saturation; therefore, as soon as saturated hydraulic conductivity of samples was measured they had been attached to the Hyprop device (Fig. 19).

Figure 19. Transferring sample from KSAT to Hyprop unit. At the top of the sample is a porous membrane used as a mechanical support by the Ksat device.

Hyprop is a fully automated measuring and evaluation system to determine the hydraulic properties of soil samples. Hyprop measures the water tension at two levels of the samples by using two tensiometer shafts. This device is very sensitive so every part of device requires special preparation. The tensio shafts "transduce" the matrix potentials of the soil sample through their porous ceramic tip and the water filled shafts to the pressure sensors in sensor unit. The tensio shafts provide via their pores a capillary contact between the water in tensio shafts and the soil water. To make sure the pressure is "transduced" precisely no air must be contained in water. Therefore, tensio shafts and the sensor unit need to be degassed completely.

There are two possible ways of the degassing:

1. By means of the refill unit (accessory) makes all required steps simple and fast.
2. By means of syringes (basic scope of delivery) some more manual work needs to be done and take more time.

Because of simple and fast preparation and good accuracy, first method was used in this thesis. Detailed information about these methods is given in Hyprop manual (UMS, 2015).

After all needed components were degassed, they were merged together; tensio shafts were screwed into the Hyprop sensor unit. Sensor unit is very sensitive; therefore, screwing procedure should be carried out carefully. To avoid damaging them, sensor units should be connected to computer and pressure always should be followed up with Hyprop Refilling Wizard operational program which is the part of Hyprop View software. The ceramic tips never should be touched with bare fingers. Grease or soap will reduce the hydrophilic characteristics of the ceramic (UMS, 2015). That is why during the attaching process, ceramic tips of the tensio shafts always have to covered by silicone caps. When all tensiometers are screwed successfully into Hyprop unit, silicone caps will be removed and prepared sample will be attached to Hyprop unit (Fig. 19). In the Hyprop unit there is another sensor which measures temperature during the all process.

Then, start Measurement Wizard in Hyprop View software was opened, needed information about soil was written and measurement is started when registering of changes in soil matric potential and mass of the sample induced by evaporation started.

With Hyprop software potentially up to 20 measurements can be done at the same time; therefore it offers two weighing modes: single balance mode and multi balance mode. In multi balance mode Hyprop unit is permanently placed on balance and balance automatically measures weight in each half hour. In single balance mode, on the other hand, many samples can be measured with one balance and samples should be placed out of it. Measurement of the tensions always are being measured all the time in both modes. But in single balance mode weighing has to be done manually. The recommended interval between weighting is 12 hours (UMS, 2015). For this thesis single balance mode was used (Fig 20). Up to four samples were measured at the same time and when measurement was finished samples replaced from Hyprop unit to ceramic bowl (in order to not get weight lost all Hyprop unit parts that contacted to the soil were washed into the bowl) and dried at 105°C for determining the real bulk density.

Figure 20. Samples are measuring with single balance mode (on the photo is one soil sample and three samples of pure biochar).

4.7.1 Parametrization of measured soil water retention curves

SWRC were measured in 30 min interval, which is very detailed observation. Obtained points were for further evaluation fitted by van Genuchten (1980) equation, bimodal model according to Peters and Durner (2015) as described in Pertassek et al. (2011). The equation (eq. 5) is a weighted superposition of two van Genuchten functions:

$$\theta(h) = (1-w)\left(\frac{\theta_S-\theta_R}{(1+(\alpha_1|h|)^{n_1})^{1-\frac{1}{n_1}}}+\theta_R\right)+w\left(\frac{\theta_S-\theta_R}{(1+(\alpha_2|h|)^{n_2})^{1-\frac{1}{n_2}}}+\theta_R\right) \quad \text{(eq. 5)}$$

Where: $\theta(h)$ is soil water content by volume calculated for a particular pressure head h, θ_S and θ_R are parameters of saturated water content and residual water content, respectively (cm^3/cm^3), α_1, α_2 (1/cm) and n_1, n_2 (-) are shape factors and w (-) is the weighting criterium.

The equation has seven parameters, thus this function is much better for fitting the measured points than the unimodal models to describe the retention functions of structured soils.

5 Results

Measurements were accomplished in laboratory of Water Resources Department, Faculty of Agrobiology, Food and Natural Resources. In total, three different variants of biochar concentrations were used for soil hydraulic properties measurements and each concentration has three repetitions at least. In saturated hydraulic conductivity determination, each repetition was measured minimum three times. In addition, pure biochar is also measured with three repetition in order to compare results.

Target dry bulk density was used for preparing samples. After samples were repacked they were weighed to determine initial water content. Saturated water content was found out at the beginning of the measurement of soil water retention curve. Real dry bulk density was determined after measurement. In addition, particle size distribution curve by Pario device and particle density by water pycnometer method were determined.

5.1 Basic physical properties of the tested soil

Table 3 shows the example of data that was registered during the measurement for the samples. These data were obtained by weighing the Kopecky rings, soil samples after repacking, tare of the bowl and dried soil sample with ring and bowl. Then, some of the data such as initial water content, pure mass of the dry soil, actual dry bulk density and porosity were calculated.

As written above, target bulk density of soil was taken as 1.4 g/cm^3. However, residual water content of air-dry soil was ignored, also there was small lost during the repacking process. In addition, some amount of soil also could be flown out of the sample during repeated Ks measurement and transferring sample to Hyprop device. Therefore, the real dry bulk density was somewhat lower and to determine real porosity of the samples, calculating actual dry bulk density was necessary.

Figure 21 demonstrates comparison of average target and dry bulk densities. For the measurements it is important keeping bulk density constant. By doing this was limited soil heterogeneity which is one of the biggest source of variability in these measurements. As we can see in graph, actual bulk densities were lower than target but not significantly different from each other. Biochar was gently compacted to the rings without any target bulk density.

In order to determine porosity particle density of the samples should be calculated. Particle density of the soil was determined by water pycnometer method. Calculated particle density for the Haplic Cambisol of Trebsin was 2.67 g/cm^3 and from the previous researches that carried out on the same biochar we know particle density of the biochar is 1,097 g/cm^3.

Table 3. Example of collected data.

Name of the samples	Mass of the ring (g)	Mass of the sample with initial water content (g)	Mass of bowl (g)	Mass of the dry soil with ring and bowl (g)	Pure mass of dry soil (g)	Actual bulk density (g/cm^3)	Actual porosity (%)
1TR2	206.34	606.51	355.67	901.11	339.10	1.356	49.1
1TR3	206.20	602.32	348.16	885.51	331.15	1.324	50.3
2TR1	206.25	609.20	345.25	889.52	339.02	1.356	49.1
2TR2	204.33	607.94	335.48	879.32	339.51	1.358	49.1
1TR4	207.77	608.82	340.71	889.34	340.86	1.363	48.8
1TR5	205.92	605.85	361.81	908.94	341.21	1.364	48.8
2TR3	204.98	605.96	350.14	894.63	339.51	1.358	49.1
0TR4	206.39	607.59	349.92	902.44	346.13	1.384	48.1
0TR5	204.93	612.10	335.48	888.46	348.05	1.392	48.0
0TR6	202.92	598.09	349.92	897.88	345.04	1.380	48.2
1TR6	205.97	590.22	355.67	890.71	329.07	1.316	50.7
2TR4	207.78	611.68	357.32	913.53	348.43	1.393	47.7
2TR5	202.93	595.12	335.48	888.21	349.80	1.399	47.5

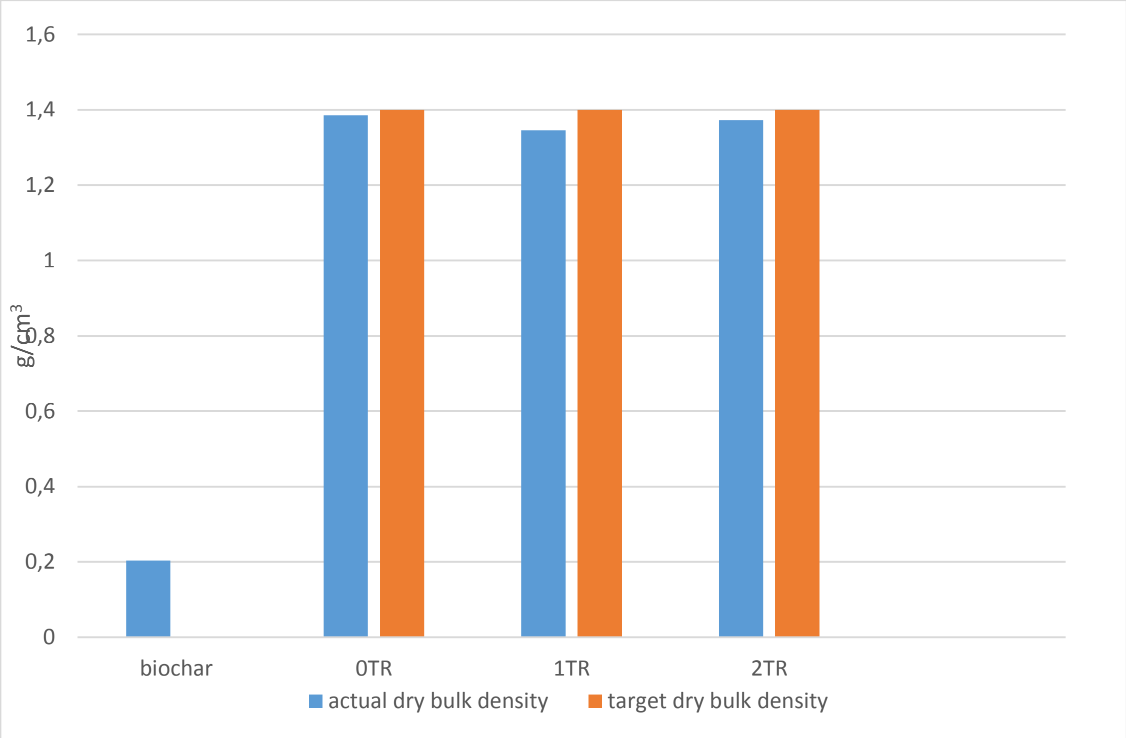

Figure 21. Comparison of actual and target bulk densities.

Before saturation, samples were weighed and initial water content determined. Figure 22 shows comparison of initial water content, saturated water content and porosity. Saturated water content was obtained from the first reading of Hyprop device when samples were weighed before evaporation process starts. In initial water content, which is result of water added by spraying in preparation process described in chapter 4.3, differences are very small. That is because of samples were repacked by the same method and repacked carefully. Saturated water content was observed always smaller than porosity. In a Table 4 maximum degree of saturation (ratio between saturated water content and porosity) for tested soil and biochar was given. Average maximum degree of saturation for the three variants is 88.8 %. Highest max. degree of saturation was shown in 1TR soil with 91.7%. Usually, for Czech soils max. degree of saturation is 89% (Mihalikova et al., 2013). This factor for pure biochar was 89%.

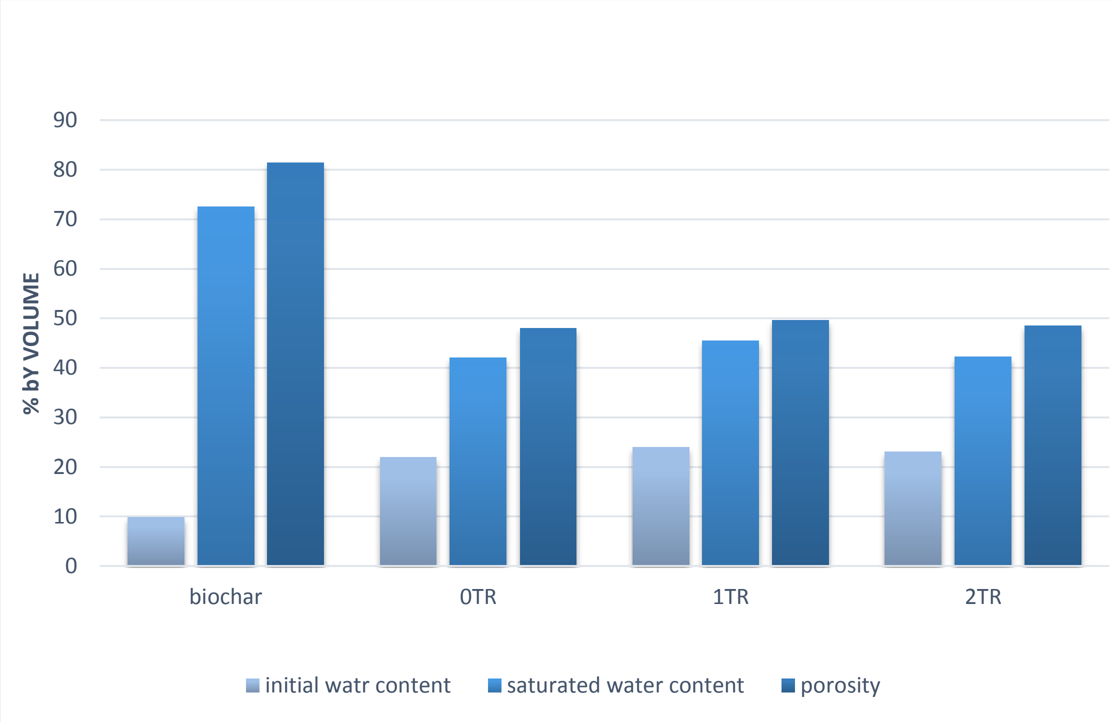

Figure 22. Ratio among initial water content, saturated water content and porosity in tested variants and pure biochar.

Table 4. Maximum degree of saturation.

Name of the sample	Maximum degree of saturation (%)
Biochar	89.1
0TR	87.6
1TR	91.7
2TR	86.9
Average	88.8

In Figure 23, cumulative curve of particle size distribution of the tested soil from Trebsin locality is shown. USDA categories are as follows; content of clay is 20.6% (particles below 0.002 mm), silt 58.3% (between 0.002 and 0.05 mm), and sand 21.1% (between 0.05 and 2 mm). The soil texture class is **Silt Loam** according to Soil Taxonomy (Soil Survey Staff, 1999).

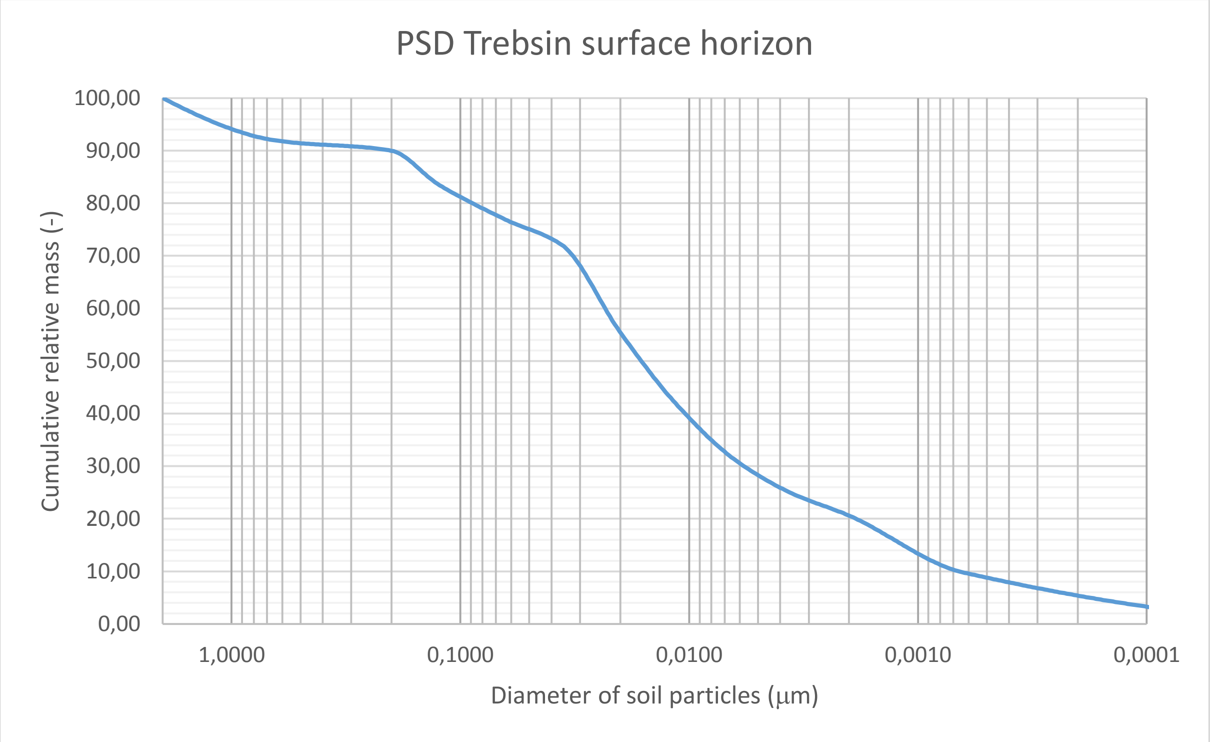

Figure 23. Particle Size Distribution curve.

5.2 Results of Saturated Hydraulic Conductivity test

5.2.1 Avoiding outliers from Ks measured values

When samples were attached to KSAT device, they were measured 3-9 times (Table 5, number of replicants). The result of the Ks value should be represented by average value of replicates. However, in some values outlying occurred and they were not included to results. KSAT software calculates Ks value directly by fitting the curve of decreasing water level over the time by using formula for falling head method. In addition it calculates fitting parameter too. The values were not included to results had low determination coefficient (fitting parameter). Values less than 0.95 were considered as outlier and they were significantly differentiated from other replicates. Variability of measurements is represented by coefficient of variation (CV; Ks sample CV in Table 5) which is ratio between standard deviation and arithmetic mean. Replicates which contributed to significant increase of CV were not considered as valid. Minimum, maximum and average Ks values are presented.

5.2.2 Saturated hydraulic conductivity of the tested variants

Table 5 shows the results of soil saturated hydraulic conductivity for each applied biochar concentration and pure biochar with basic descriptive statistics. Results can be divided into two parts. Results for the samples that were prepared with lower bulk density (0TR1, 0TR2, 0TR3 and 1TR1; details in chapter 4.3) are showing relatively high Ks values, it means bulk density influenced resulting Ks value much more than biochar admixture. Although it is not representative, the control variant (0TR) has two times higher KS than field biochar application (1TR). Although the samples were carefully prepared and homogeneous, the variability of measurements between individual samples is rather high (see Ks variant average CV in Table 5). Coefficient of variation values represents stability of the measurement and calculated values of CV are very high that means samples measurement are differing lot from each other (especially, for the samples 0TR and 2TR with BD (1.4)).

Table 5. Overall results of Ksat data for all concentration of the soil. CV is coefficient of variation.

Variant	Sample name	Number of replicants	Number of valid replicants	Ks min (cm/d)	Ks max (cm/d)	Ks sample average (cm/d)	Ks sample average (m/s)	Ks sample CV (%)	Ks variant average (cm/d)	Ks variant average (m/s)	Ks variant CV (%)
	0TR1	*7*	*4*	*587*	*983*	*938*	*1,1E-04*	*4*			
	0TR2	*4*	*4*	*1460*	*1830*	*1665*	*1,9E-04*	*8*			
	0TR3	*4*	*4*	*2200*	*2570*	*2350*	*2,7E-04*	*6*	*1651*	*1,9E-04*	*35*
	0TR4	3	3	8	9	9	1,0E-06	5			
	0TR5	4	3	52	54	53	6,1E-06	2			
0TR	0TR6	3	3	12	14	13	1,5E-06	6	25	2,9E-06	80
	1TR1	*3*	*3*	*405*	*435*	*418*	*4,8E-05*	*3*			
	1TR2	3	3	43	44	44	5,1E-06	1			
	1TR3	3	3	26	31	29	3,4E-06	7			
	1TR4	3	3	22	24	23	2,7E-06	4			
	*1TR5**	*4*	*3*	*159*	*164*	*161*	*1,9E-05*	*1*			
1TR	1TR6	3	3	17	23	20	2,3E-06	12	29	3,4E-06	31
	2TR1	4	4	31	37	34	3,9E-06	8			
	2TR2	3	3	6	6	6	6,9E-07	0			
	2TR3	3	3	4	4	4	4,6E-07	0			
	2TR4	3	3	14	19	16	1,9E-06	14			
2TR	2TR5	3	3	9	9	9	1,0E-06	0	14	1,6E-06	79
	biochar 1	5	4	2990	3540	3074	3,6E-04	6			
	biochar 2	7	5	3000	3740	3256	3,8E-04	9			
biochar	biochar 3	6	6	2890	3530	3243	3,8E-04	7	3266	3,8E-04	3

F-test of equality of variances between the variants of experiment was employed to better observe the results (Table 6). The F value is ratio between the variances s_1^2 and s_2^2 where $s_1^2 > s_2^2$. If the F value is bigger than F critical value the two variances are statistically different on significance level $p = 0.05$ (values written with red color).

Table 6. F-test of equality of variances between the variants of experiment.

F \\ F crit.	Biochar	0TR-1.2	0TR-1.4	1TR1-1.2	1TR-1.4	2TR-1.4
Biochar	**1,000**	0,374	3,550	244,690	2,887	2,507
0TR-1.2	0,209	**1,000**	3,313	19,405	2,818	2,507
0TR-1.4	162,316	853,417	**1,000**	19,371	2,948	2,641
1TR1-1.2	1862,773	1590,504	1,864	**1,000**	3,982	3,682
1TR-1.4	935,798	4065,142	4,763	2,556	**1,000**	2,719
2TR-1.4	557,377	2608,046	3,056	1,640	1,559	**1,000**

T-test for independent samples (with equal/unequal variance, based on F-test) was performed. Statistically significant differences on the significance level p = 0.05 were found between biochar and all soil samples (Table 9, red colour). Samples with low BD (1.2 g/cm^3) differed from all other samples and there was also difference between control variant (0TR-1.2) and field biochar application (1TR-1.2), which was significantly lower. In the case of samples with higher BD (1.4 g/cm^3), a difference was observed between field biochar application (1TR-1.4) and lab biochar application (2TR-1.4), which was lower than both field biochar application (and than control as well, insignificantly). However, between control and lab, and control and field was no significant difference. Graphical overview of result is given on Figure 24. (Sample 1TR5 was excluded from statistical analyses as outlier.)

Table 7. T-test for independent samples.

	Biochar	0TR-1.2	0TR-1.4	1TR1-1.2	1TR-1.4	2TR-1.4
Biochar	**1,000**					
0TR-1.2	0,000	**1,000**				
0TR-1.4	0,000	0,000	**1,000**			
1TR1-1.2	0,000	0,000	0,000	**1,000**		
1TR-1.4	0,000	0,000	0,587	0,000	**1,000**	
2TR-1.4	0,000	0,000	0,226	0,000	0,003	**1,000**

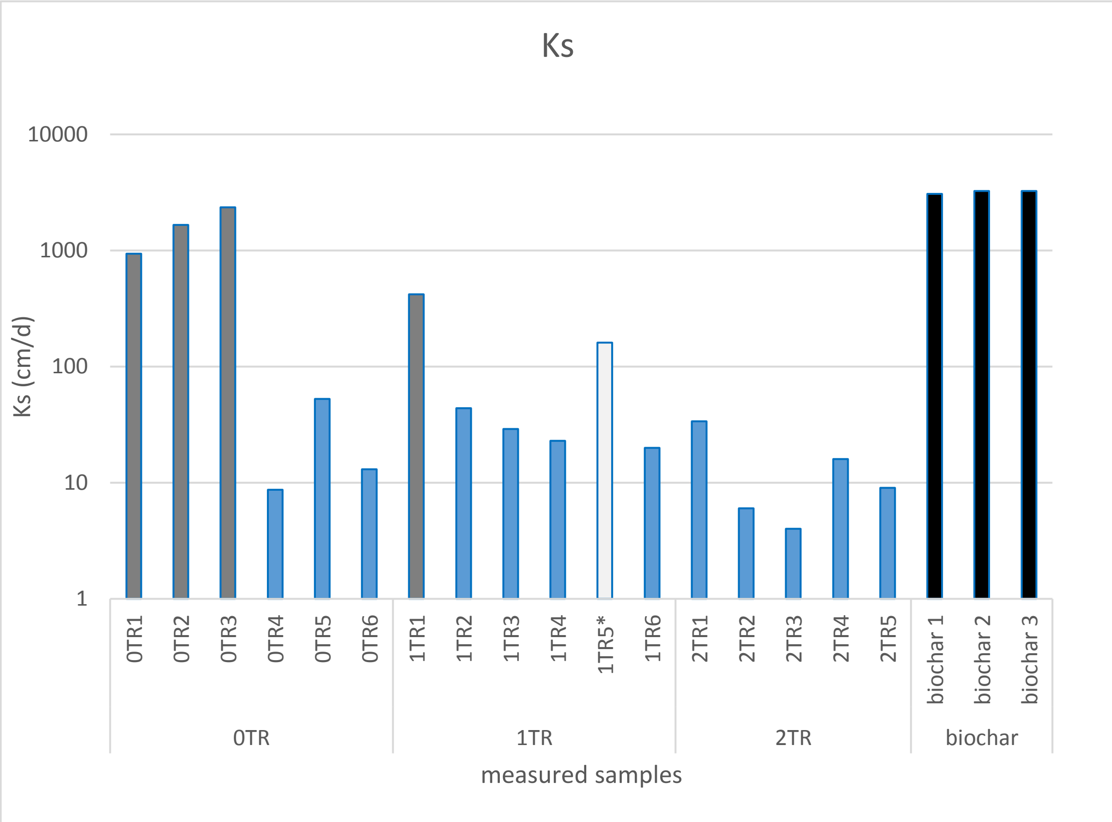

Figure 24. Measured Ks values for each sample (blue - samples with BD (1.4); grey - samples with BD (1.2); white is outlier; black - pure biochar).

5.3 Results of Soil Water Retention Curve

On Figures below (Fig 25-29) SWRCs are demonstrated for each tested variant and pure biochar. Should be noted, samples were measured up to about 1000 cm pressure head (around pF 3) because measuring range of tensiometers are limited. Wilting point can be measured with another device (e.g. pressure plate device). But the device was not available during thesis experimental period.

The soil water retention curves (SWRC) as they were measured on repacked soil core samples are influenced by dry bulk density. Samples shown by dashed lines on Figure 29 and denoted as "1.2" were prepared for target dry bulk density 1.2 g/cm3. They have lower soil water retention, because during measurement on KSat device the structure of repacked soil collapsed, soil was thus more compacted and volume of the soil in the core ring decreased. Thus, the tensiometers were covered with thinner soil layer than designed (see Figure 11 and photo in Enclosure 1 for the construction of the Hyprop device). Anyway, the field biochar treated soil (1TR) showed higher water retention then the control variant (0TR).

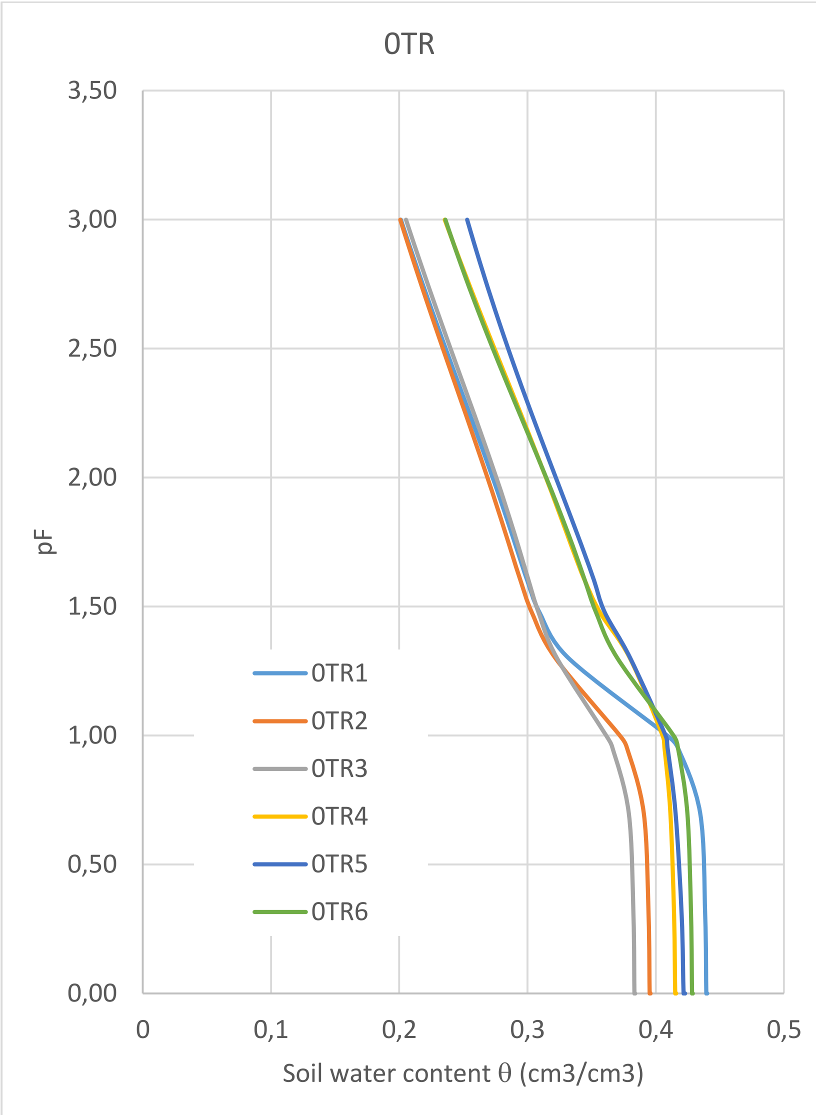

Figure 25. SWRC for control variant (0TR).

After the first experience, the target dry bulk density was increased to 1.4 g/cm^3 to avoid the problems. Control variant (0TR) and laboratory mixture (2TR) did not show any significant difference, while soil treated by biochar in the field (1TR) has obviously higher soil water retention from saturation to approximately pF 1.5 than both 0TR and 2TR variants. This is presented on Figure 28, where are average SWRC for all variants. It corresponds with the SWRC of the pure biochar (Figure 28), which shows very high water retention up to pF 1.

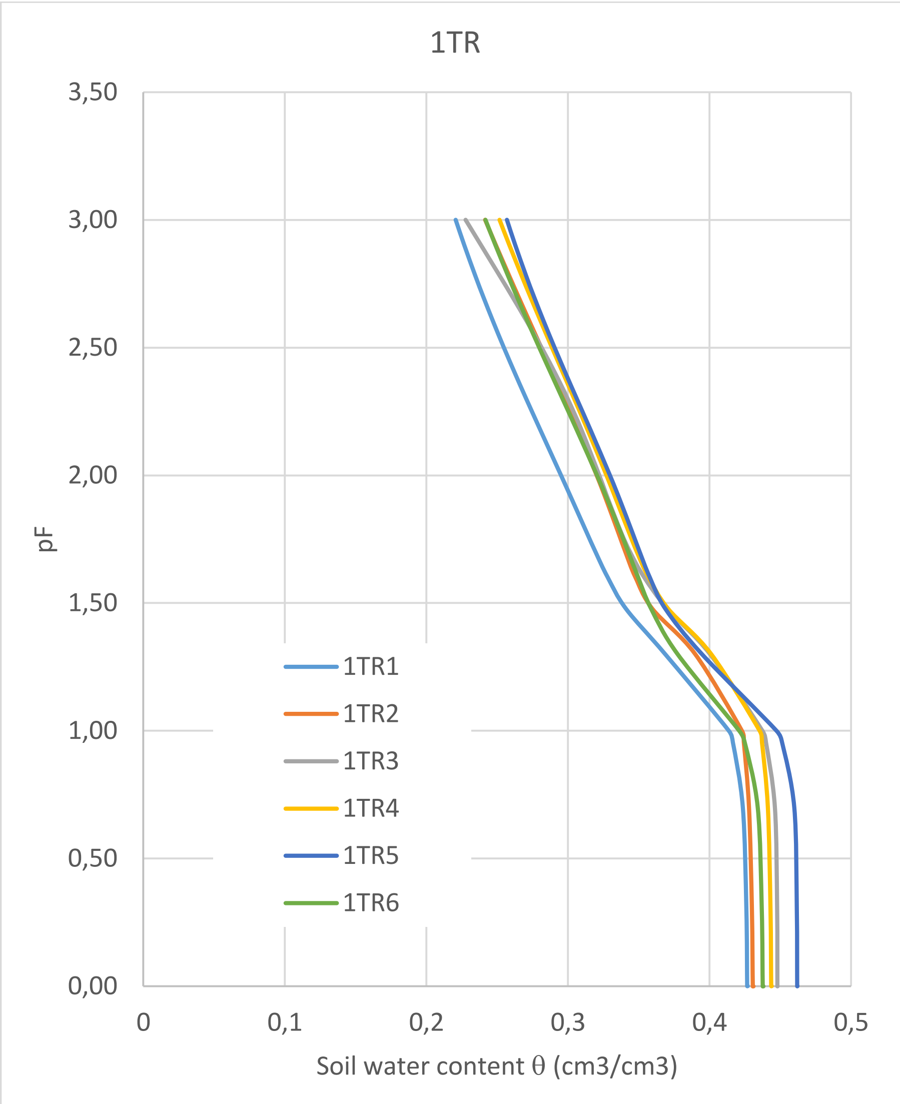

Figure 26. SWRC for 1TR (field mixture) variant.

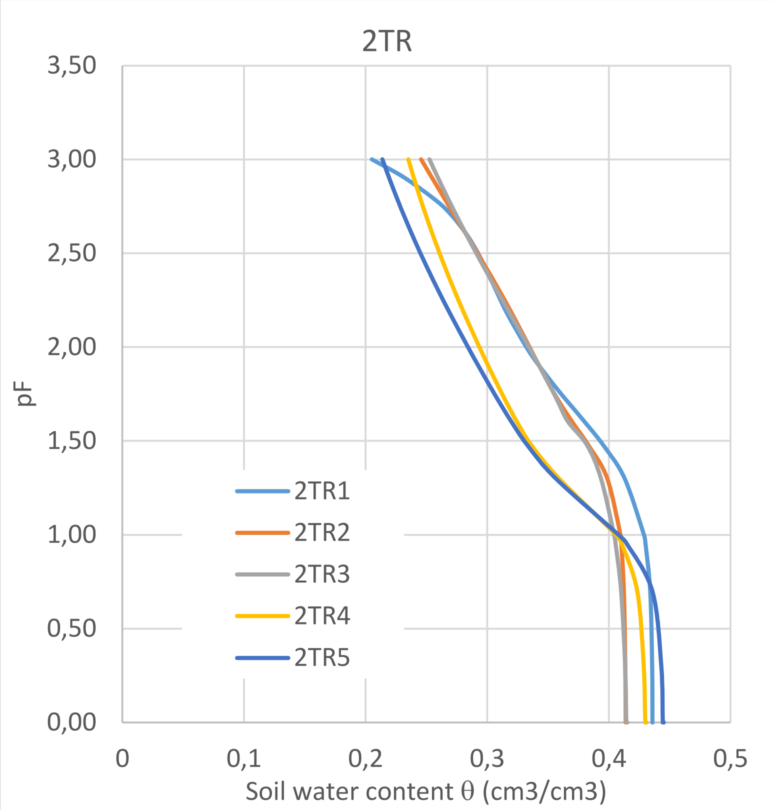

Figure 27. SWRC for 2TR (lab mixture) variant.

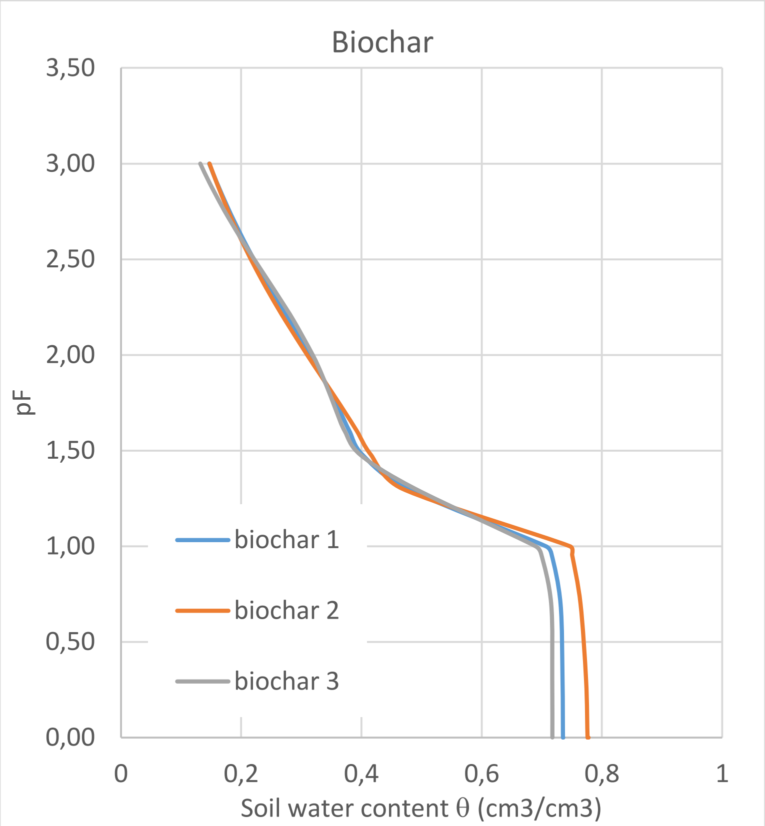

Figure 28. SWRC for pure biochar.

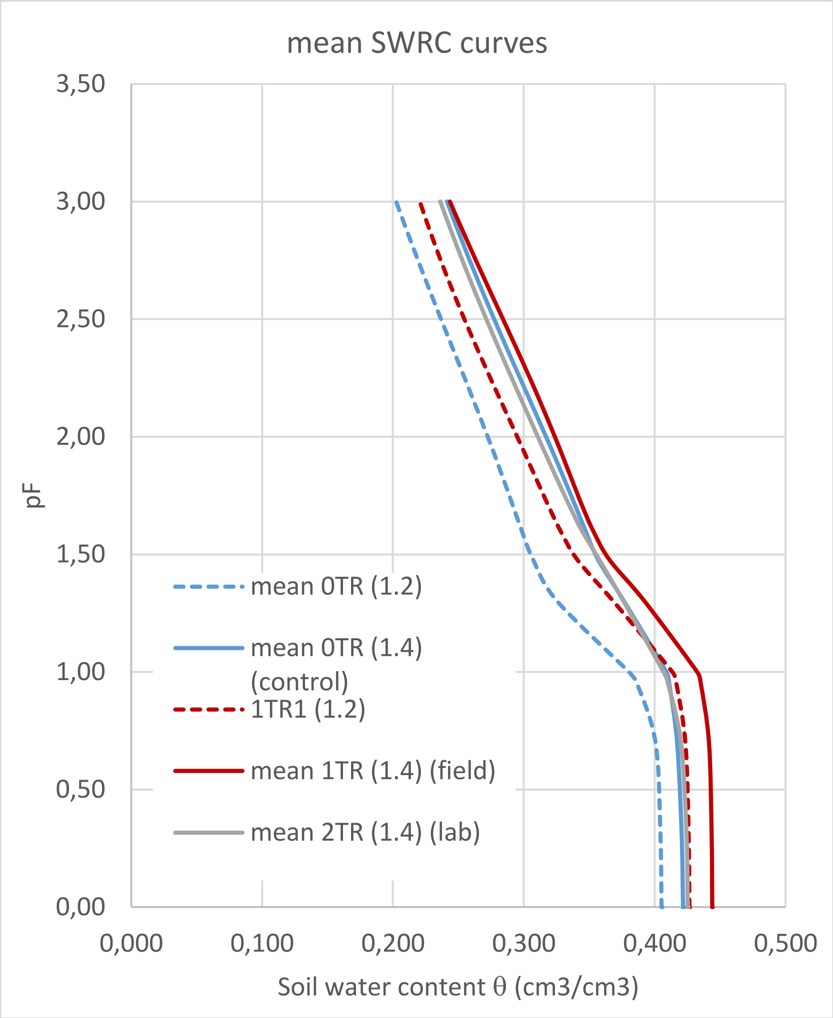

Figure 29. Mean SWRC curves.

The presented SWRC curves were fitted using Hyprop Fit software (Meter Group Inc.) by the van Genuchten bimodal model. Measured points of SWRC were registered in 30 minutes interval. Original measured graphs of soil water potential, decrease of mass of the sample and fitting procedure are presented in Enclosure 3.

6 Discussion

6.1 Measured saturated hydraulic conductivity evaluation

Results of saturated hydraulic conductivity showed that immediate biochar application affected negatively on soil with insignificant decrease in Ks value. On the other hand, long-term biochar application had positively effect on Cambisol soil and increase occurred in Ks value. However, difference in Ks value of field application soil and control was small (Table 7). Moreover, pure biochar significantly high Ks value than any concentration of the biochar added soil.

Dziadula (2017) studied saturated hydraulic conductivity of soil when three different biochar concentrations were added (control, 0.1 and 1% by mass) in laboratory conditions. It should be noted the results he obtained for Cambisol soil was similar to the present study. He reported when biochar concentration increased, Ks of soil decreased. He found Ks for pure biochar 1683.6 cm/d which is twice as smaller than values in this thesis, despite the same methodology and negligible differences in BD.Possible reason why there is such big difference in Ks values might be that different porous membranes were used for measurements (the membrane is on Figure 19). The producer recommends a special handling with the membrane and sample in order to avoid air bubbles. It should be saturated overnight before the measurement starts. When attaching membrane, a vessel with samples was filled and sample was completely left under water (see Fig. 17). Then the membrane was carefully attached without any air bubble letting in. However, while attaching membrane to biochar samples, some particles flowed out due to very light weight of biochar particles. This is probably one of the reasons why Ks values for biochar was discrepant from the values obtained during previous work.

Huislova and Cechmankova (2017) studied long-term effect of biochar on soil hydraulic conductivity haplic cambisol at Trebsin locality in field study. They used the same biochar as in the present study and compared blank control parcels to biochar treated field parcels.. Two years experiment has proven improvement of soil structure on soil aggregate stability. Ks value also increased to $1.17 . 10^{-4}$ m/s as compared with variant without biochar $5.89 . 10^{-5}$ m/s. Effect of biochar on Ks was studied by Kidane (2016) as well. He tested chernozem, cambisol, and silica sand soils with falling head method with three different concentrations (control, 0.1 and 1% by mass). In his results significant increase was seen in chernozem soil, but in cambisol soil significant change did not occurred.

Barnes et al. (2014) learned biochar effect on Ks with in situ method. 10 % concentration (by mass) was applied into clay-loam, sand and organic soil. The increase in Ks was from 3.2 . 10^{-8} to 1.2 . 10^{-7} m/s in clay-loam, while significant decrease occurred in other two types of soil. In this study, they also reported that adding 10 % of biochar, Ks of compacted clay was estimated less than half order of magnitude. It implies that the effect of biochar addition on the increase in Ks of clay is less significant if the clay was compacted at relatively high degree of compaction.

According to the results from Pario device, the soil texture is silt loam. Herath et al. (2013) studied biochar effect on soil physical properties on silt loam. They compared three type of admixture; control soil, fresh corn stover (CS), low temperature biochar (CS-350), and high temperature biochar (CS-550) admixture. Application rate was almost similar to the present study (about 1%). According to the results they obtained, total pore volume of soils increased significantly compared to control soil. The highest value is 19 % and it occurred for CS-550. Also, for CS and CS-350, 10 and 13 %, respectively. As the result of increase in pore volume, they observed decrease in BD, increase in total porosity and water holding capacity, most importantly in Ks value. The increase in Ks agrees with the increase in the overall porosity of these soils. Development of macroporosity causes the hydraulic conductivity to increase, which reflects the drainage level of a given soil (Azooz and Arshad, 1996; Heard et al., 1988; Logsdon et al., 1990). As expected, the improvements observed in the Ks due to biochar application were colaborated by the increases of macropore volume.

6.2 Evaluation of SWRC results

The diference between control variant and soil treated by biochar in the field is about 2.4% by vol. The difference is not big, but it may help to plants to overcome short period of drought. Folaufová (2017) found similar differences in her work on sand and luvisol, and she worked with laboratory mixtures only.

The pure biochar SWRCs are very different from soil's SWRCs as the mean saturated water content is 74.4% by vol. These curves are in agreement with measurement of Folaufová (2017). Puhringer (2016) studied effect of different biochar application rates on some soil chemical and physical properties of the soil. The research was conducted on smallholder farms in two counties in Kenya, namely Siaya and Embu. Two application rates, 10 t/ha and 5 t/ha was compared to control (zero) soil. Results from Embu, which is cambisol soil, showed no significant change in soil moisture while notable change occurred at the two lower tensions (pF of 1.7 and 3) in Siaya in chernozem soil.

Burrel et al. (2016) researched about biochar effect on soil hydrophysical properties. As their result, the mostly affected soil by biochar was Planosol in terms of plant available water. Koide et al. (2014) also studied biochar effect on four different types of soil and they reported that biochar had most positive effect on plant available water in sandy loam. Sun and Lu (2014) made comparison of different biochar effect to Cambisol; they found straw biochar improved plant available water while woodchip biochar had no effect.

Soil bulk density and porosity which are considered to be main driving forces of soil hydrophysical properties affect soil water potential with regards to soil aeration, water infiltration, structural support and soil water retention. Results from the present study showed that both applications of biochar almost did not change total porosity; however,this is caused by the experimental setup based on repacked samples. Previous authors reported sustainable decrease in bulk density and relatively high increase in total porosity. Arthur and Ahmed (2017) applied 3 % biochar to the coarse textured soil and reported that bulk density decreased for 32% three months after biochar application. This was translated into 22 % increase in total porosity after 3 month and 16% increase after 15 months.

Amoakwaha et al. (2017) investigated corncob biochar application to silt loam soil. Biochar was applied in two different concentration to sandy loam: 20 t/ha and 10 t/ha. Study results showed that biochar application at 20 t/ha significantly increase soil water content at lower matric potentials (pF 2-3) while no noticeable effect of biochar on soil water retention occured at application rate 10 t/ha.

Randolph et al. (2017) noted significant increase in soil water retention after applying 2 % (by mass) biochar admixture. Similarly Ulyett et al. (2014) reported noticeable increase in water retention at matric potential of – 5kPa when wood biochar pyrolyzed at 600°C was at rate of 60 t/ha.

Hlavacikova et al. (2016) considered the effect of biochar on sandy loam with the similar way as in this study. They investigated application rate of biochar were 40 t/ha and 80 t/ha, however, as their results showed there was no significant effect of biochar on soil water retention.

6.3 Irregularities in measurements

Statistical analysis showed that Ks results of samples, which prepared from one soil, differentiate significantly; on the other hand, results of replicates did not vary lot. During the experiments, soil was sieved on 8 mm sieve in order to keep the natural structure aggregates, therefore, the sample contained wide range of structure aggregates' sizes. Based on my observation during measurement, when sample had higher ratio of larger aggregates, its Ks value was bigger than of the sample, which had more finer aggregates. The uneven distribution of the structure aggregates might be the reason for higher CV of the measurements.

When samples 2TR4 and 2TR5 were measured with Hyprop device, measurement failed due to the problem with Hyprop View software. Therefore, two new samples were prepared to measure the SWRC, but they were not attached to Ksat device, because Ks values for these samples were already received. Their SWRC varied from the other samples' result. When pictures were compared (pictures are given in Enclosure 2) it was seen that compaction degree of samples after Ks measurement was very high. In future works it should be noted and measurements using repacked samples should be carried out by separate samples, despite the recommendation of the producer who presents the connection of Ksat and Hyprop devices as an advantage. As a consequence of the connected measurements, the repacked samples were overcompacted and the effect of biochar admixture could not be observed very well. Target bulk density 0.1 g/cm^3 would have probably lead to different and more realistic result.

7 Conclusions

This study focused on comparison of immediate and long-term effect of biochar on soil hydrophysical properties. Experiments were carried out with repacked soil core samples using haplic cambisol from Trebsin locality. During the lab experiments, the same bulk density was maintained in order to reduce the natural variability of soil hydraulic properties related to changing porosity.

The first main part of the hypothesis was that immediate application of biochar to haplic cambisol soil would improve soil hydrophysical properties. However, obtained results from total porosity, saturated conductivity and SWRC showed that no significant change occurred when biochar applied instantly, thus first part of hypothesis was not confirmed. The reasons were discussed in previous chapter. The second part of the hypothesis was long term effect of biochar on soil is even greater. The results of this section showed some improvement in soil structure when compared to control sample and lab applied sample. Biggest effect was observed in SWRC results with 2.4 % increase in water retention than control samples results. It means biochar affects soil structure of Cambisol soil and develops its functions. Thus, second part of the hypothesis was partially fulfilled.

The main objective of the thesis, which was to study in laboratory the influence of biochar admixture on soil hydrophysical properties using homogeneous soil core samples was fulfilled.

From the received results and discussed literature it can be concluded that long term effect of the biochar application onto the soil is more useful than immediate effect. Thus, my suggestion is that future studies mainly should be focused on long term effect of biochar on soil. Moreover, the concentrations used for this study were relatively small, on the other hand, some literature sources showed if bigger concentration of biochar were applied to soil, biochar may fill up the pores and negatively effect on soil hydrophysical properties. My last suggestion is to apply smaller concentration (e.g. 1% by mass) in certain time unit (e.g. each one or two years) until soil properties are restored.

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9 Enclosures

List of enclosures:

Enclosure 1. Hyprop device prepared for measurement.

Enclosure 2. Photo soil samples in different stages of evaporation process.

Enclosure 3. Output graphs from HYPROP FIT software

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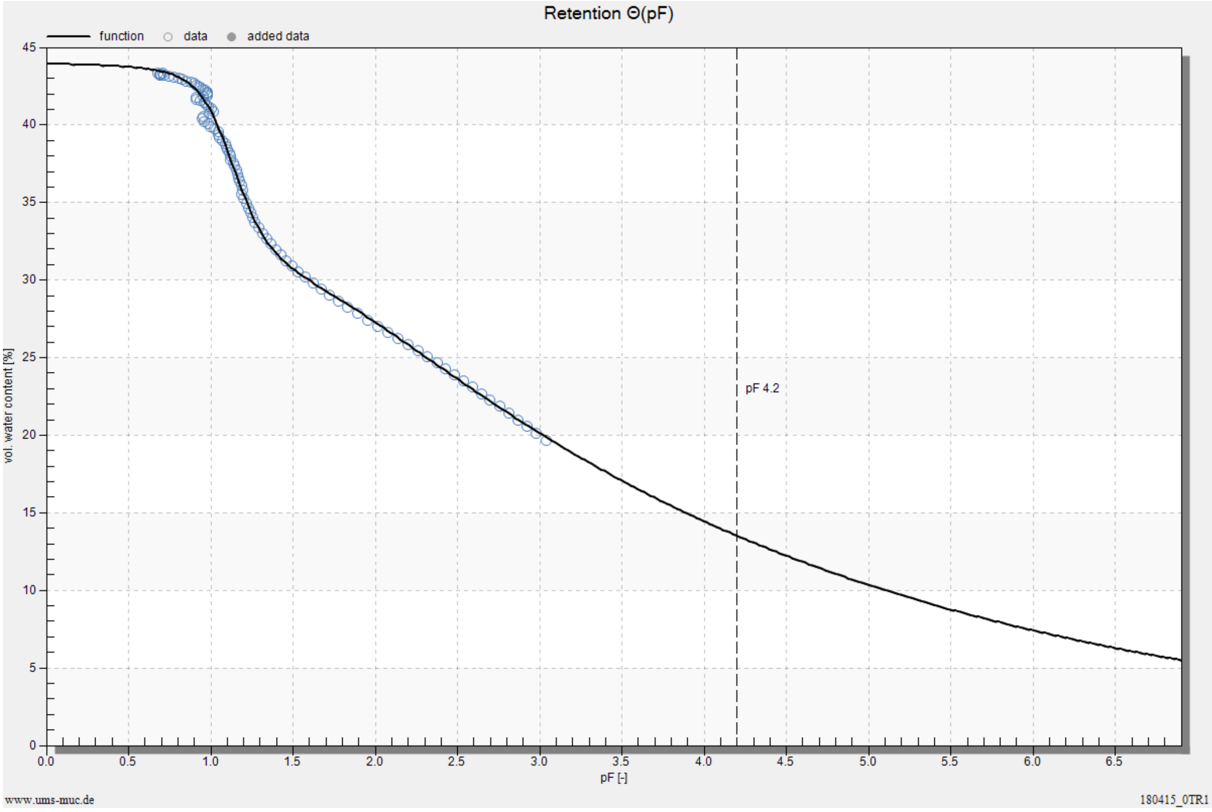

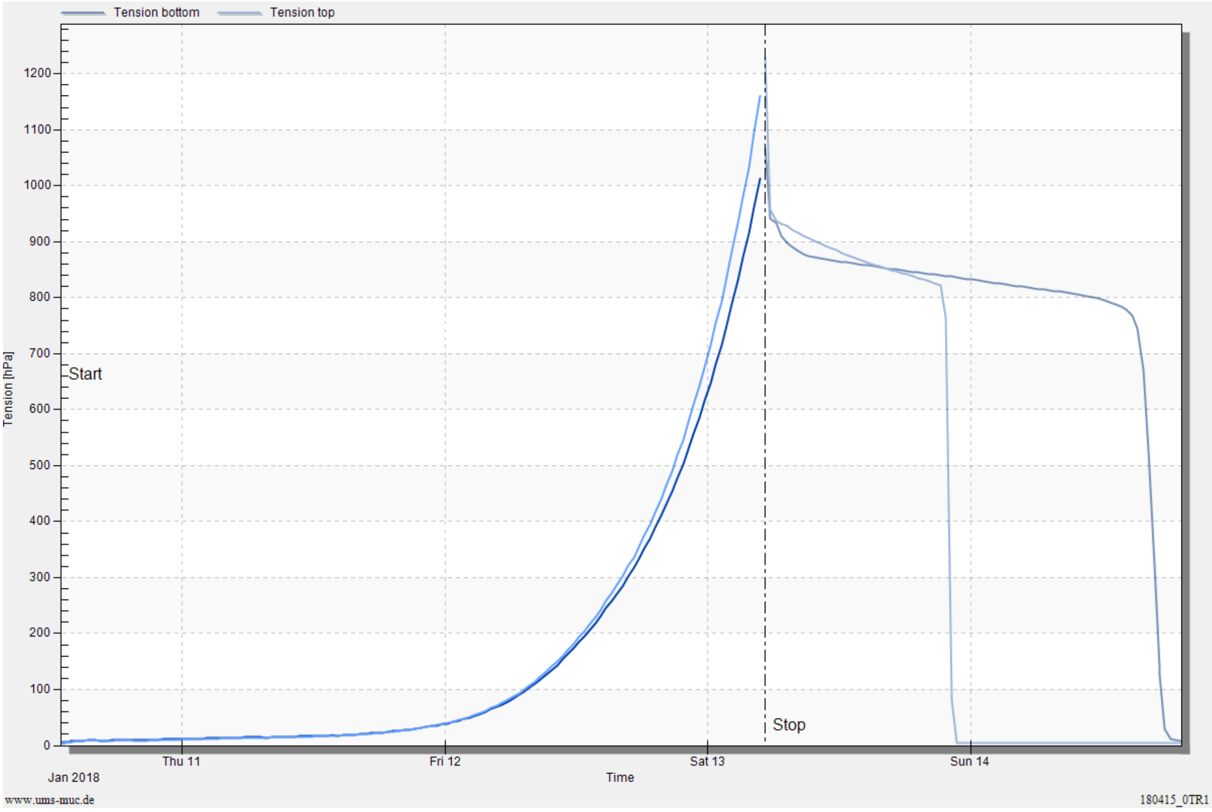

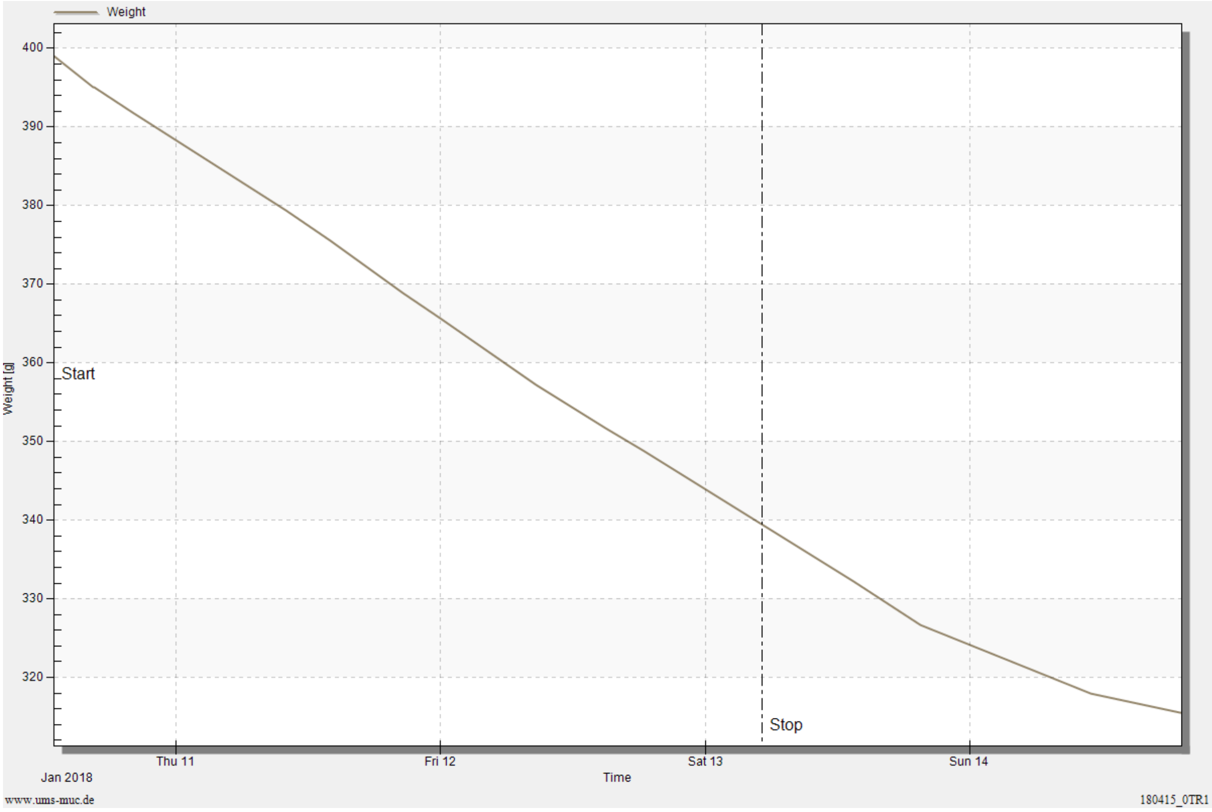
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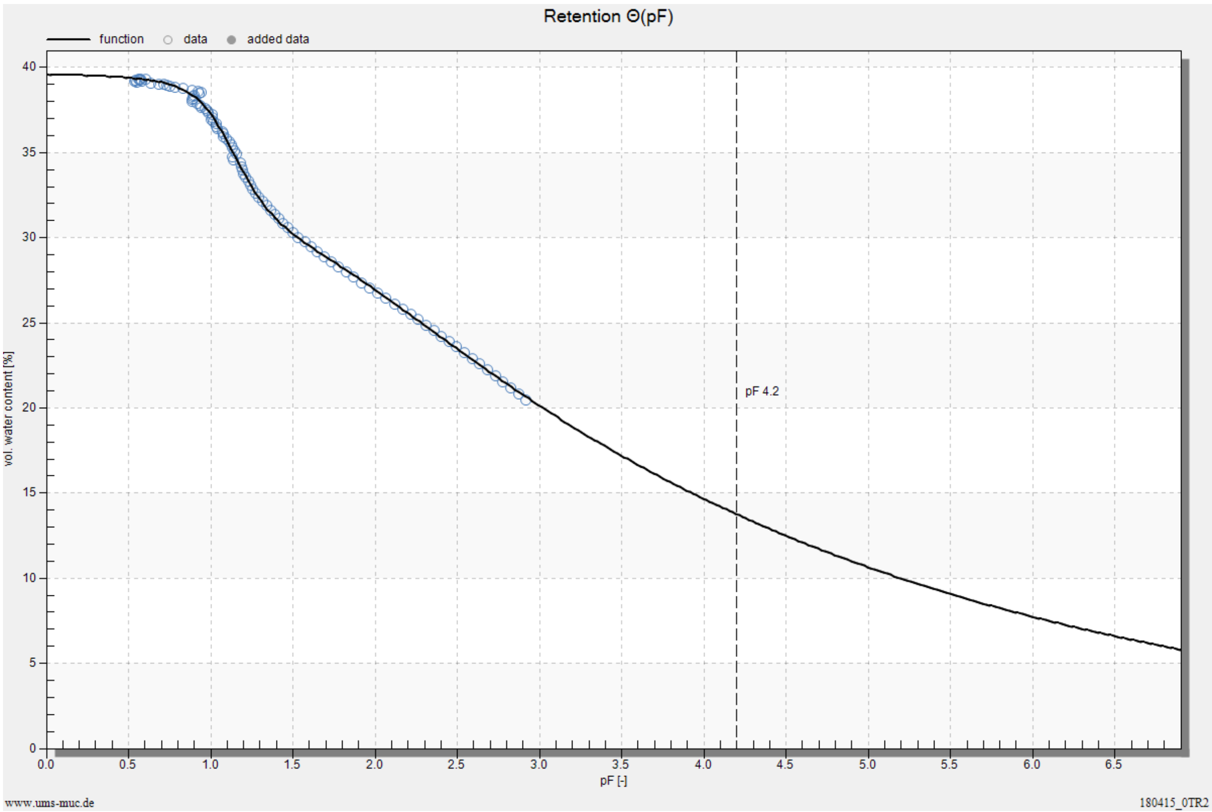
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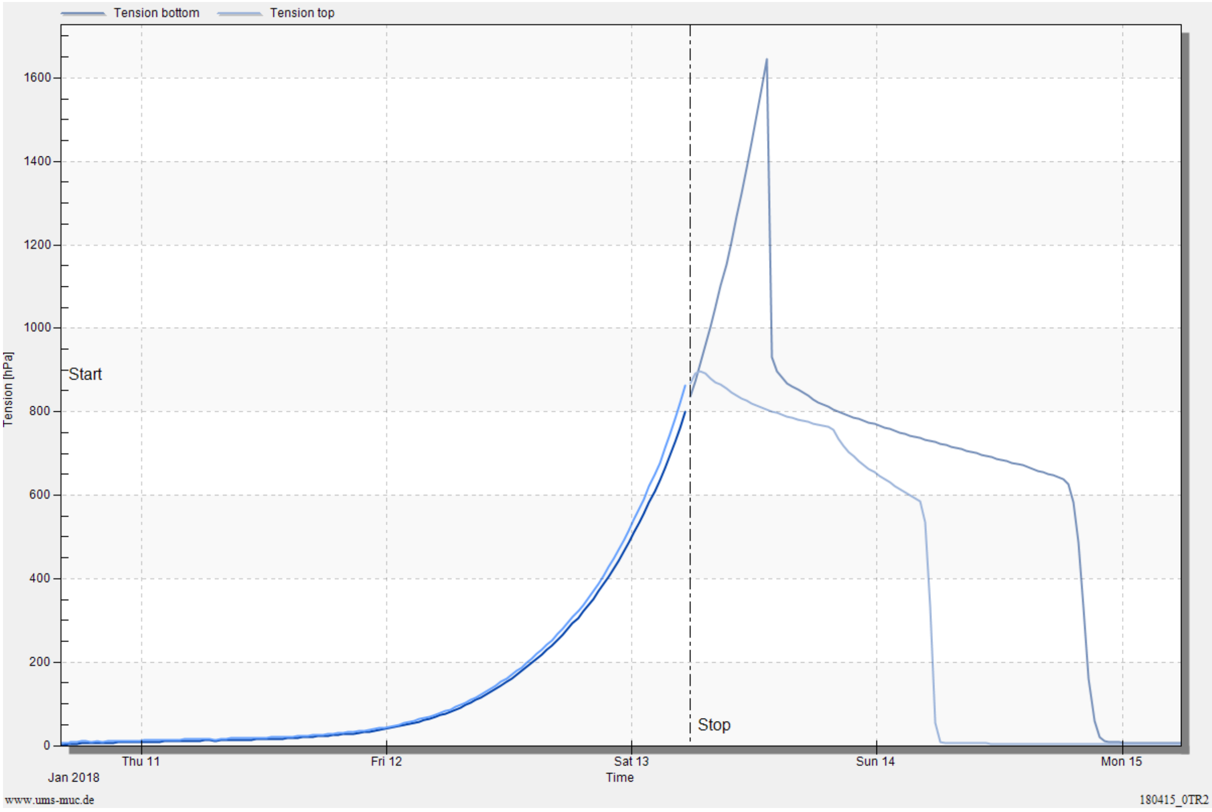

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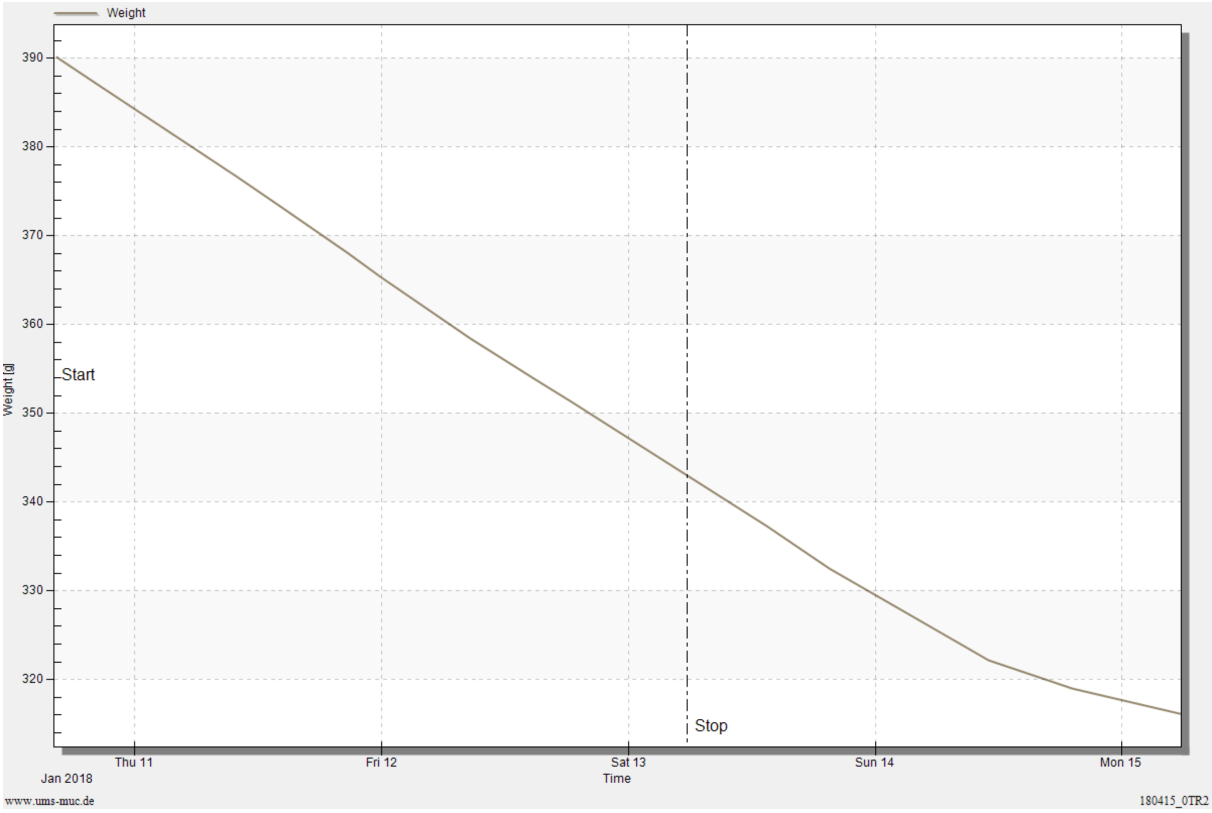

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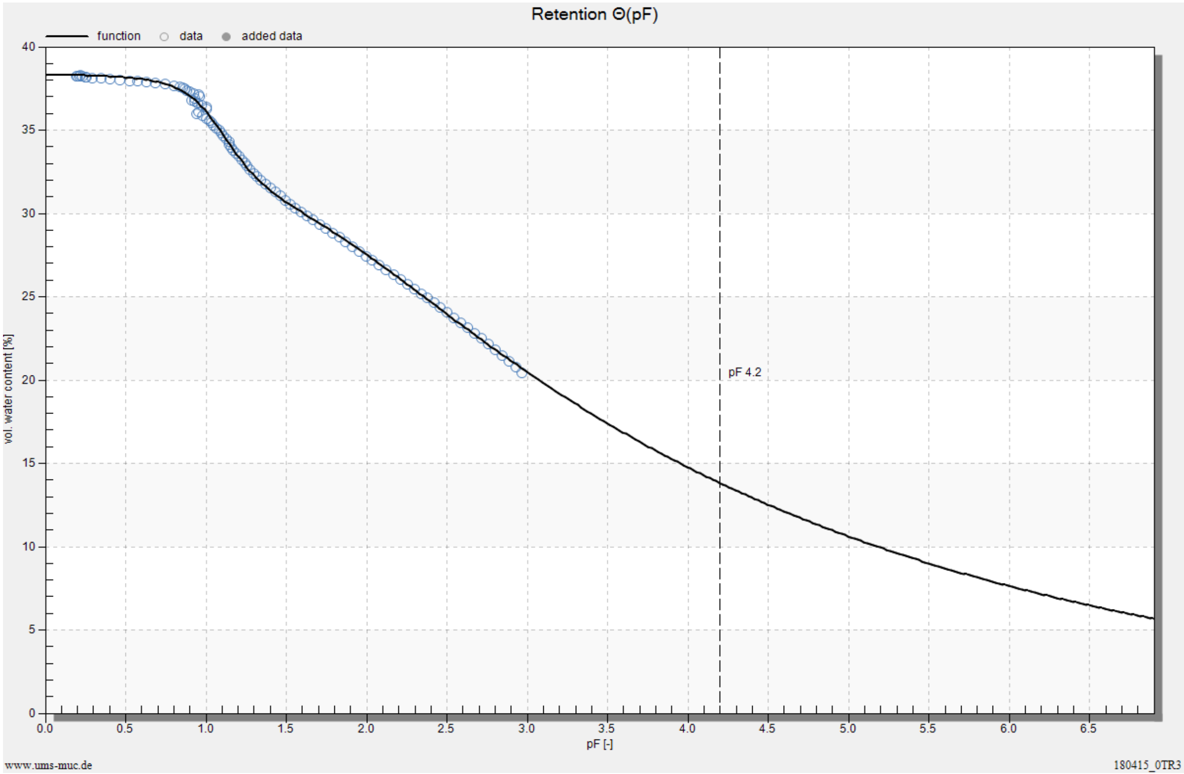
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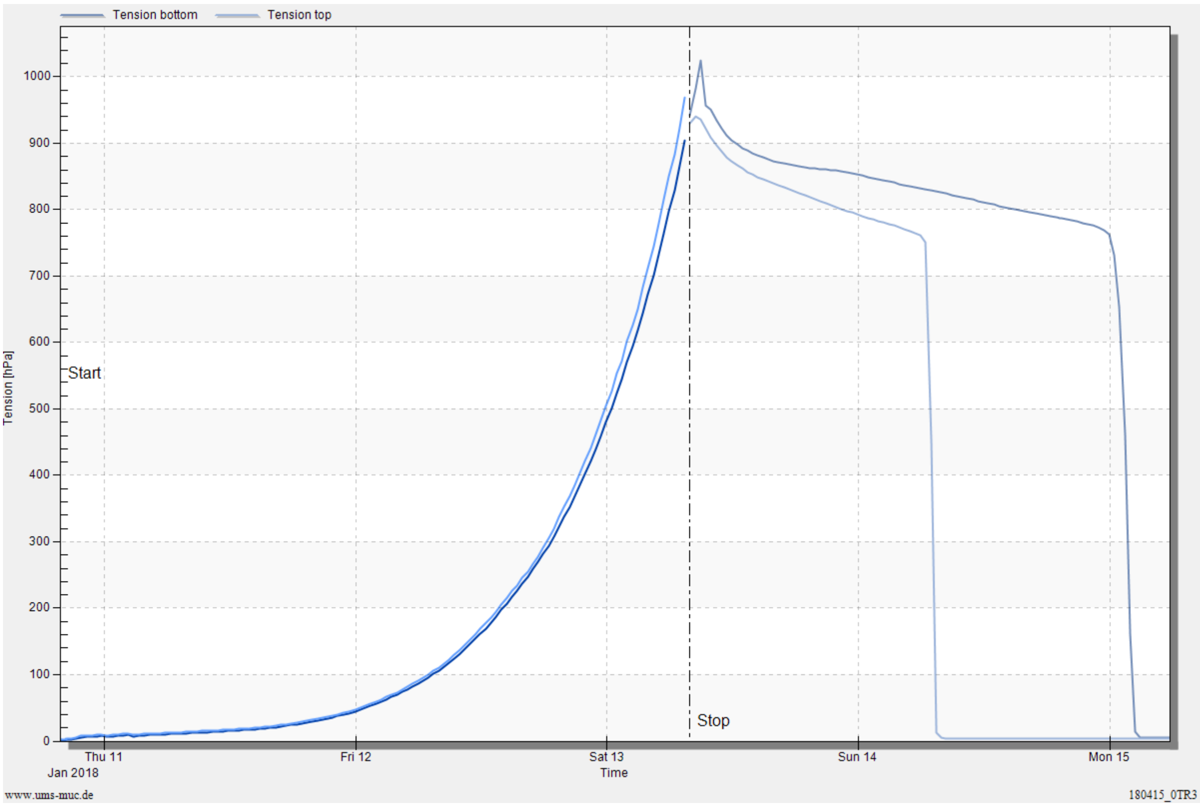
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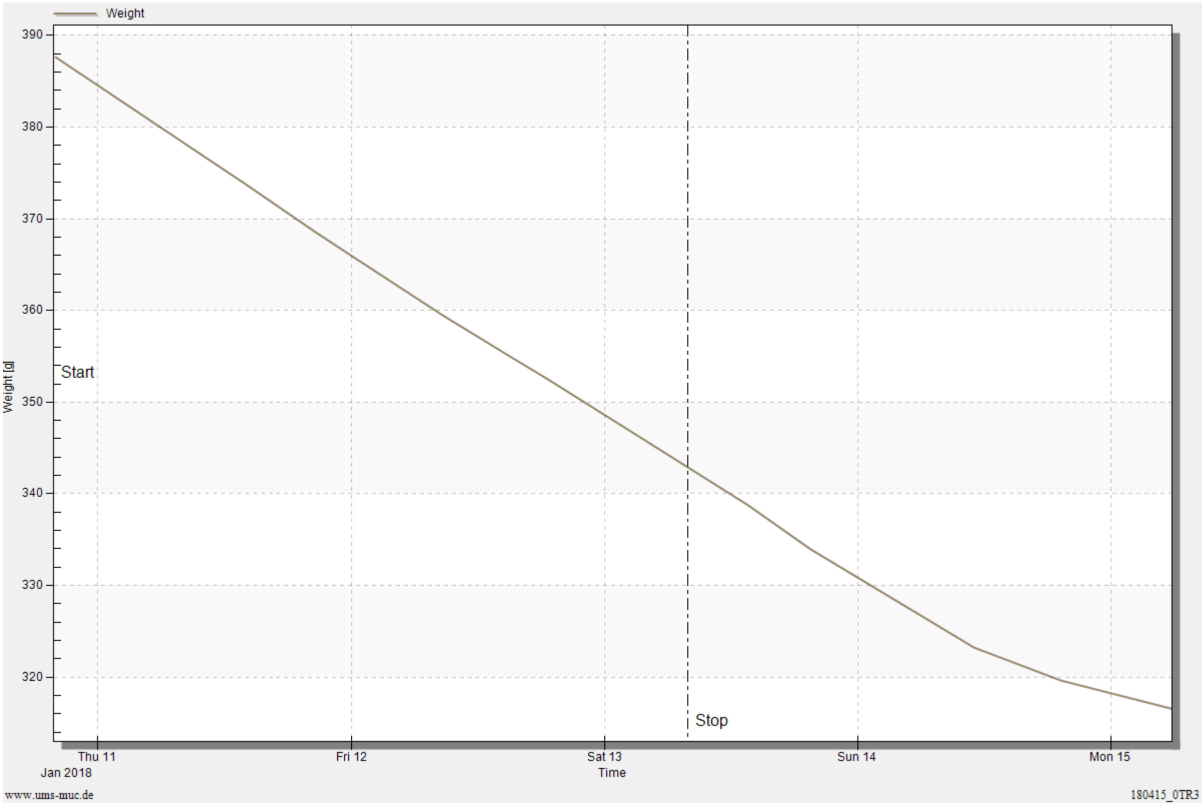
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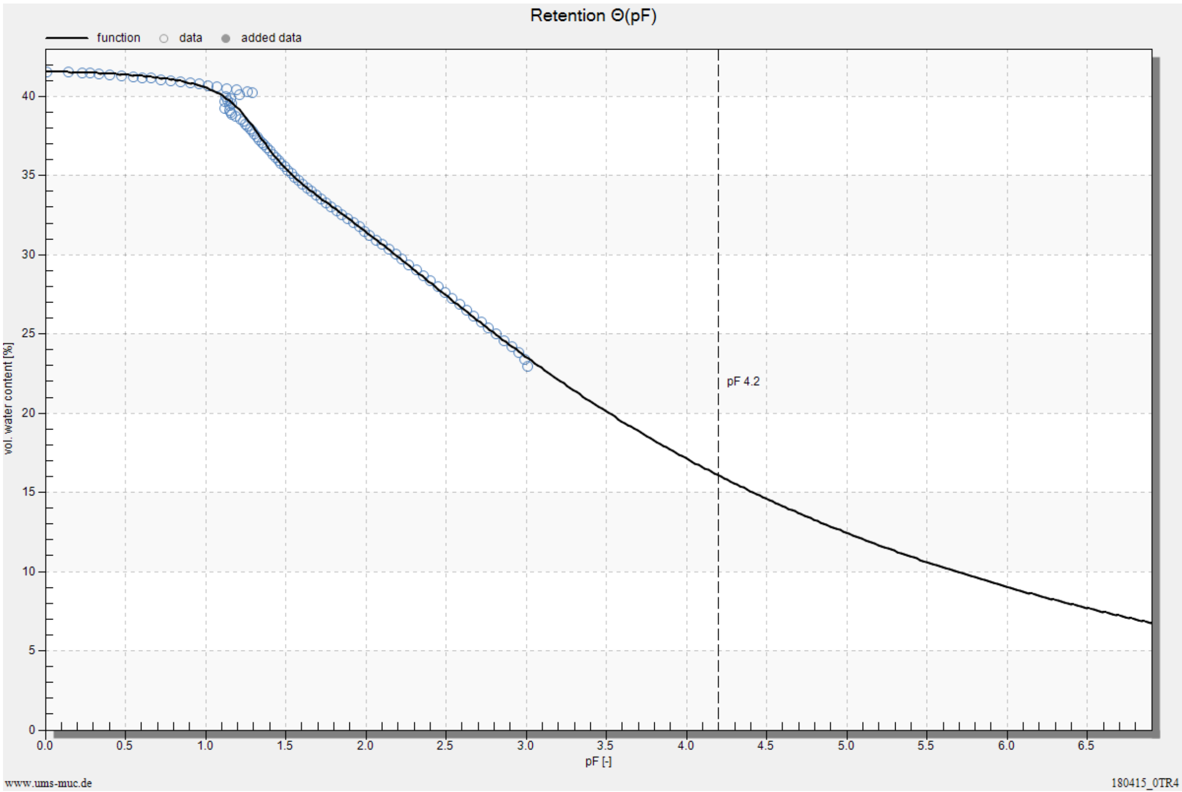
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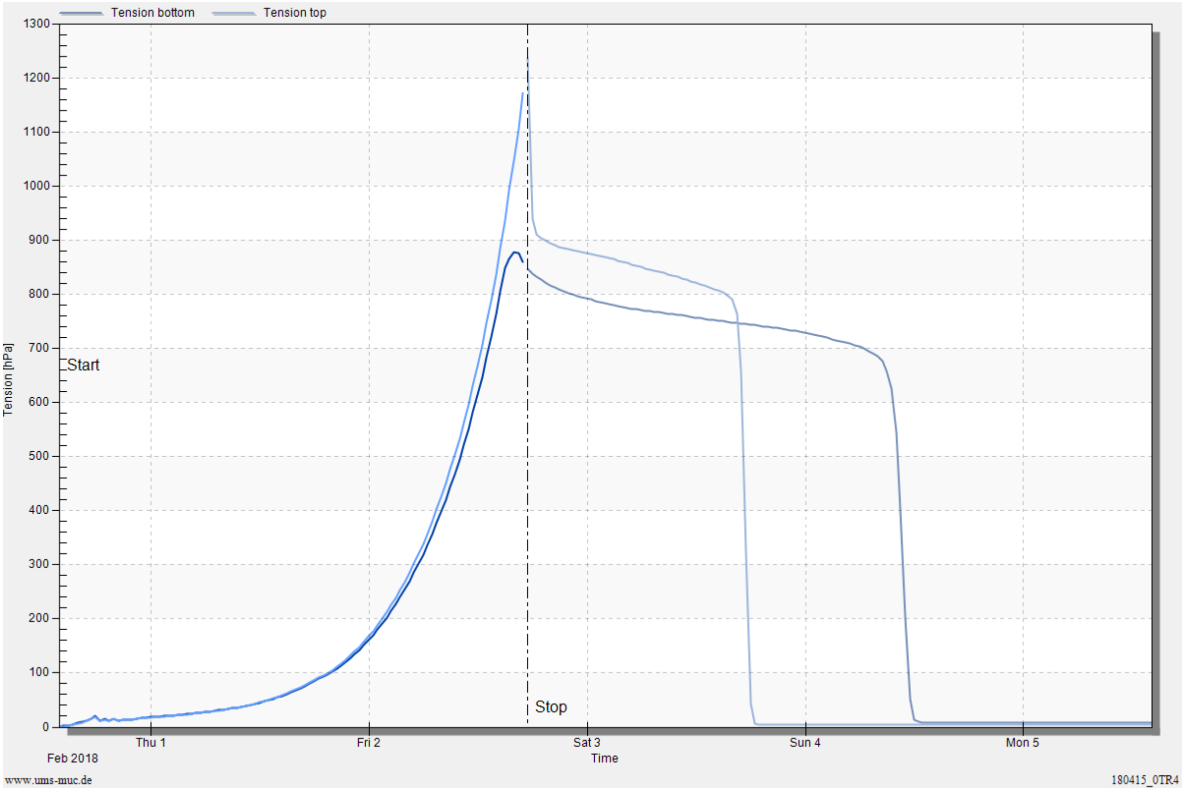

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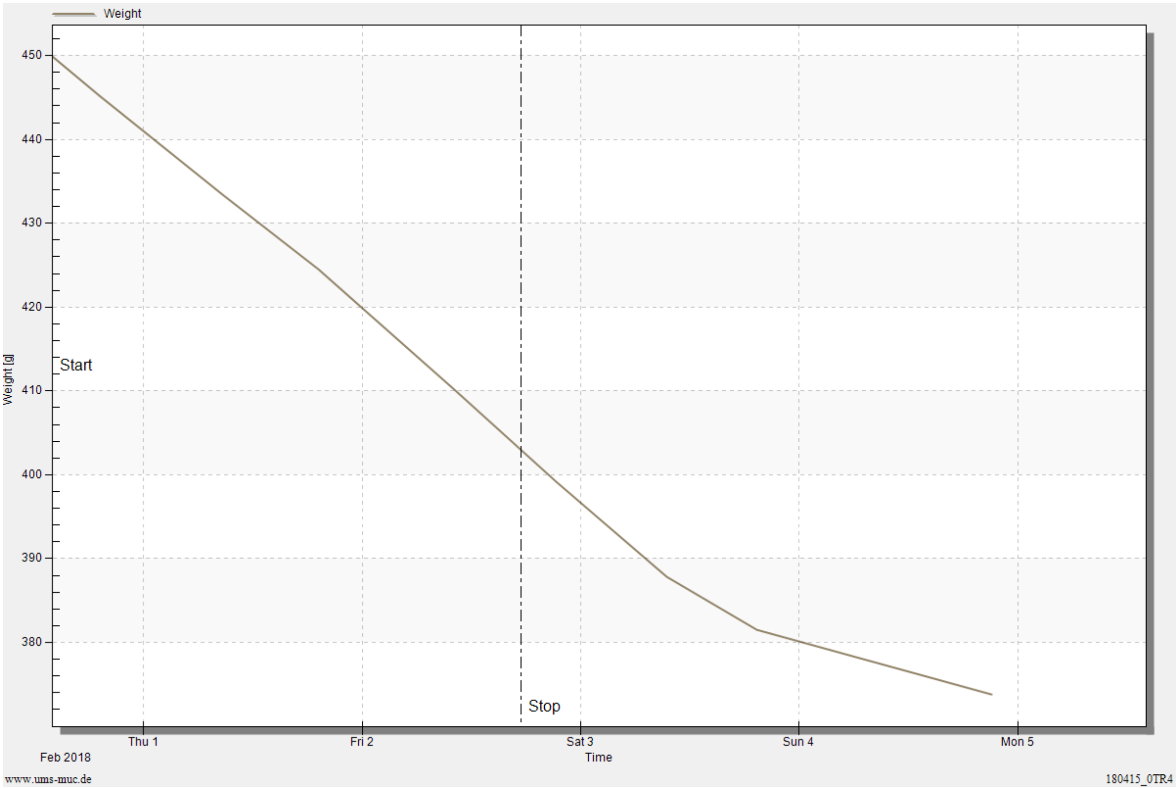

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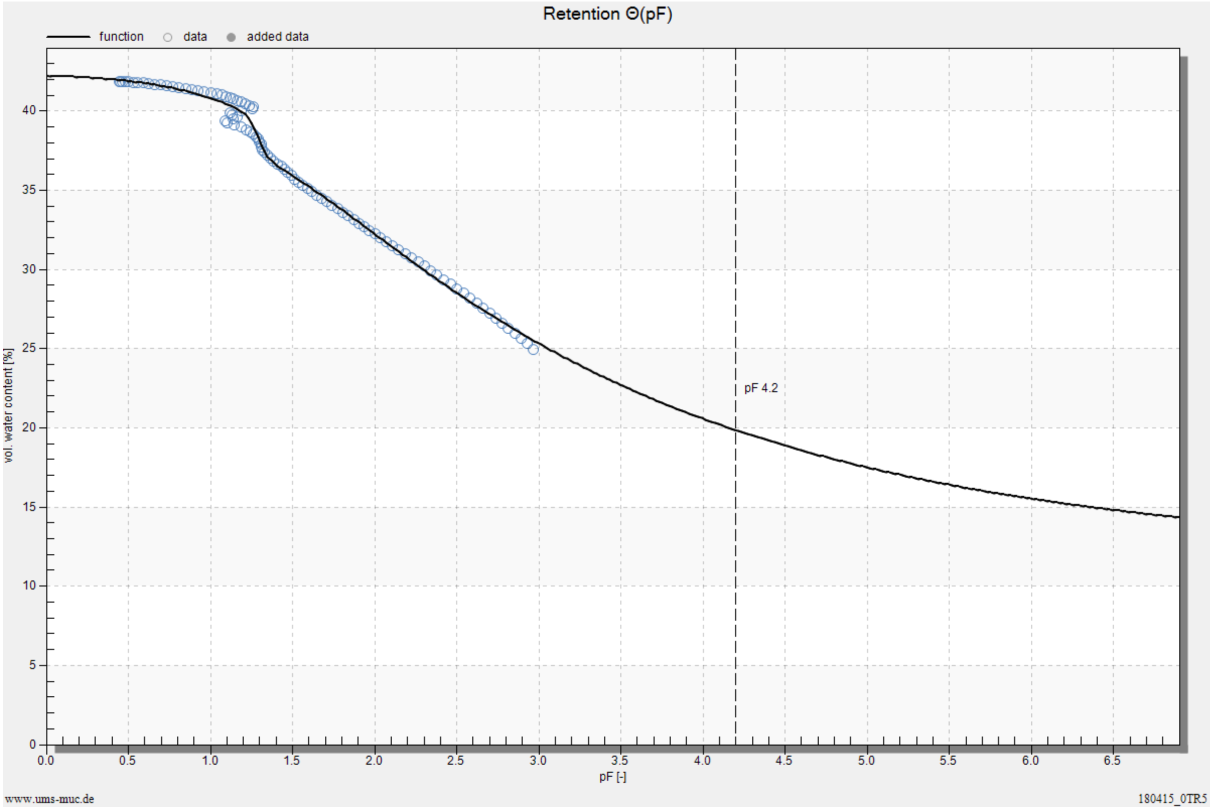

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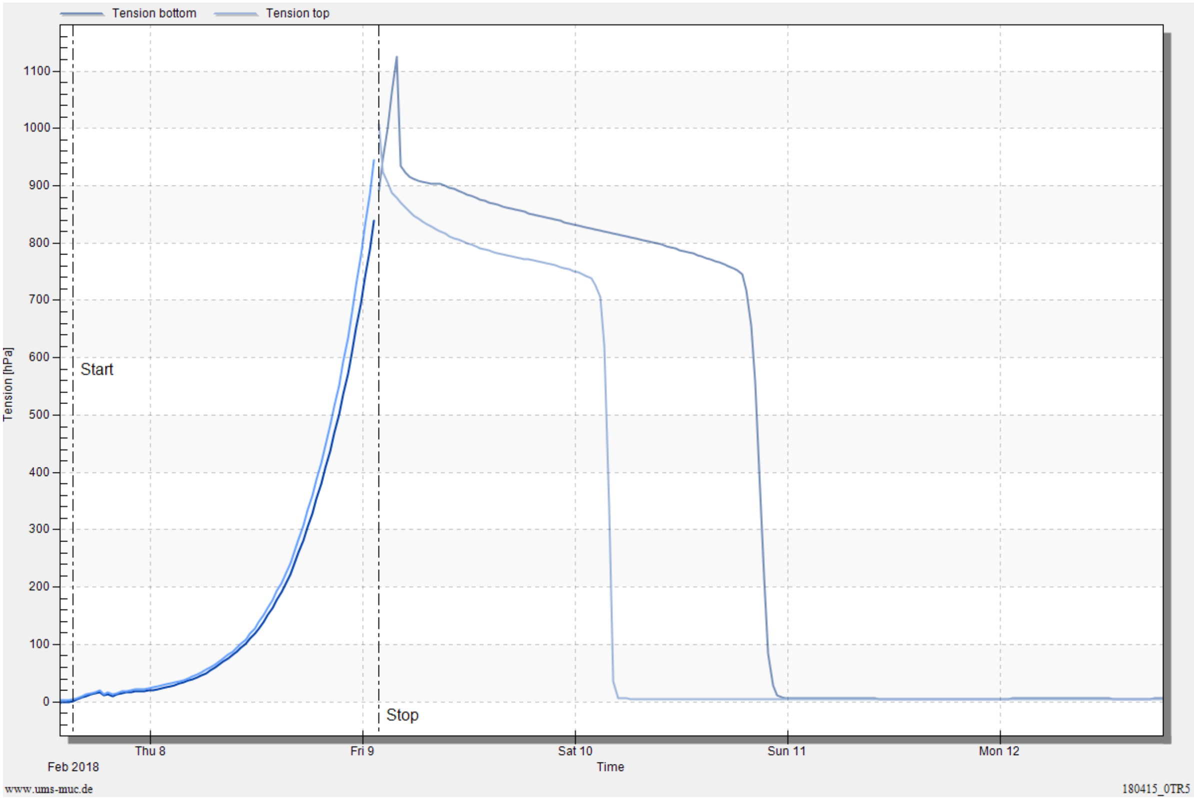

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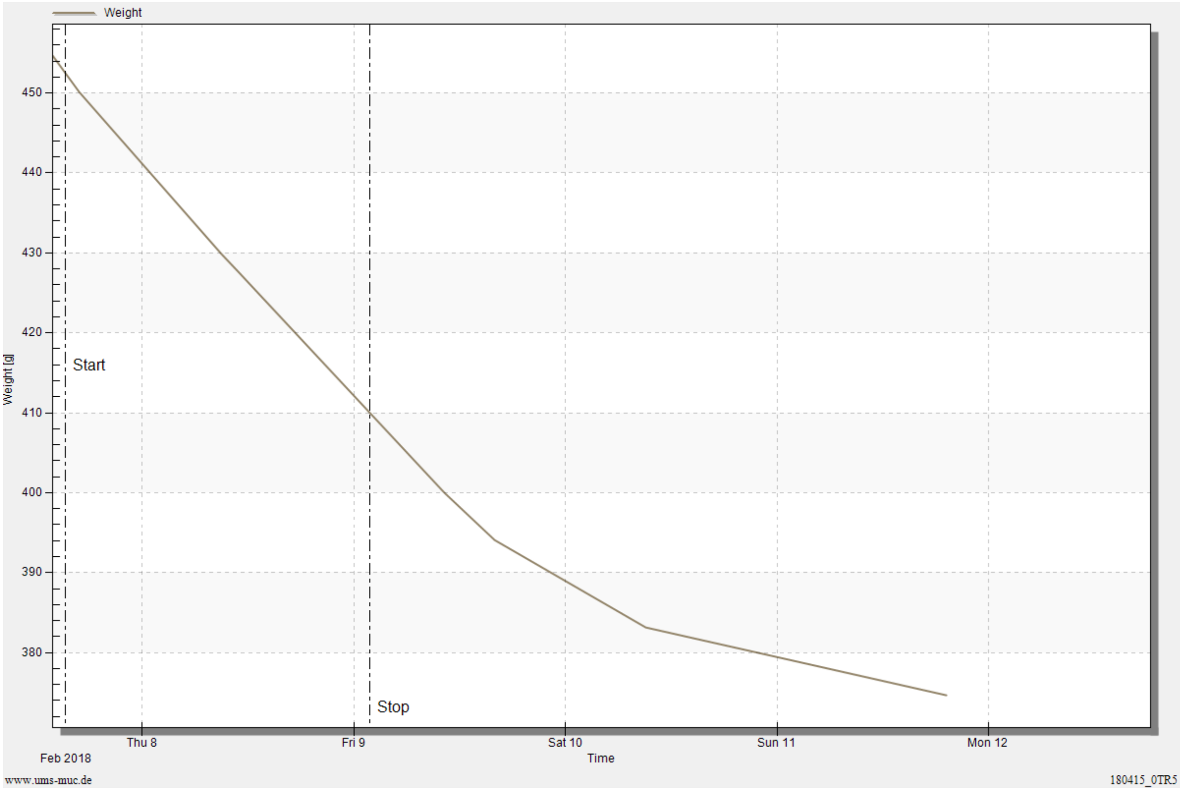

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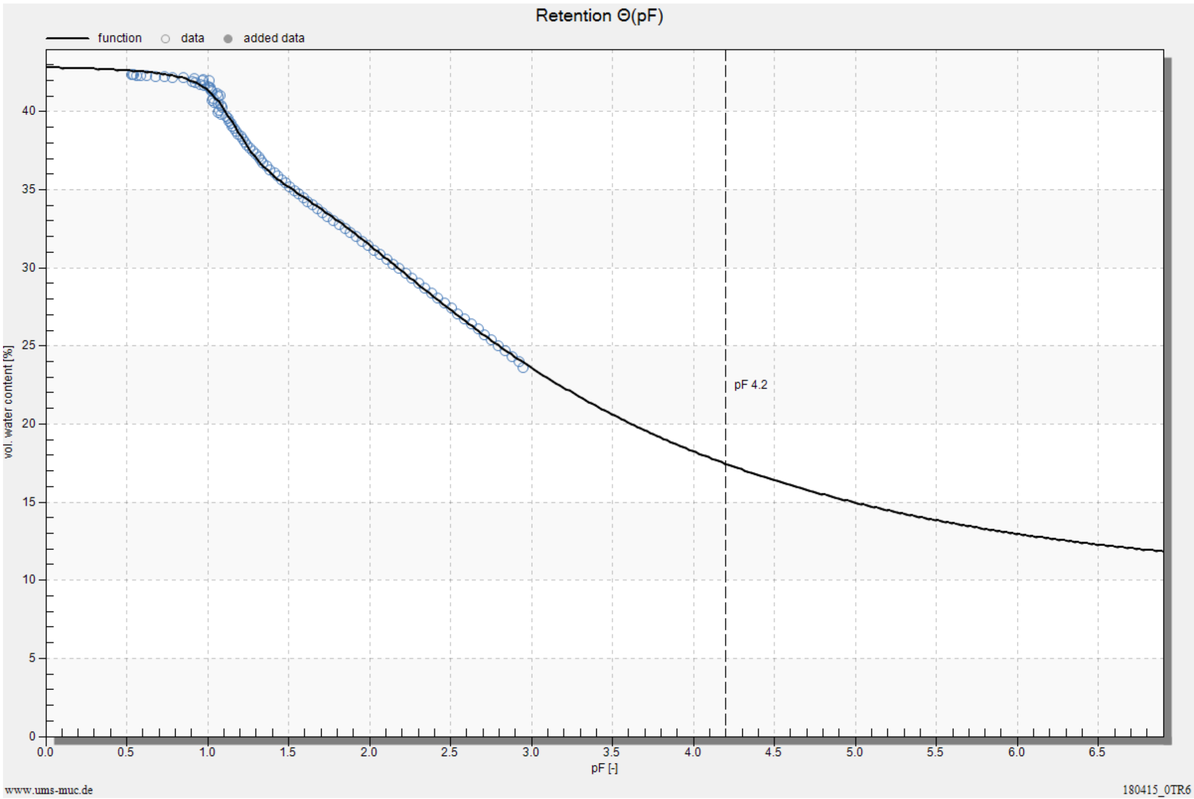

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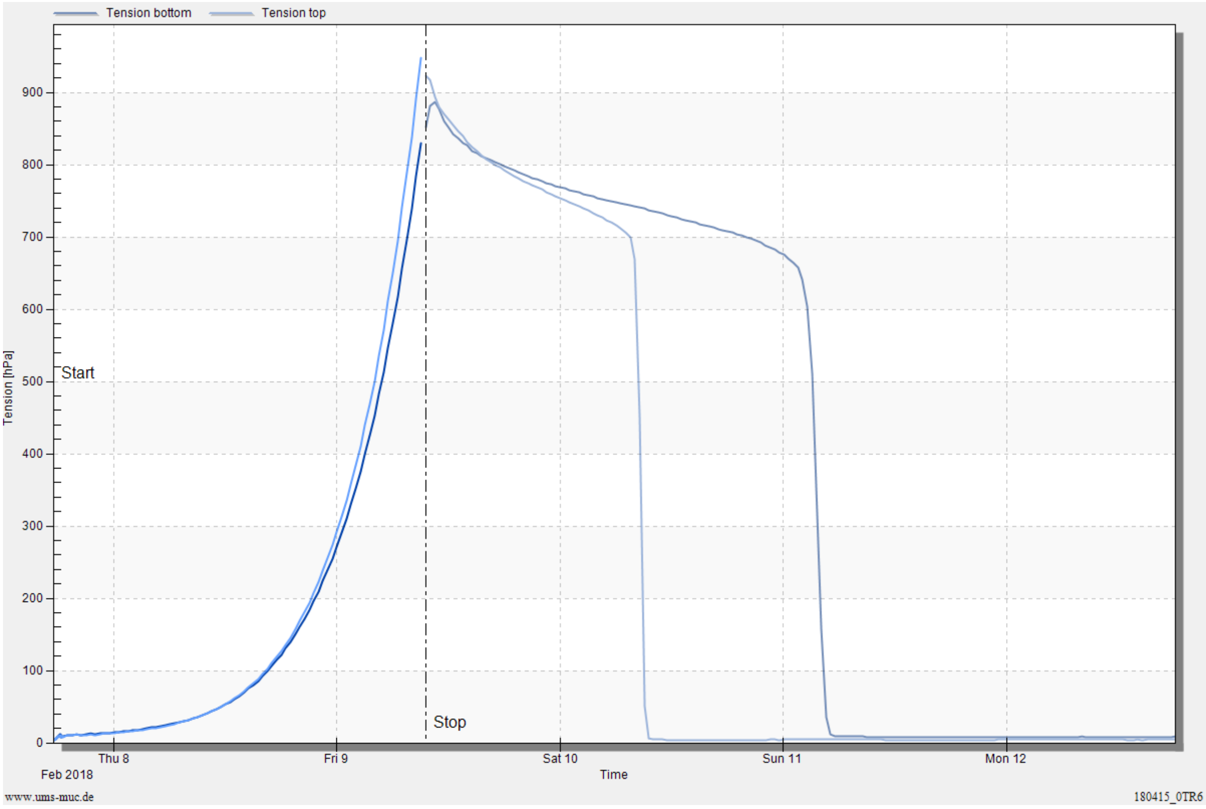
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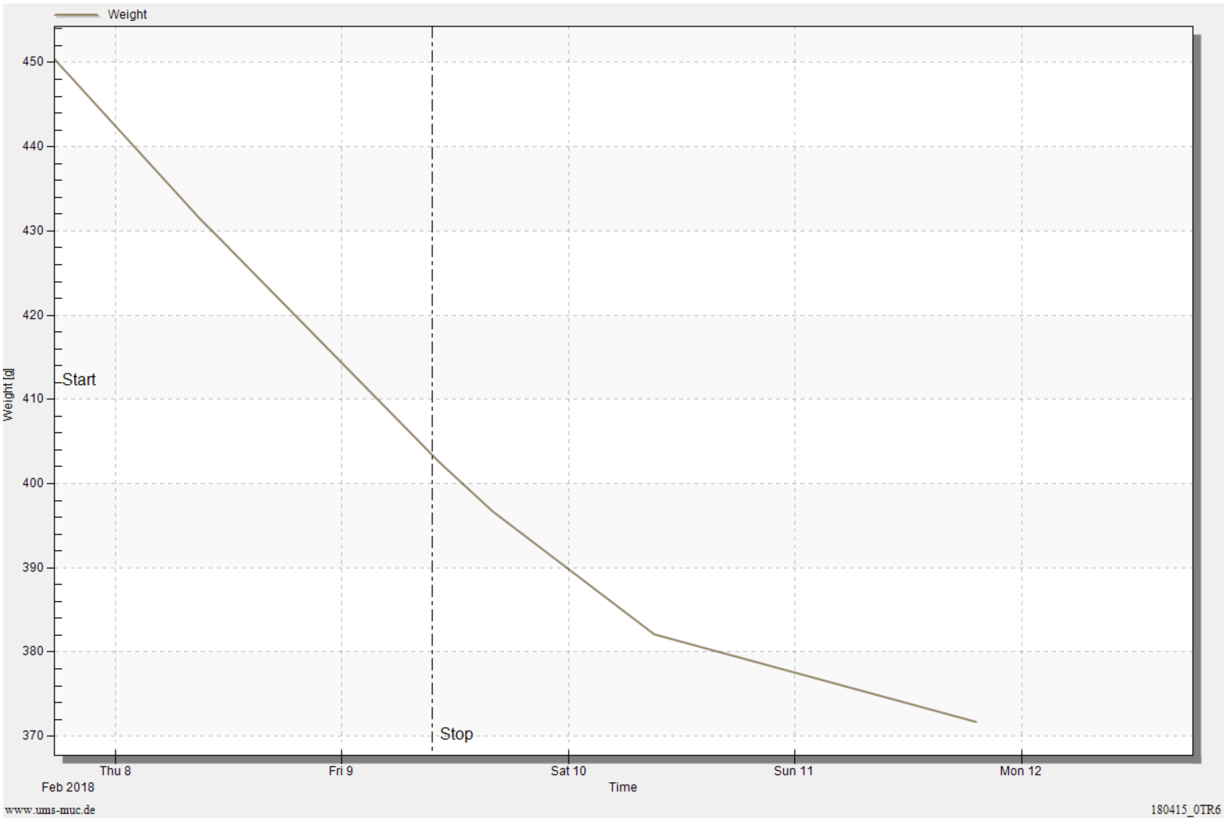
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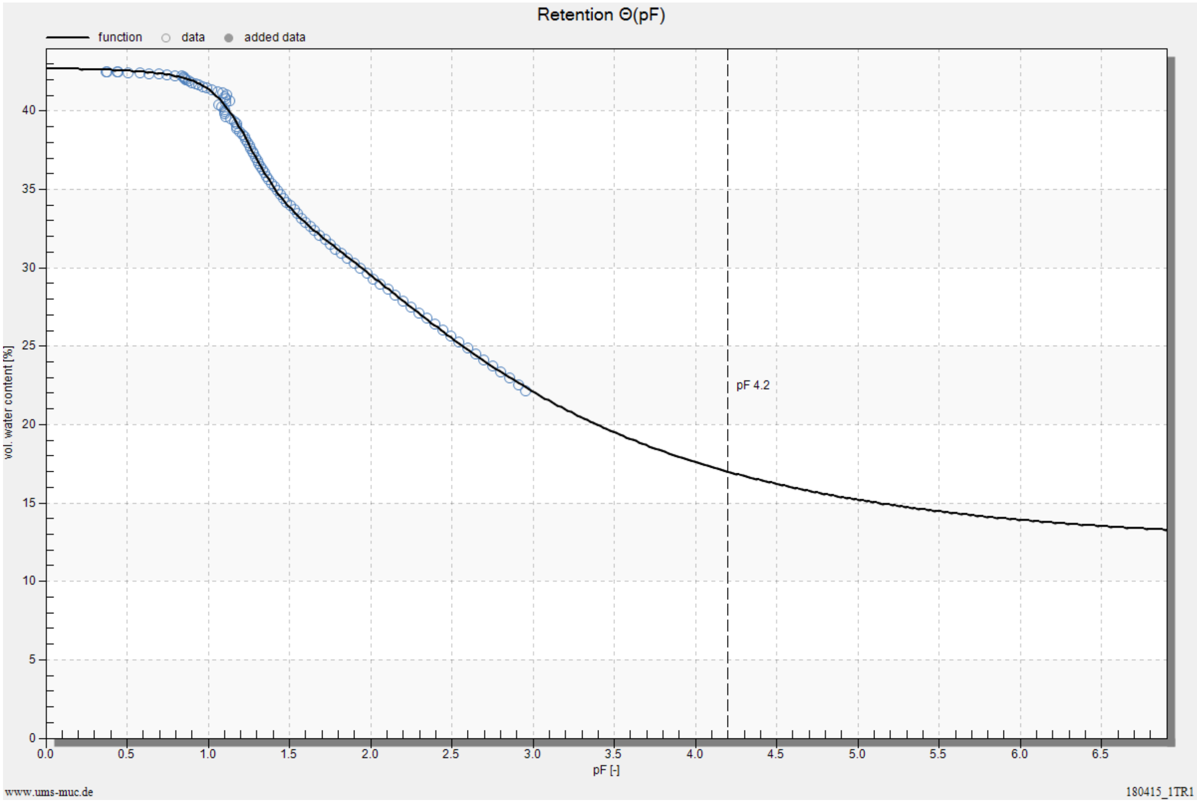
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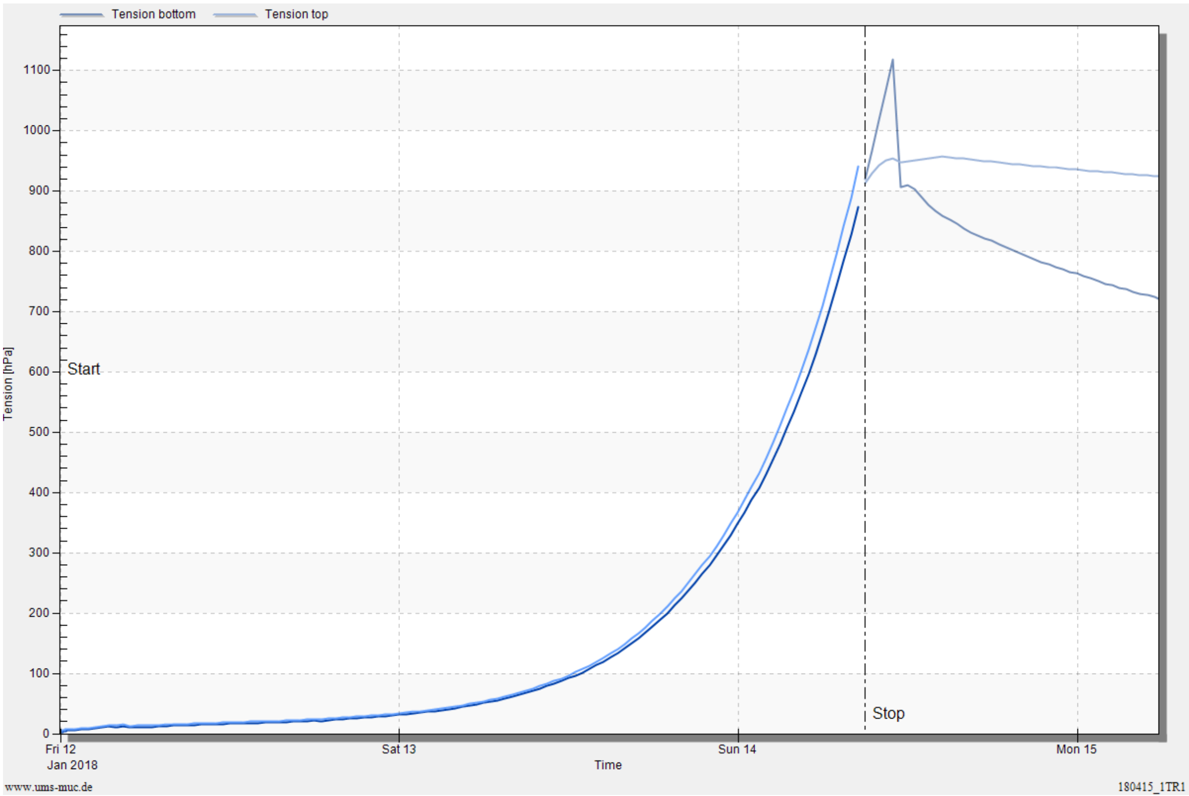
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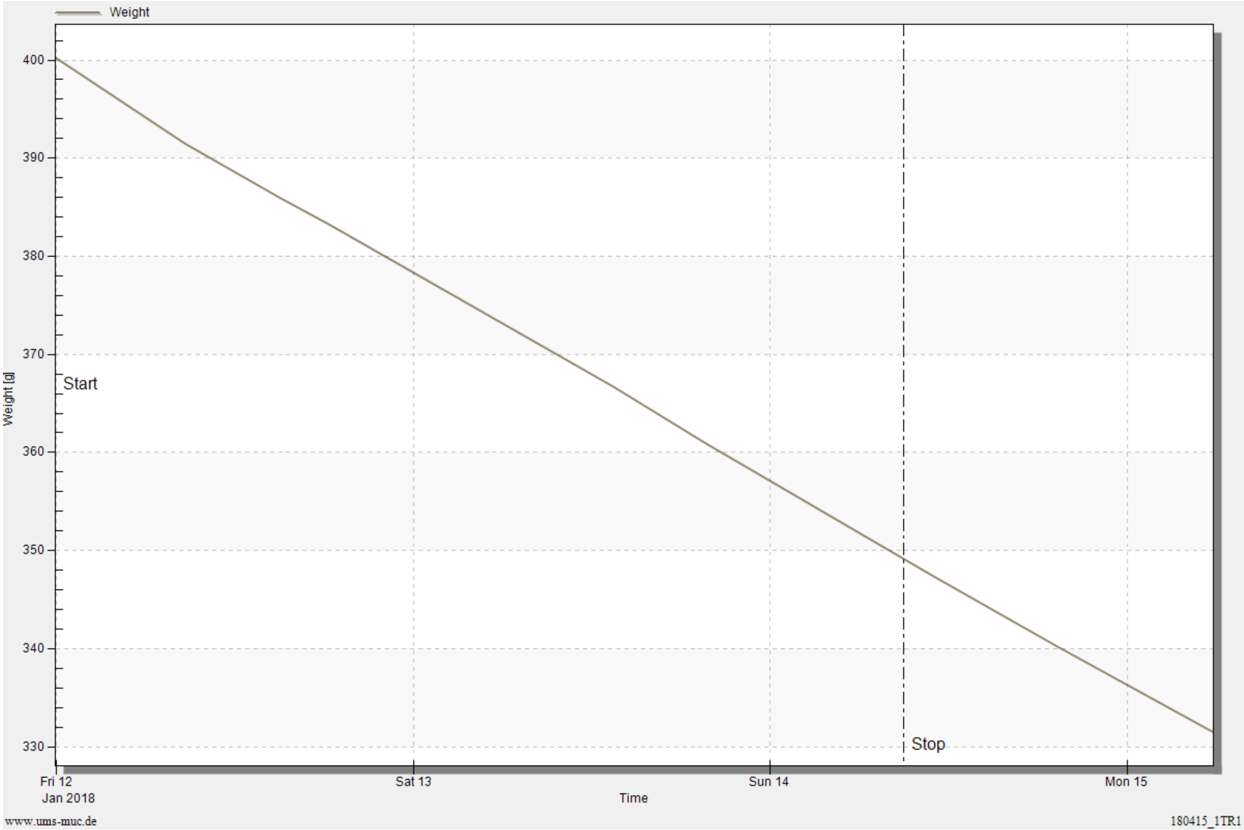
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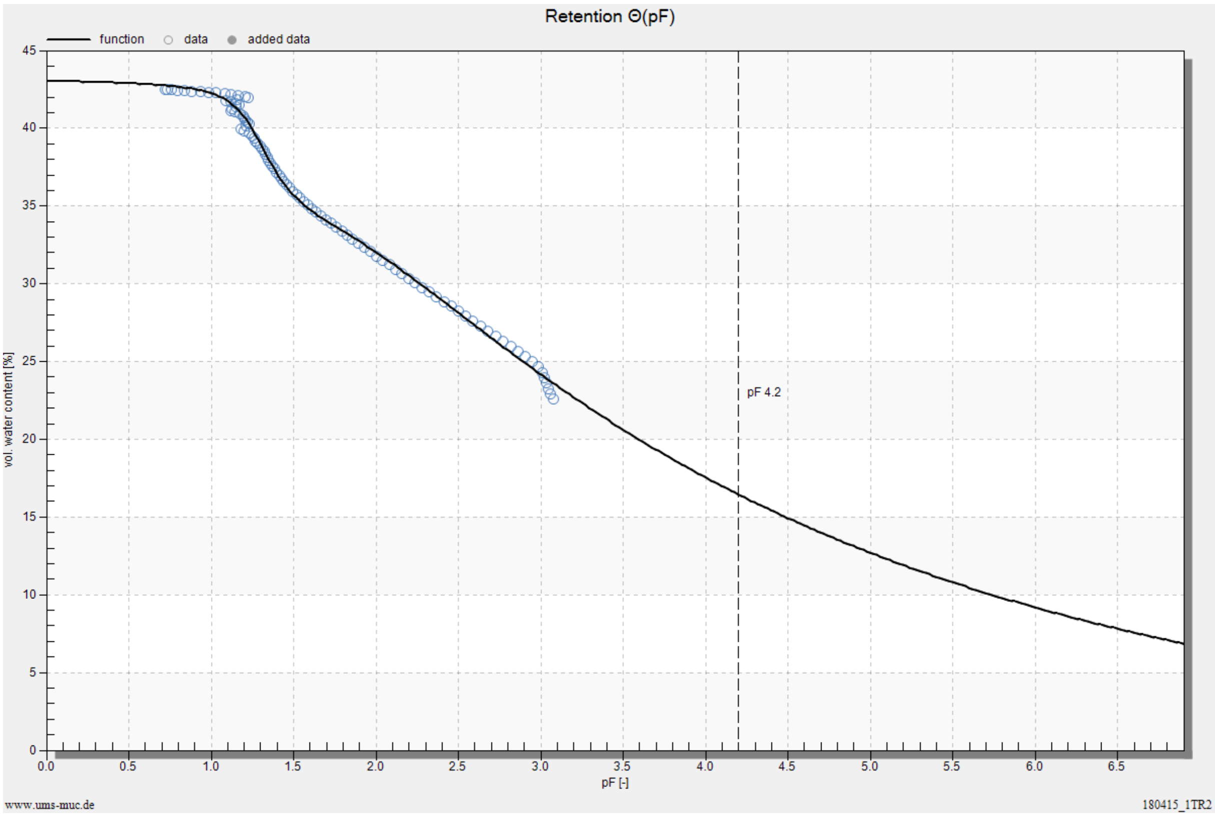
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www.ums-muc.de
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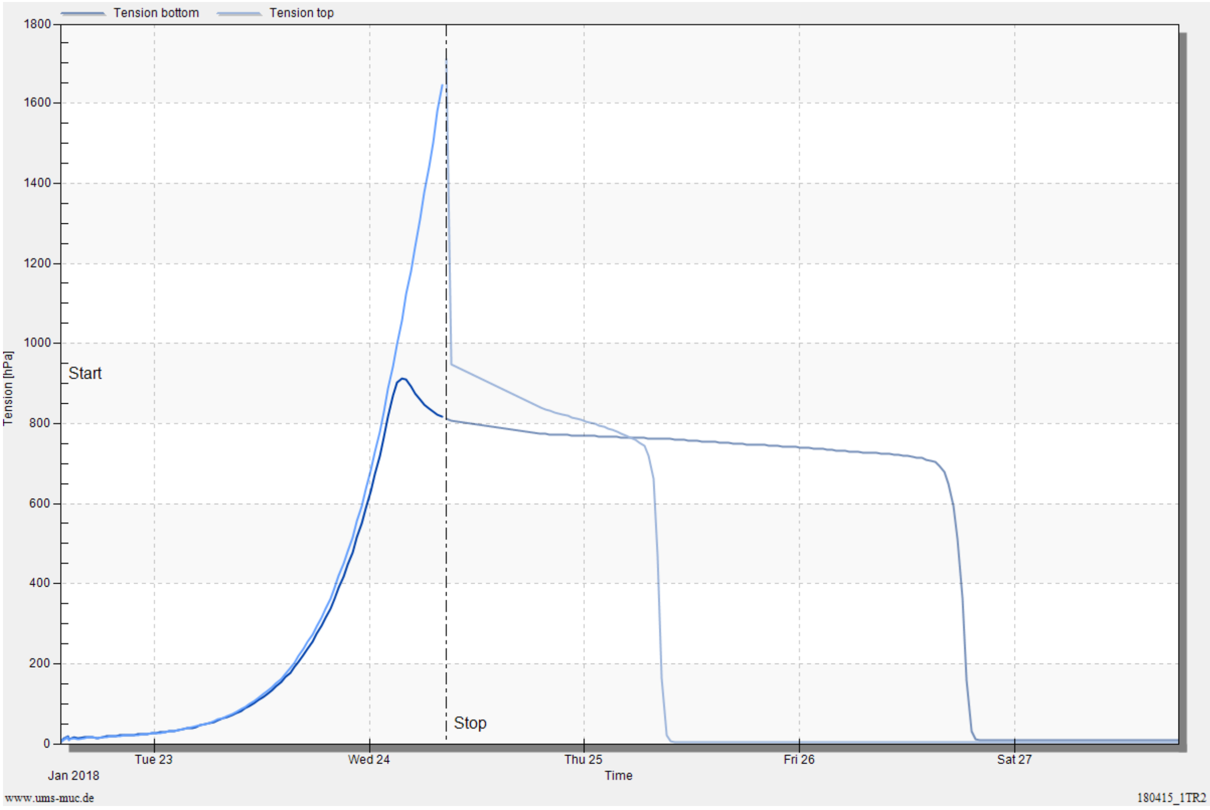
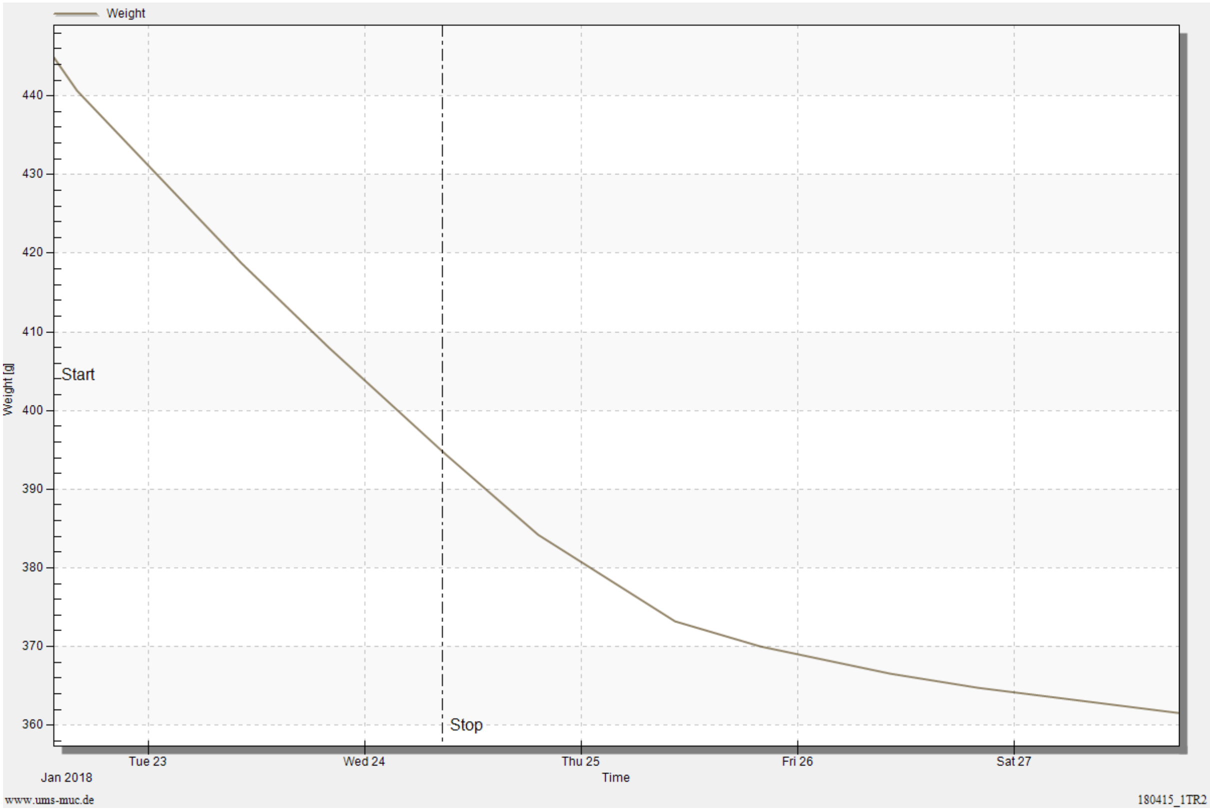
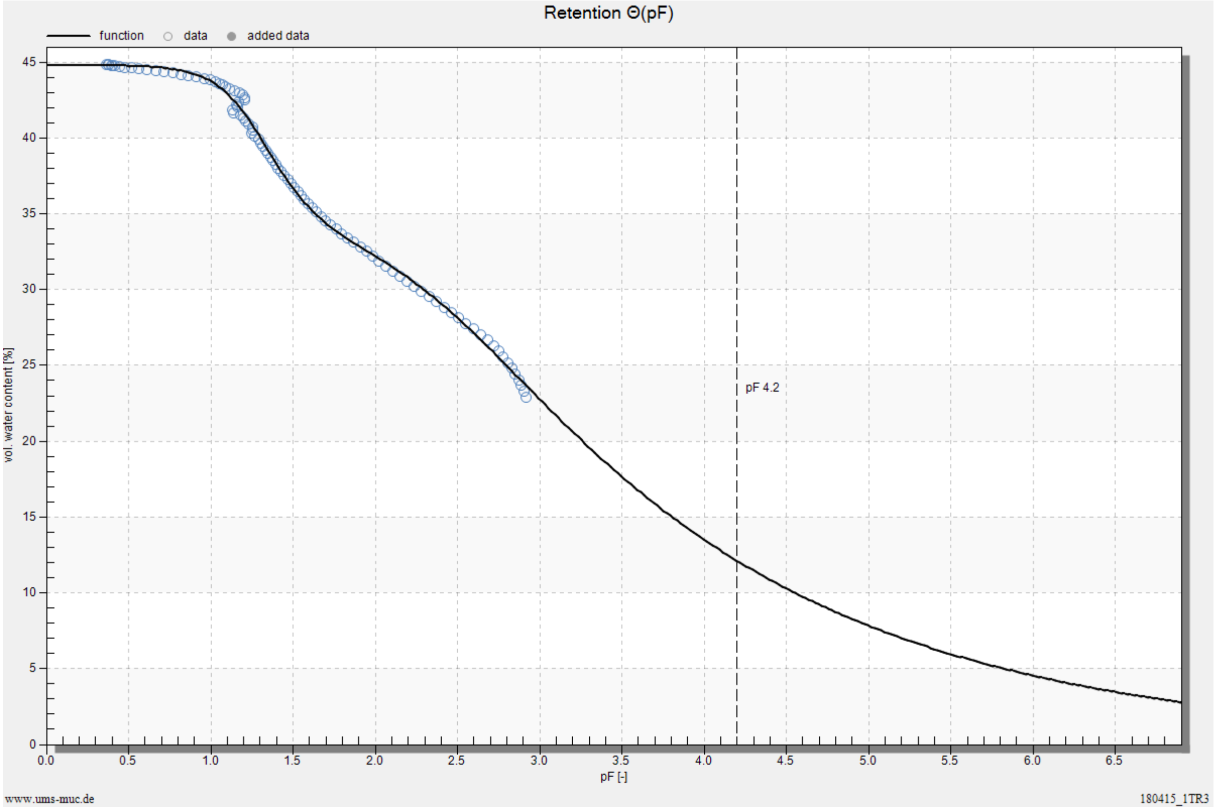
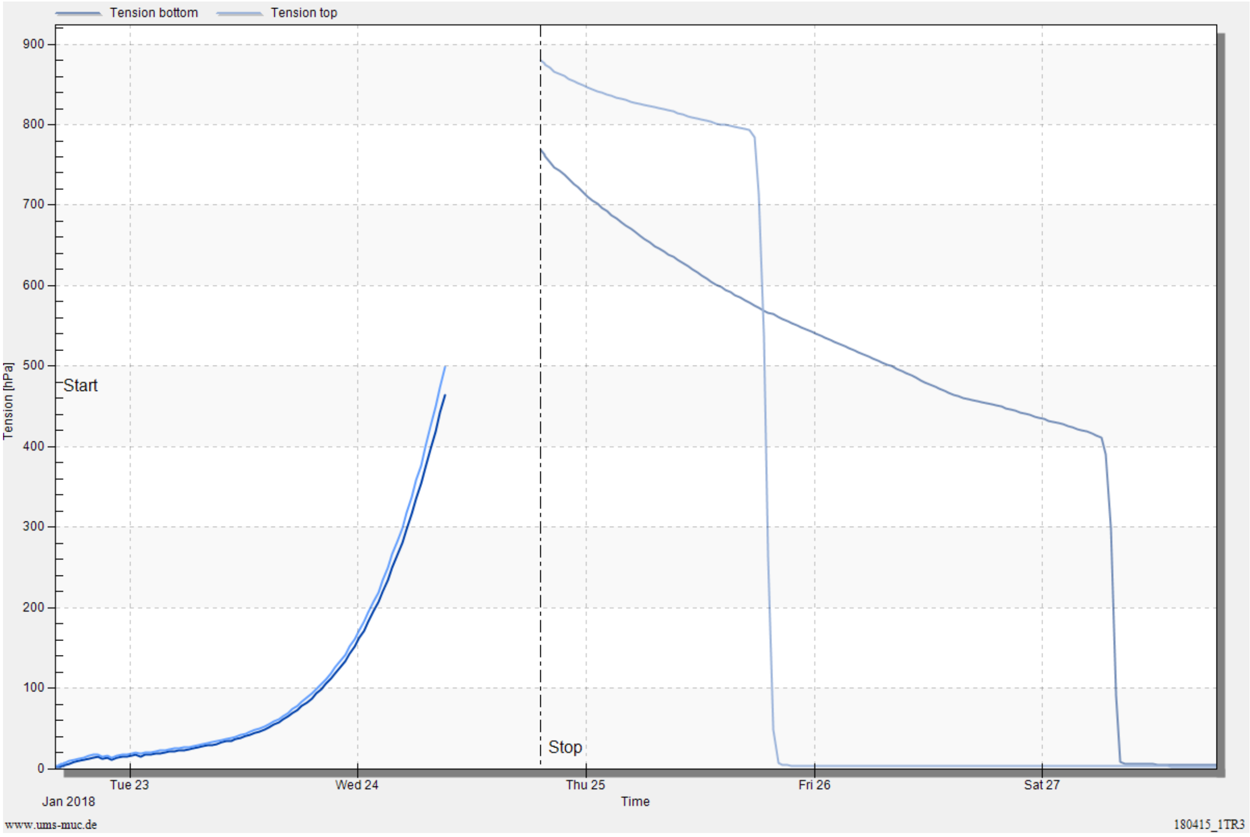
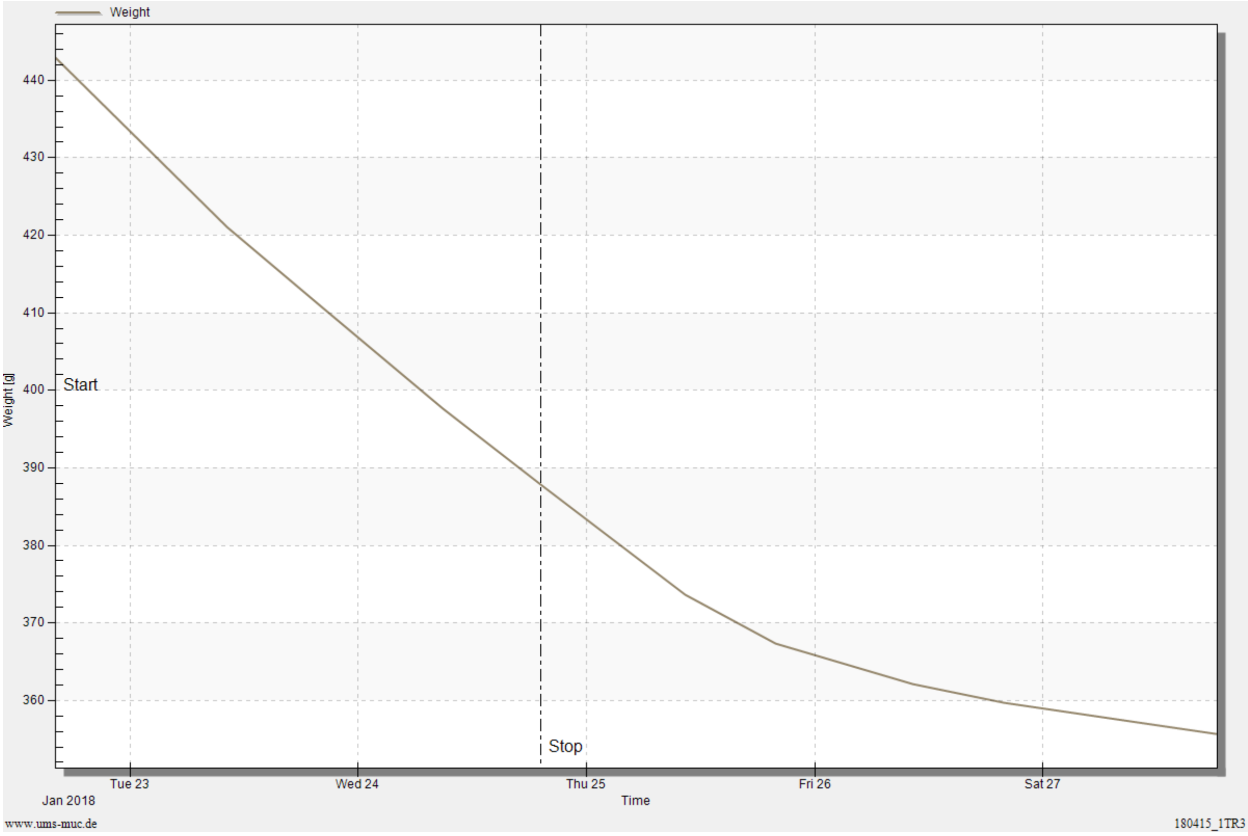

Tension bottom
Tension top
1800
1600
1400
1200
1000
800
600
400
200
0
Tension [hPa]
Start
Stop
Tue 23
Wed 24
Thu 25
Fri 26
Sat 27
Jan 2018
Time
www.ums-muc.de
180415_1TR2


Weight
440
430
420
410
400
390
380
370
360
Weight [g]
Start
Stop
Tue 23
Wed 24
Thu 25
Fri 26
Sat 27
Jan 2018
Time
www.ums-muc.de
180415_1TR2

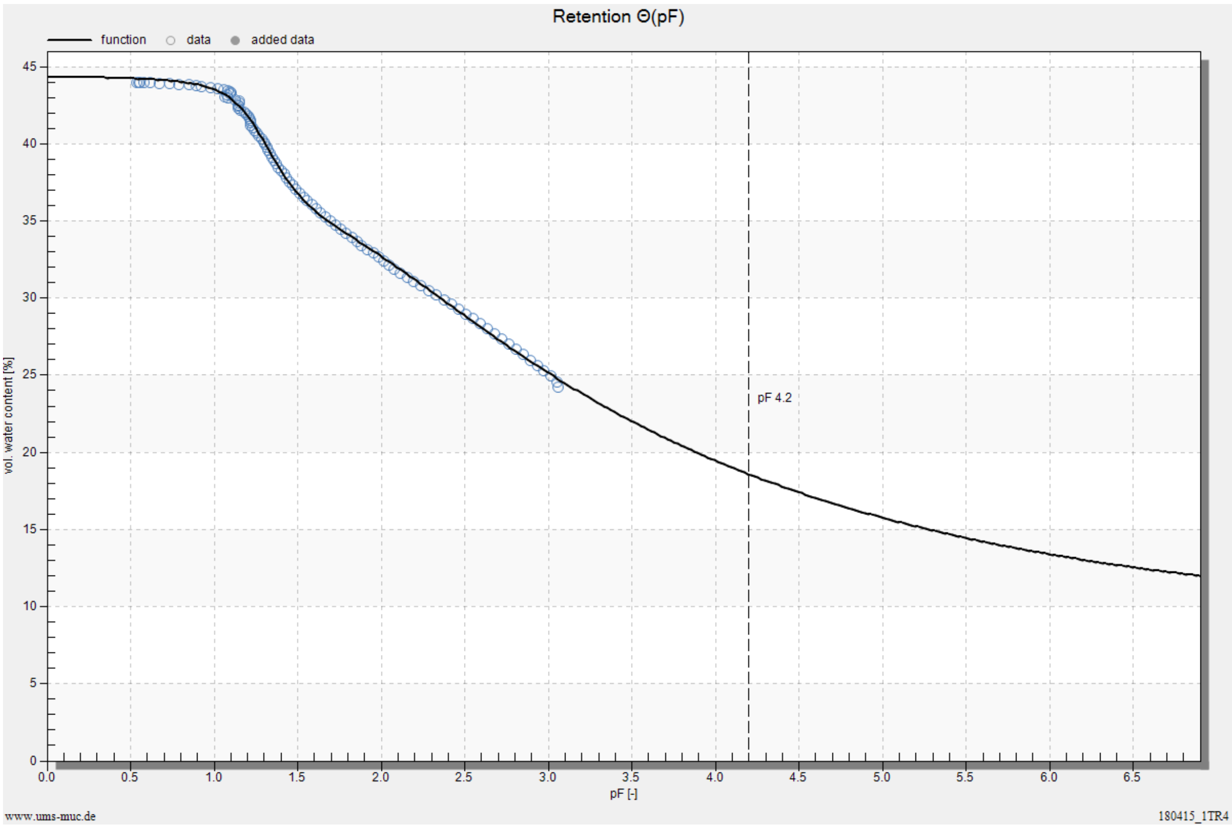
1TR3

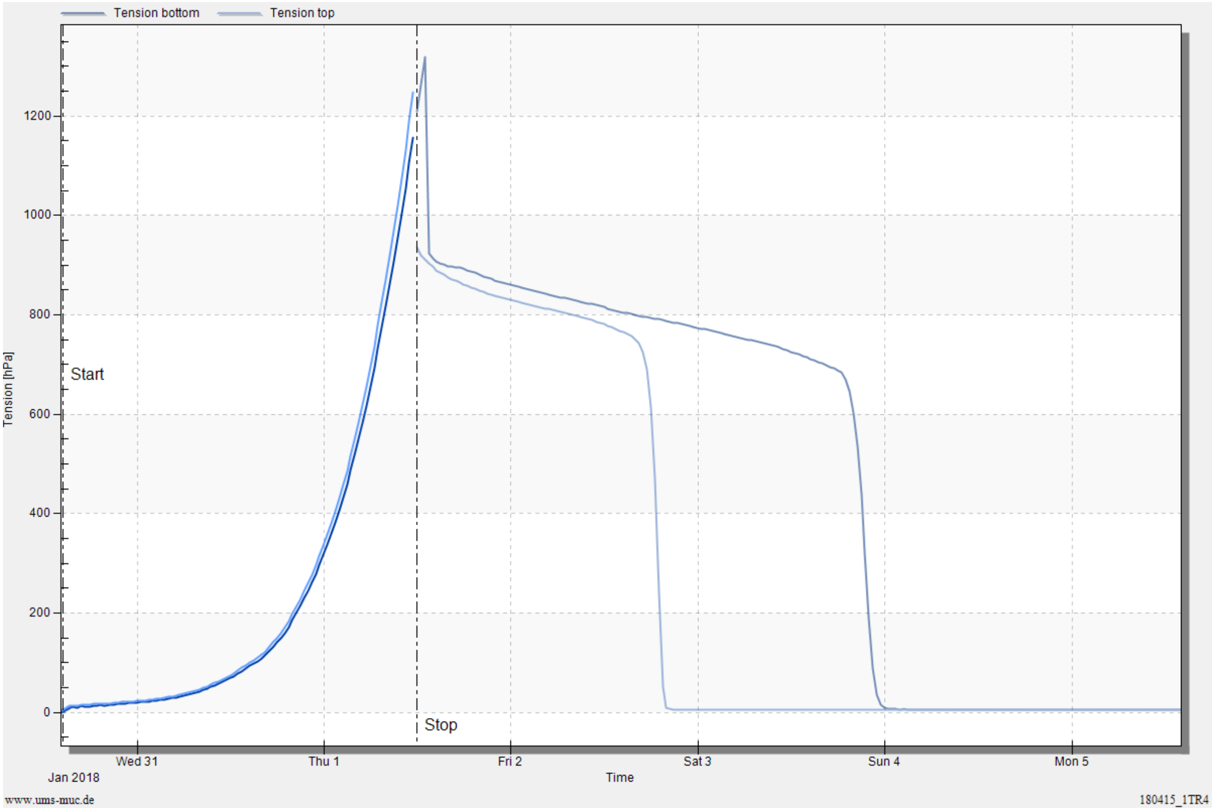

Retention Θ(pF)
function
data
added data
vol. water content [%]
pF [-]
pF 4.2
www.ums-muc.de
180415_1TR3


Tension bottom
Tension top
Tension [hPa]
Start
Stop
Tue 23
Wed 24
Thu 25
Fri 26
Sat 27
Jan 2018
Time
www.ums-muc.de
180415_1TR3

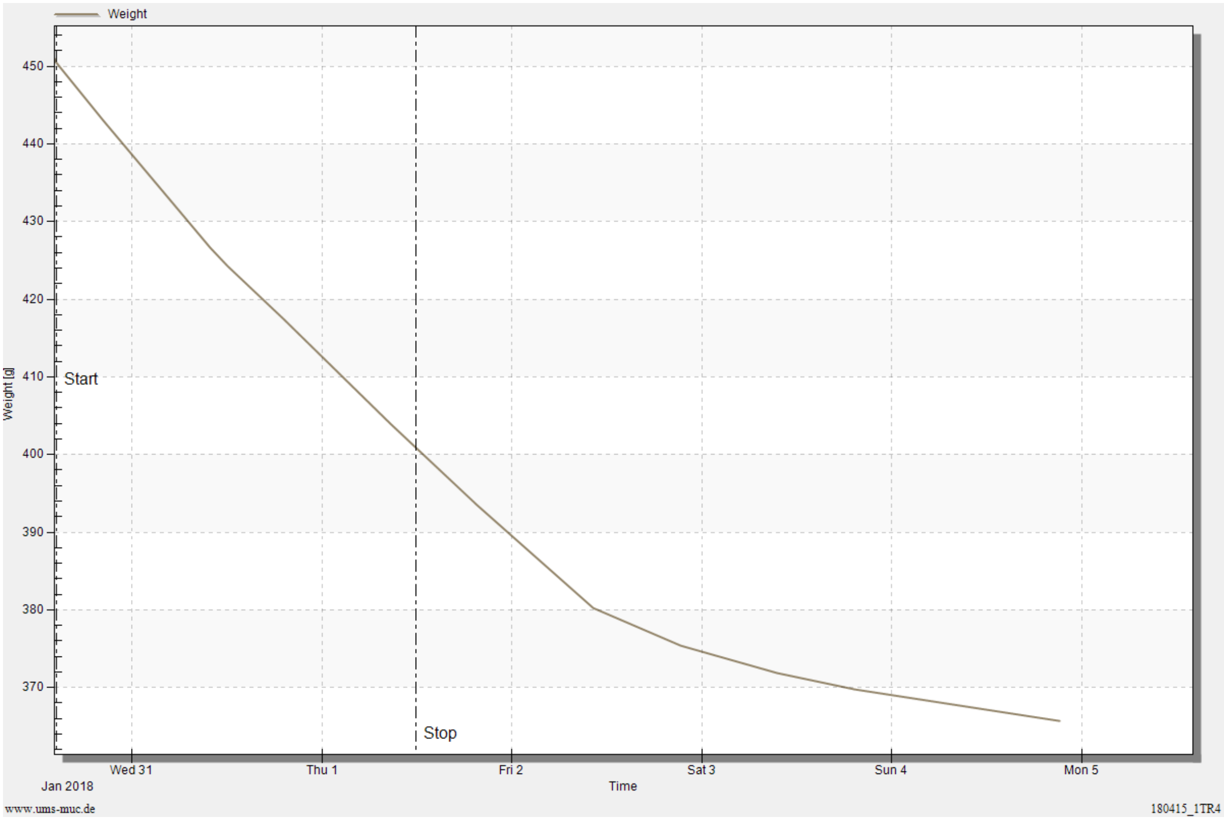

Weight
Weight [g]
440
430
420
410
400
390
380
370
360
Start
Stop
Tue 23
Wed 24
Thu 25
Fri 26
Sat 27
Jan 2018
Time
www.ums-muc.de
180415_1TR3

1TR4


Retention Θ(pF)
function
data
added data
vol. water content [%]
45
40
35
30
25
20
15
10
5
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
pF [-]
pF 4.2
www.ums-muc.de
180415_1TR4

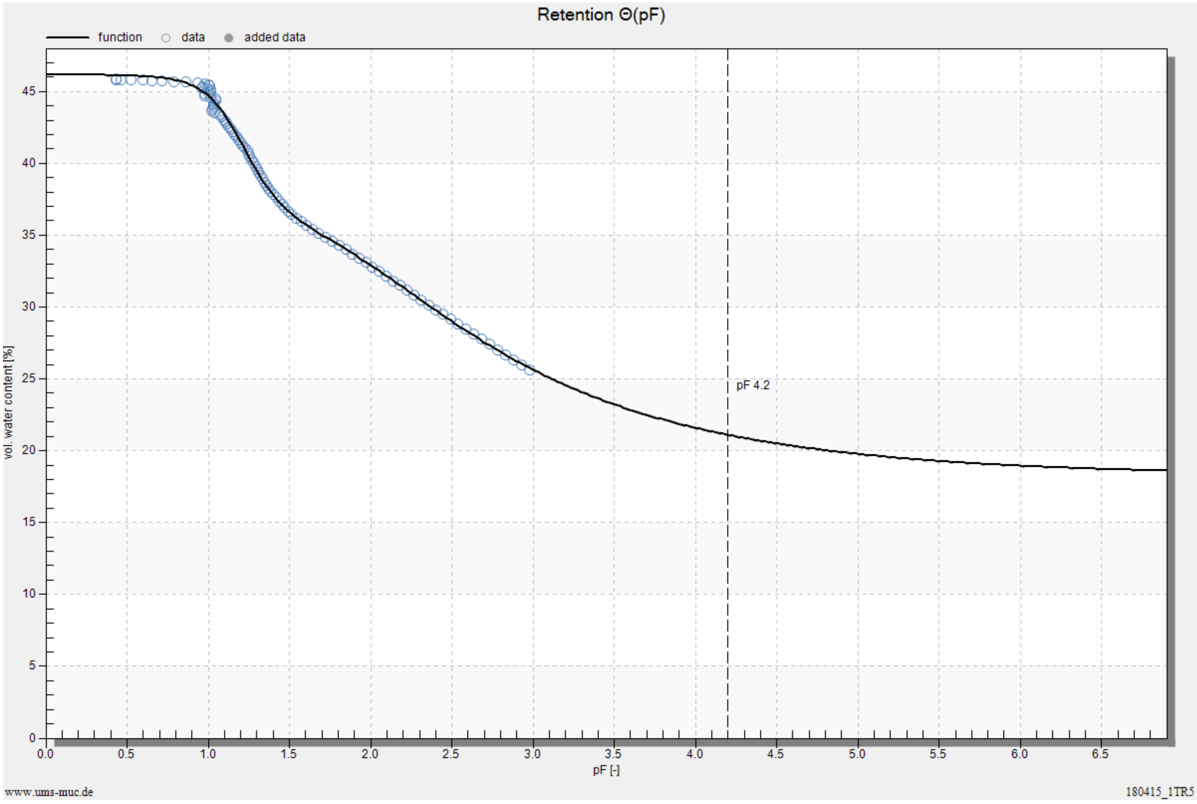


Tension bottom
Tension top
1200
1000
800
600
400
200
0
Tension [hPa]
Start
Stop
Wed 31
Thu 1
Fri 2
Sat 3
Sun 4
Mon 5
Jan 2018
Time
www.ums-muc.de
180415_1TR4

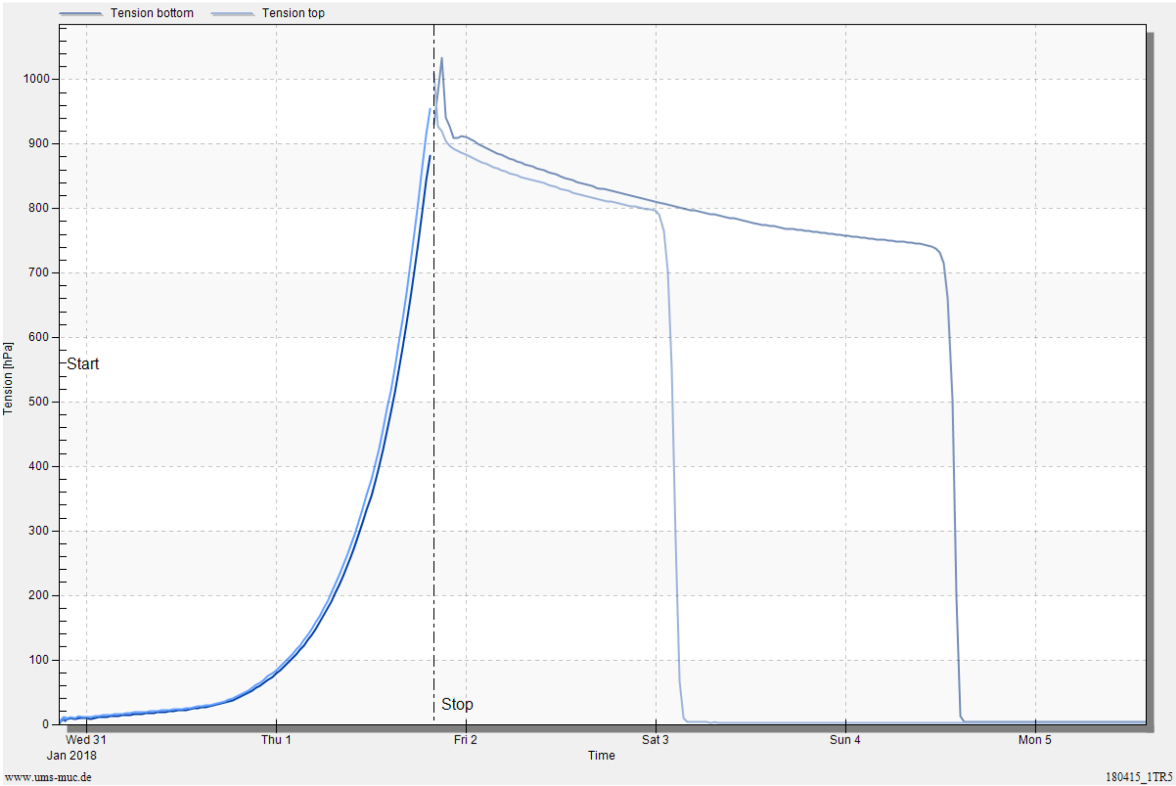


Weight
450
440
430
420
410
400
390
380
370
Weight [g]
Start
Stop
Wed 31
Thu 1
Fri 2
Sat 3
Sun 4
Mon 5
Jan 2018
Time
www.ums-muc.de
180415_1TR4

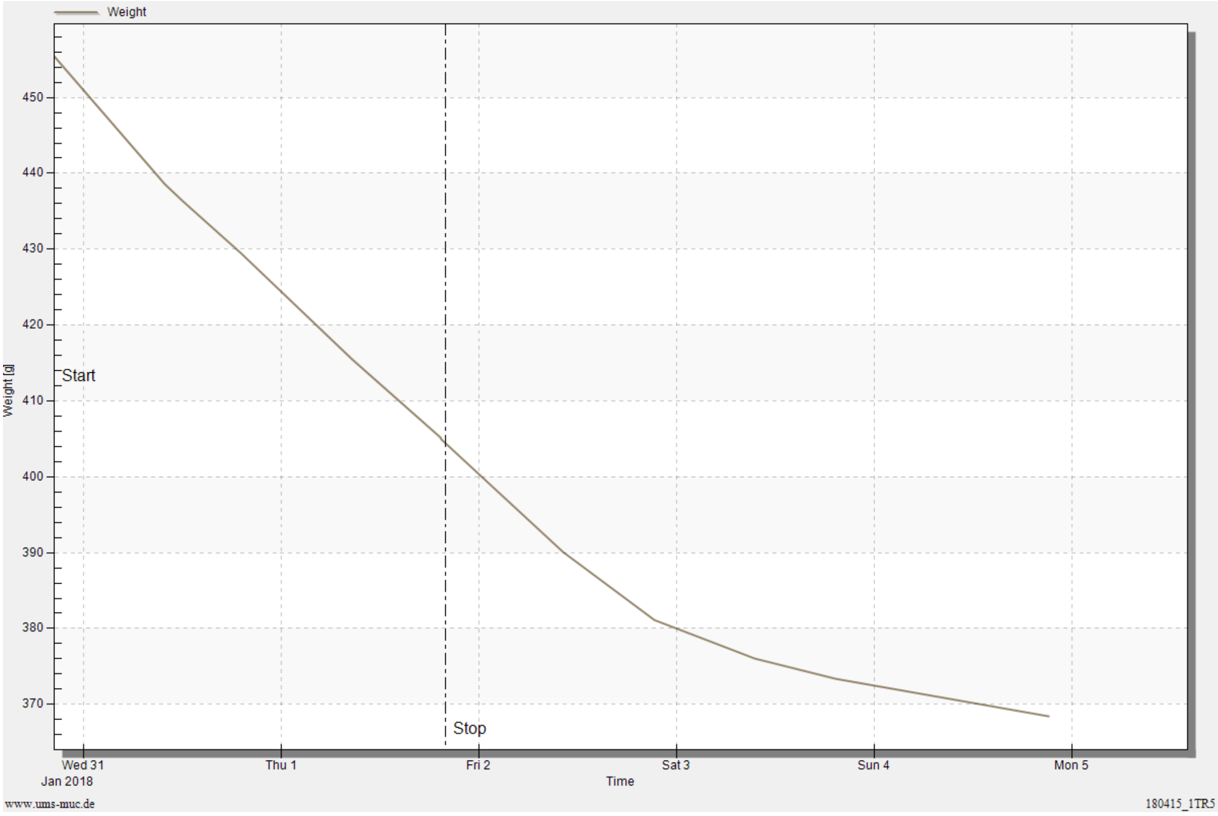
1TR5



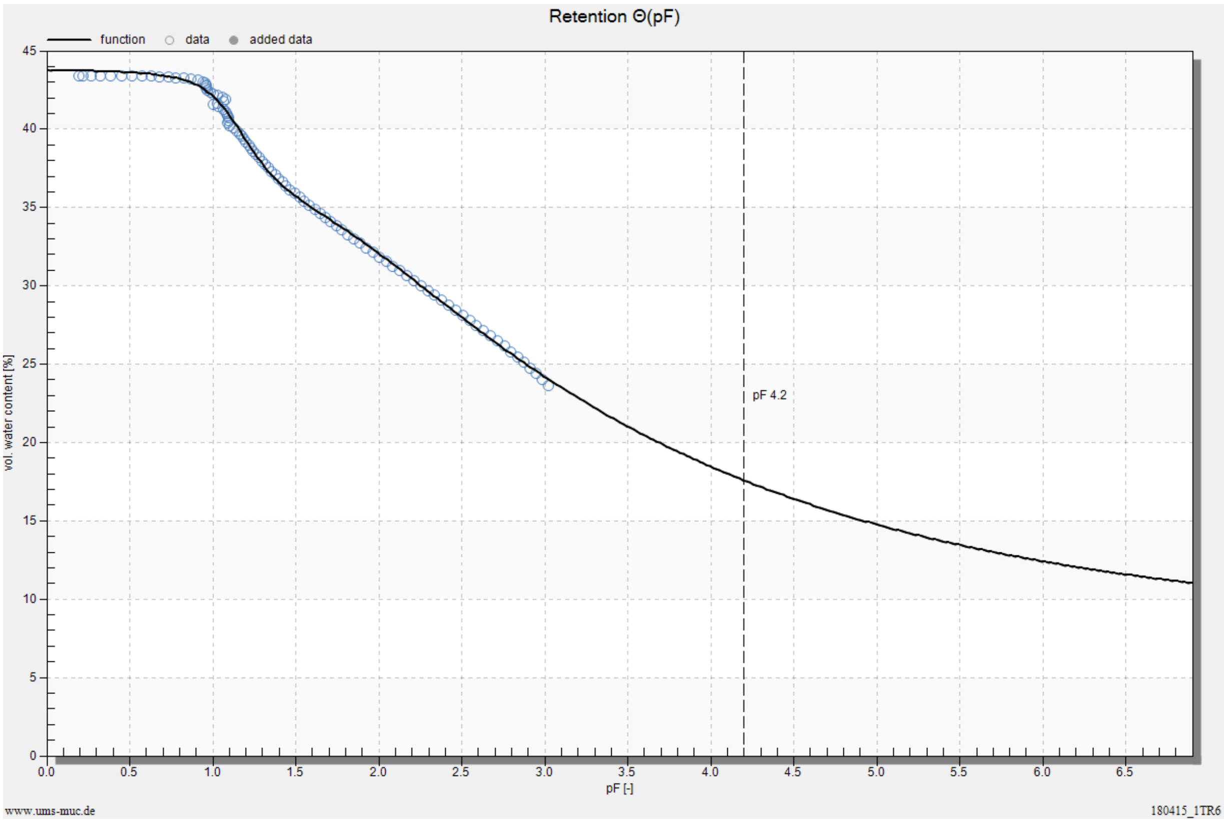
Retention Θ(pF)
function
data
added data
vol. water content [%]
pF [-]
pF 4.2
www.ums-muc.de
180415_1TR5

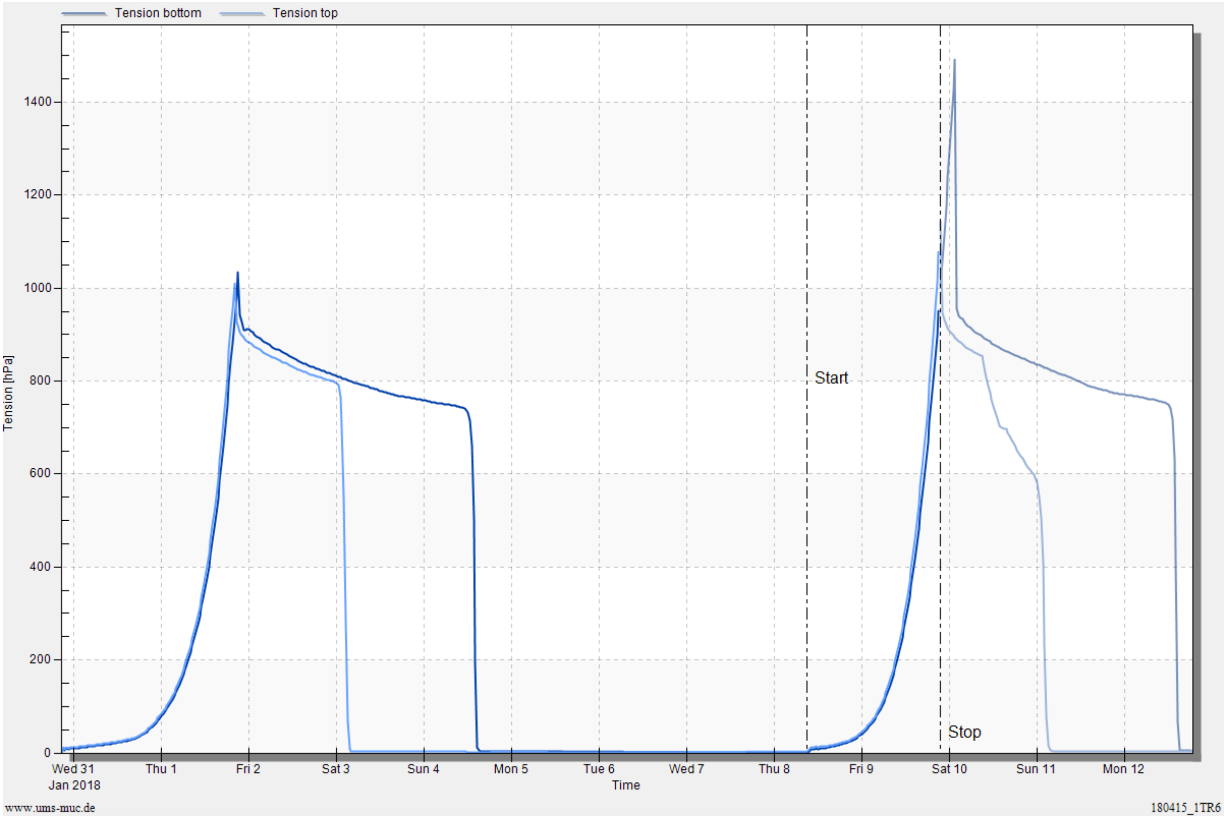


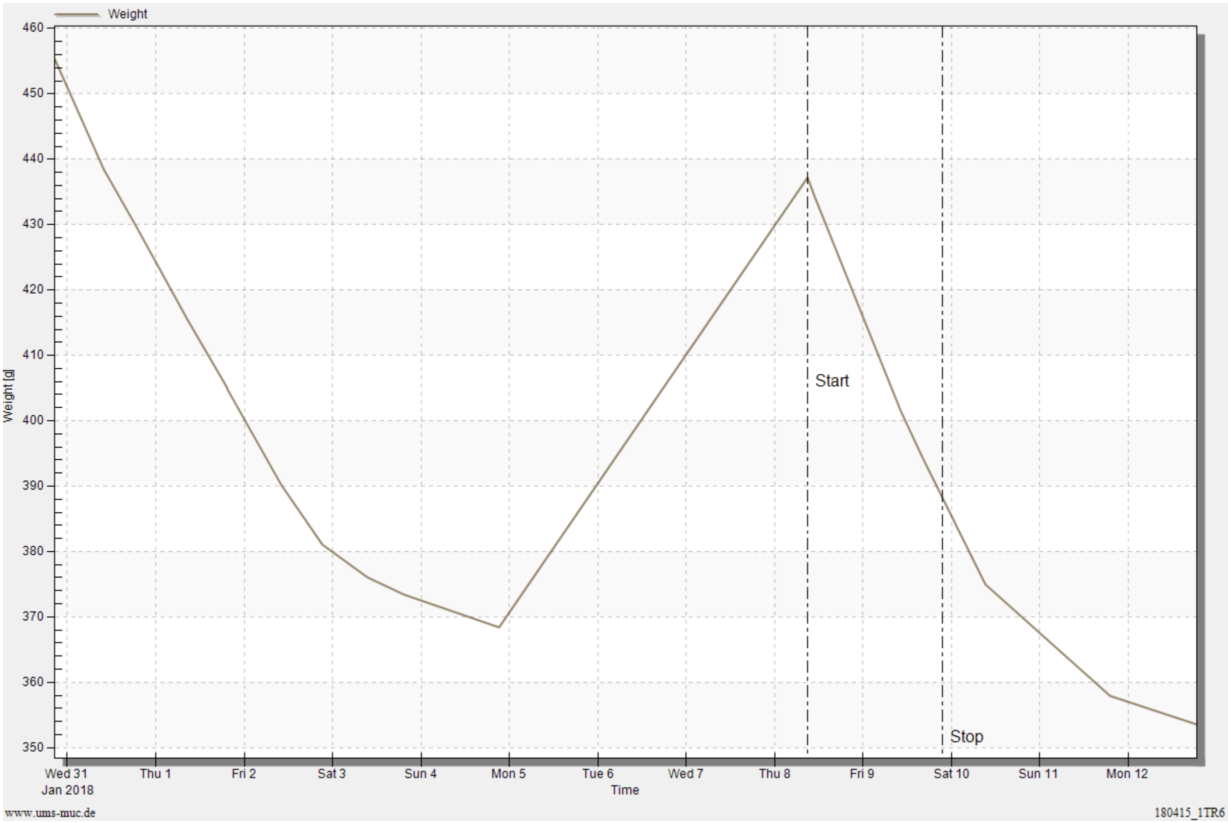
Tension bottom
Tension top
Tension [hPa]
Start
Stop
Wed 31
Jan 2018
Thu 1
Fri 2
Sat 3
Sun 4
Mon 5
Time
www.ums-muc.de
180415_1TR5


Weight
450
440
430
420
410
400
390
380
370
Weight [g]
Start
Stop
Wed 31
Jan 2018
Thu 1
Fri 2
Sat 3
Sun 4
Mon 5
Time
www.ums-muc.de
180415_1TR5

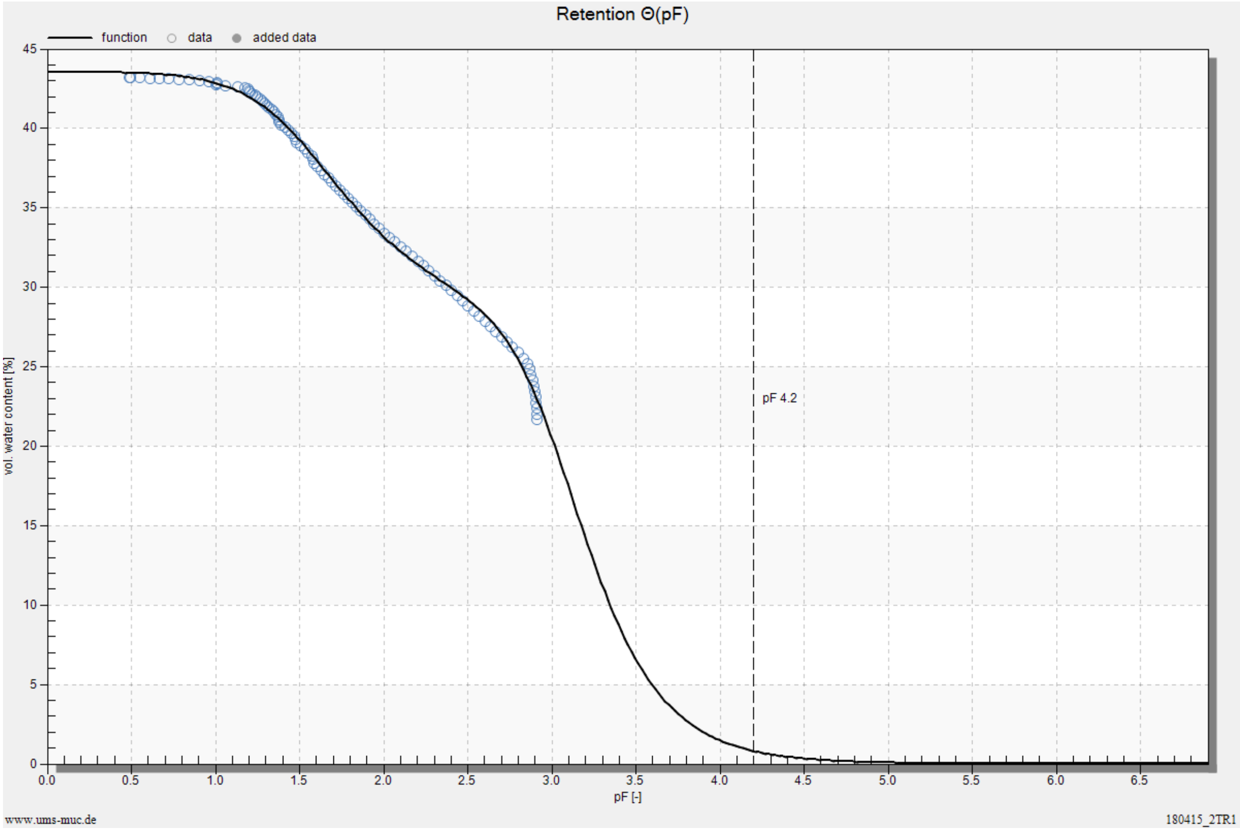
1TR6

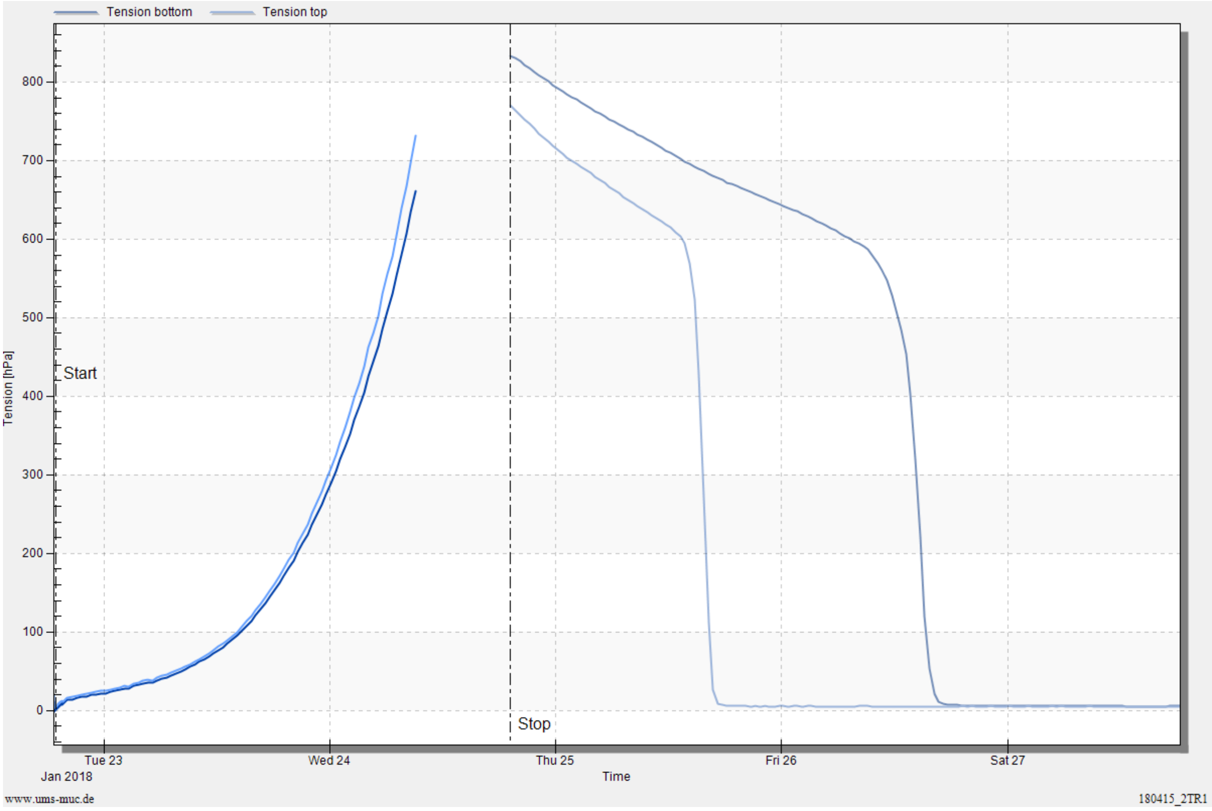

Retention Θ(pF)
function
data
added data
45
40
35
30
25
20
15
10
5
0
vol. water content [%]
pF 4.2
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
pF [-]
www.ums-muc.de
180415_1TR6

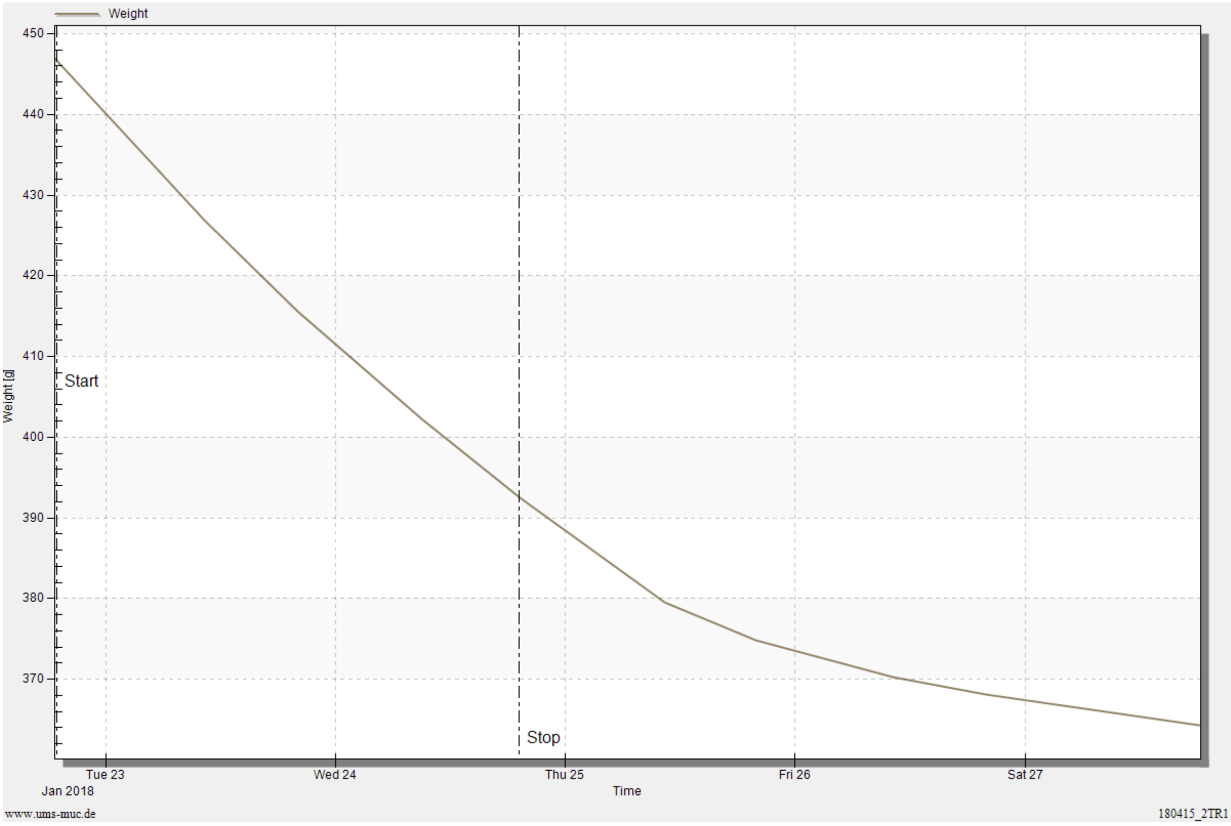

Tension bottom
Tension top
Tension [hPa]
1400
1200
1000
800
600
400
200
0
Start
Stop
Wed 31
Jan 2018
Thu 1
Fri 2
Sat 3
Sun 4
Mon 5
Tue 6
Wed 7
Thu 8
Fri 9
Sat 10
Sun 11
Mon 12
Time
www.ums-muc.de
180415_1TR6


Weight
Weight [g]
460
450
440
430
420
410
400
390
380
370
360
350
Start
Stop
Wed 31
Jan 2018
Thu 1
Fri 2
Sat 3
Sun 4
Mon 5
Tue 6
Wed 7
Thu 8
Fri 9
Sat 10
Sun 11
Mon 12
Time
www.ums-muc.de
180415_1TR6

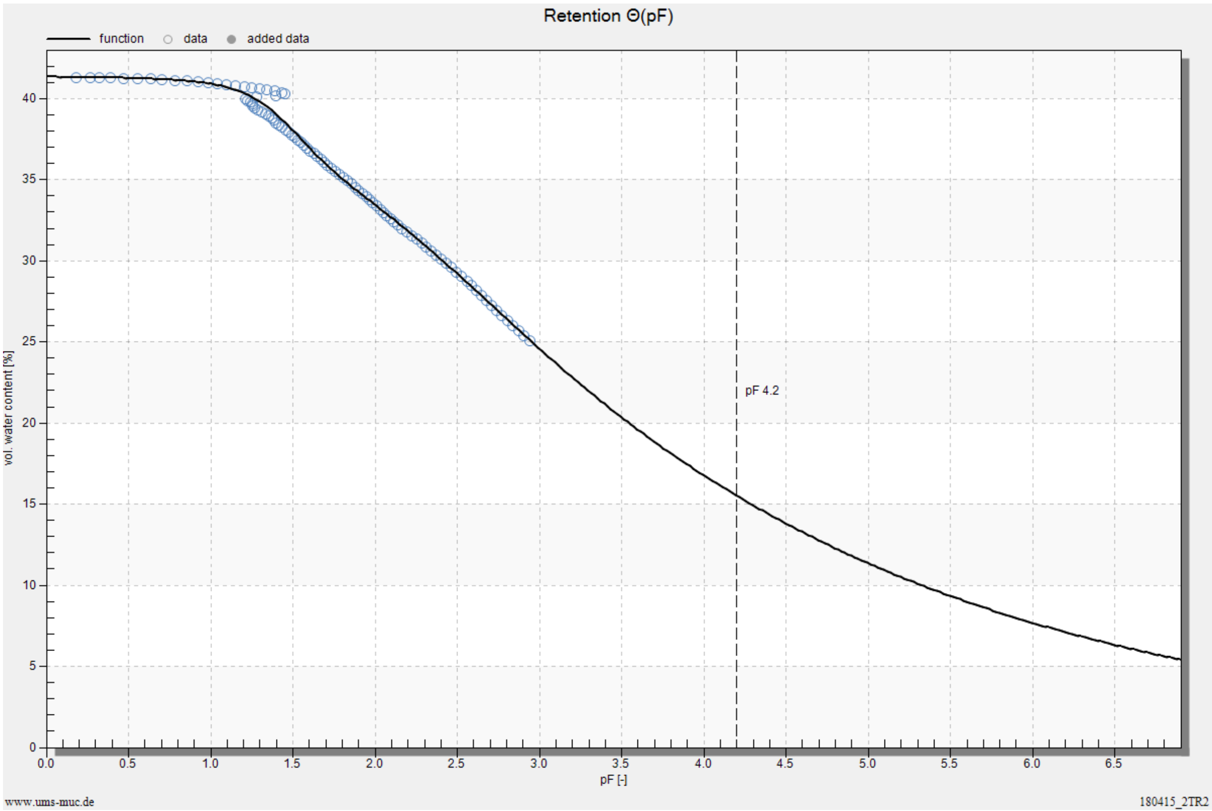
2TR1

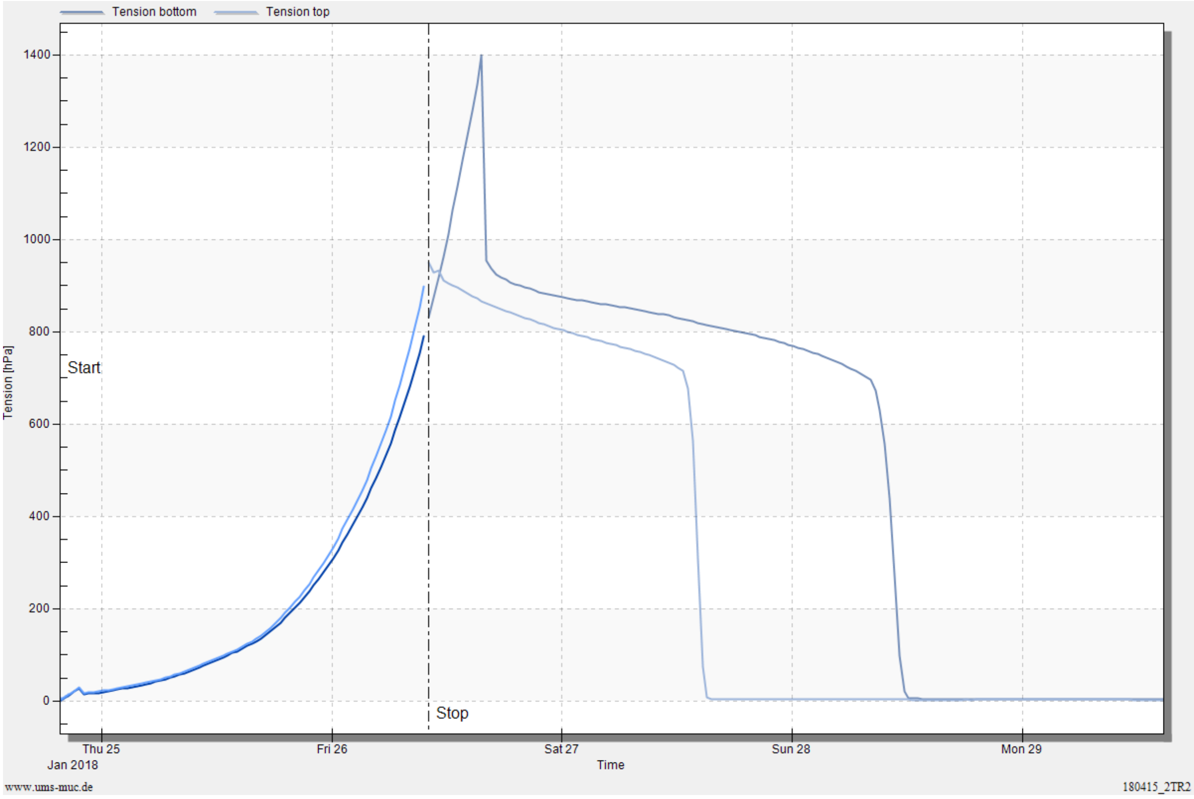

Retention Θ(pF)
function
data
added data
vol. water content [%]
pF [-]
pF 4.2
www.ums-muc.de
180415_2TR1

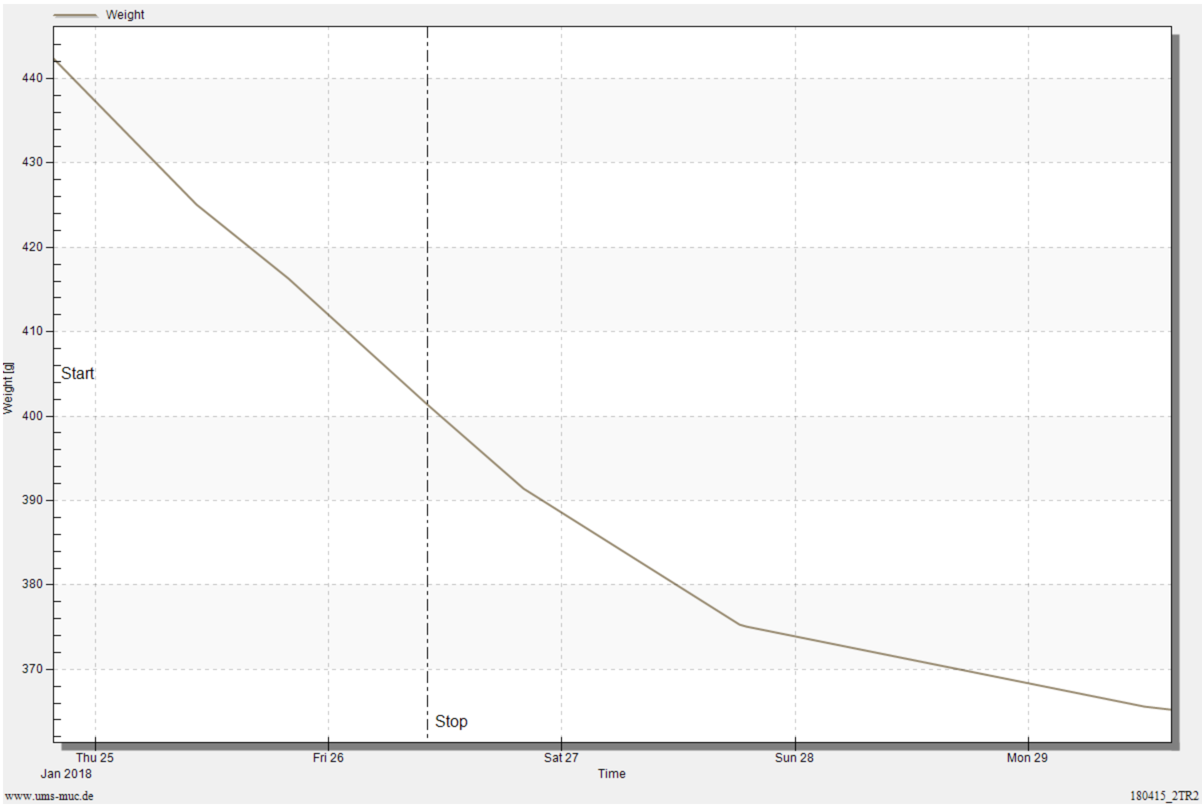

Tension bottom
Tension top
Tension [hPa]
Start
Stop
Tue 23
Wed 24
Thu 25
Fri 26
Sat 27
Jan 2018
Time
www.ums-muc.de
180415_2TR1


Weight
Weight [g]
Start
Stop
Tue 23
Jan 2018
Wed 24
Thu 25
Fri 26
Sat 27
Time
www.ums-muc.de
180415_2TR1

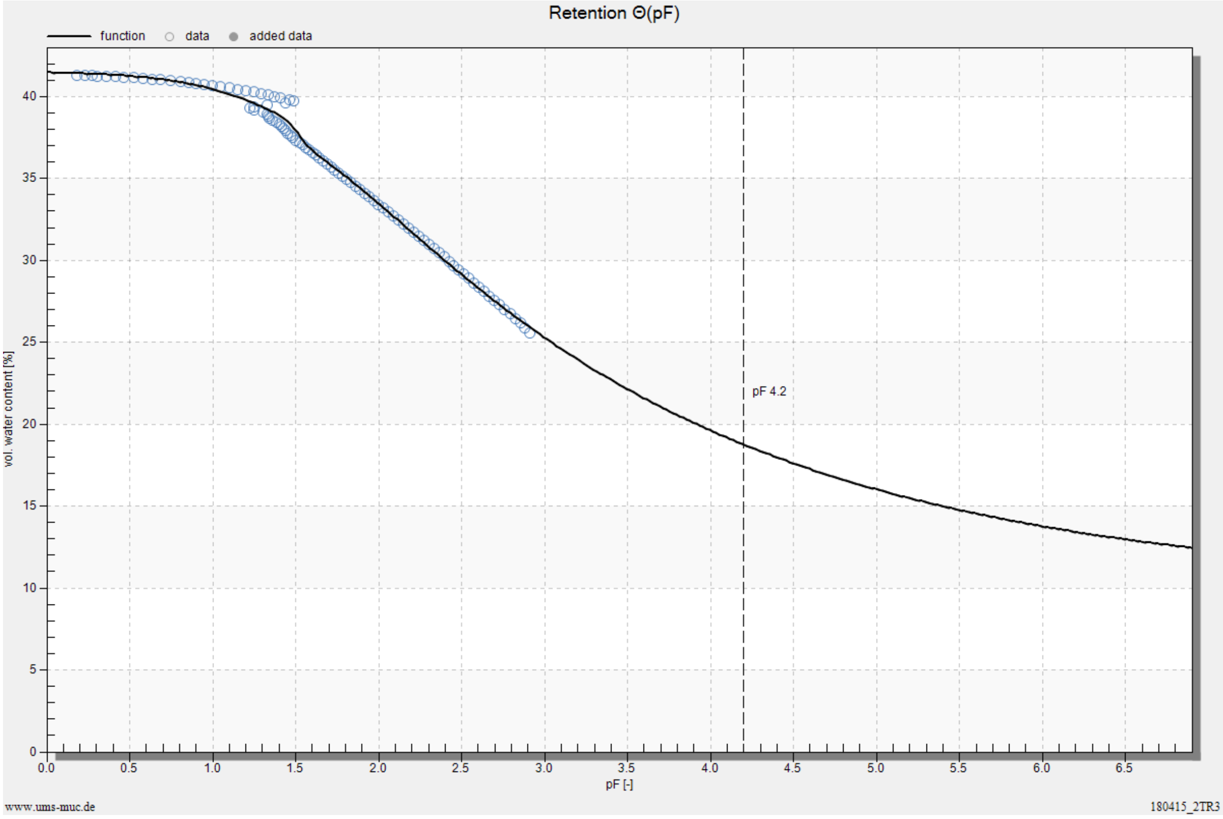
2TR2


Retention Θ(pF)
function
data
added data
vol. water content [%]
pF 4.2
pF [-]
www.ums-muc.de
180415_2TR2

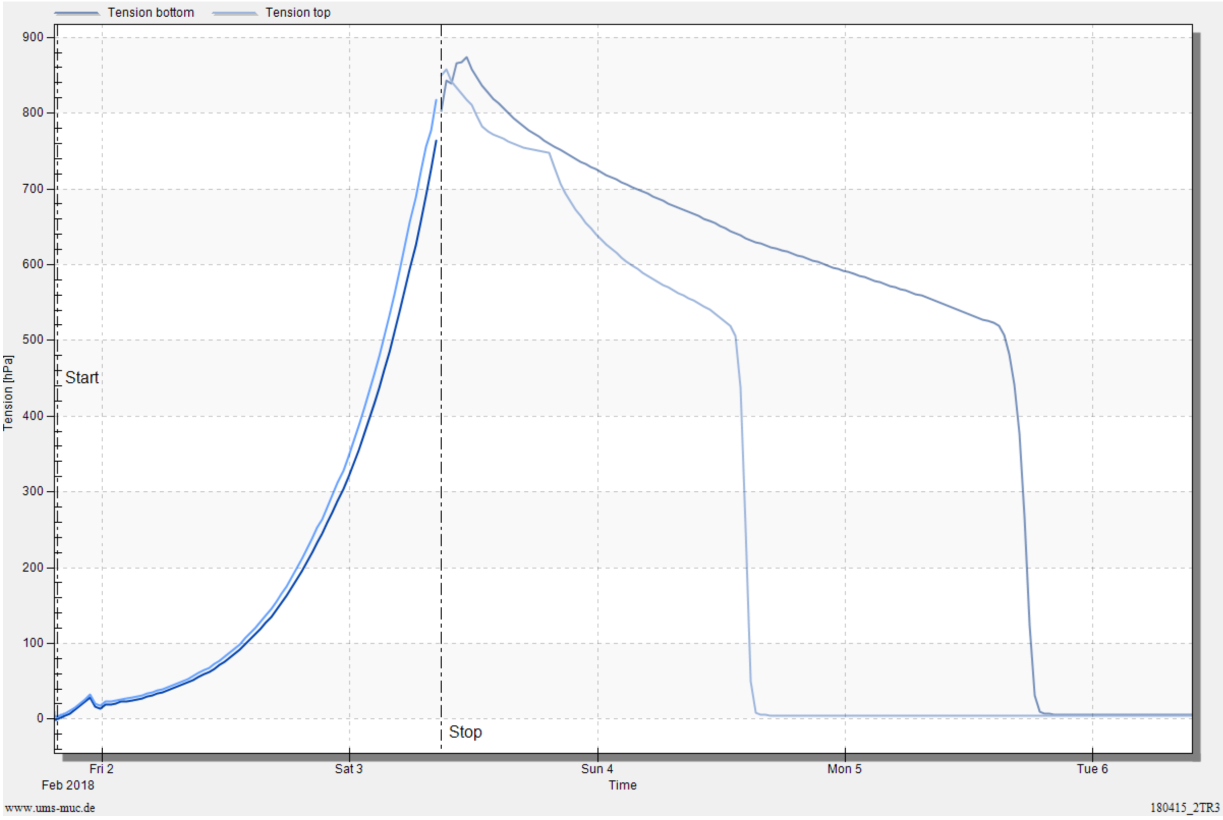

Tension bottom
Tension top
Tension [hPa]
1400
1200
1000
800
600
400
200
0
Start
Stop
Thu 25
Jan 2018
Fri 26
Sat 27
Sun 28
Mon 29
Time
www.ums-muc.de
180415_2TR2


Weight
Weight [g]
440
430
420
410
400
390
380
370
Start
Stop
Thu 25
Jan 2018
Fri 26
Sat 27
Sun 28
Mon 29
Time
www.ums-muc.de
180415_2TR2

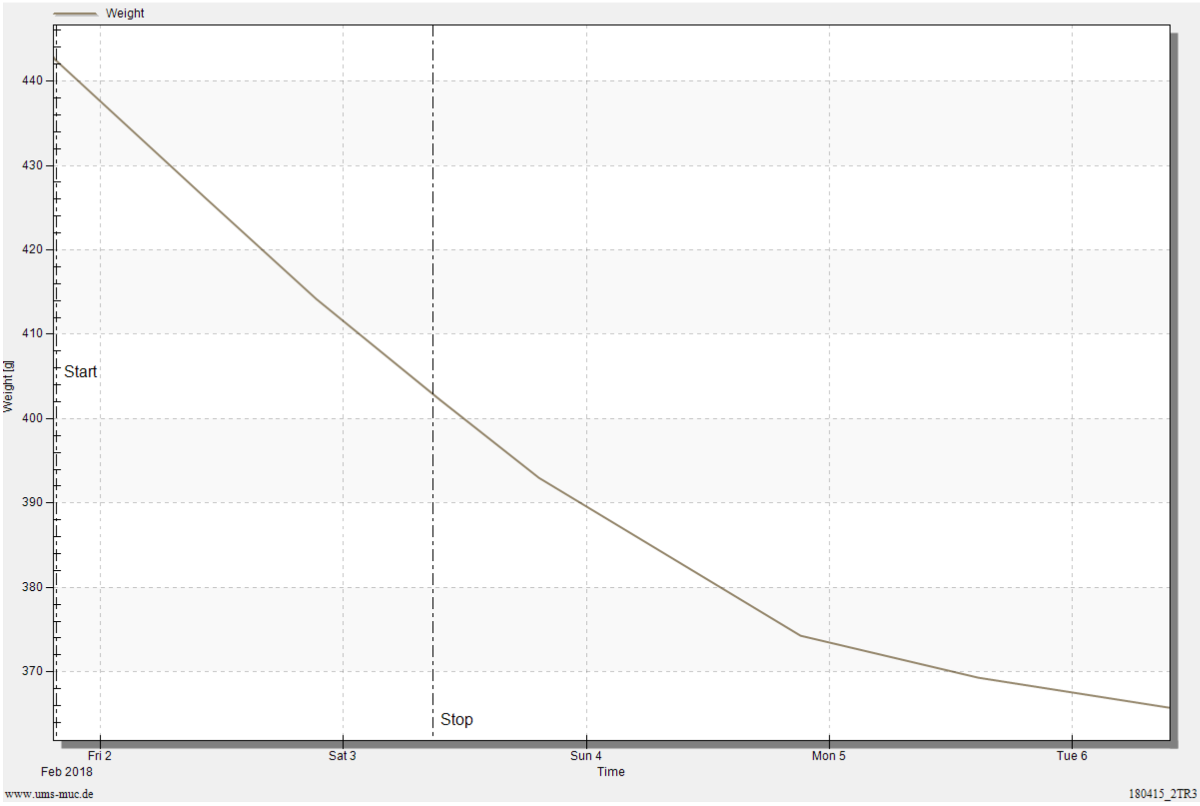
2TR3



Retention Θ(pF)
function
data
added data
vol. water content [%]
pF [-]
pF 4.2
0
5
10
15
20
25
30
35
40
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
www.ums-muc.de
180415_2TR3

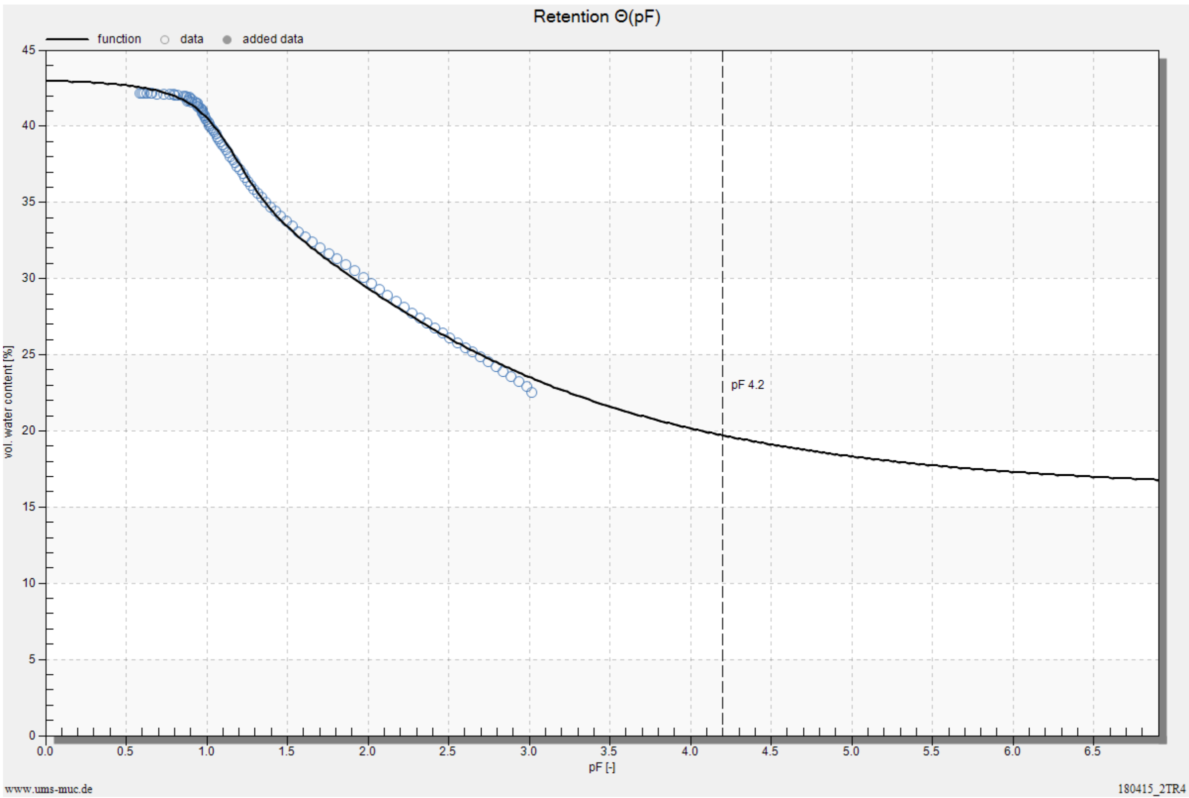


Tension bottom
Tension top
Tension [hPa]
Start
Stop
0
100
200
300
400
500
600
700
800
900
Fri 2
Feb 2018
Sat 3
Sun 4
Time
Mon 5
Tue 6
www.ums-muc.de
180415_2TR3

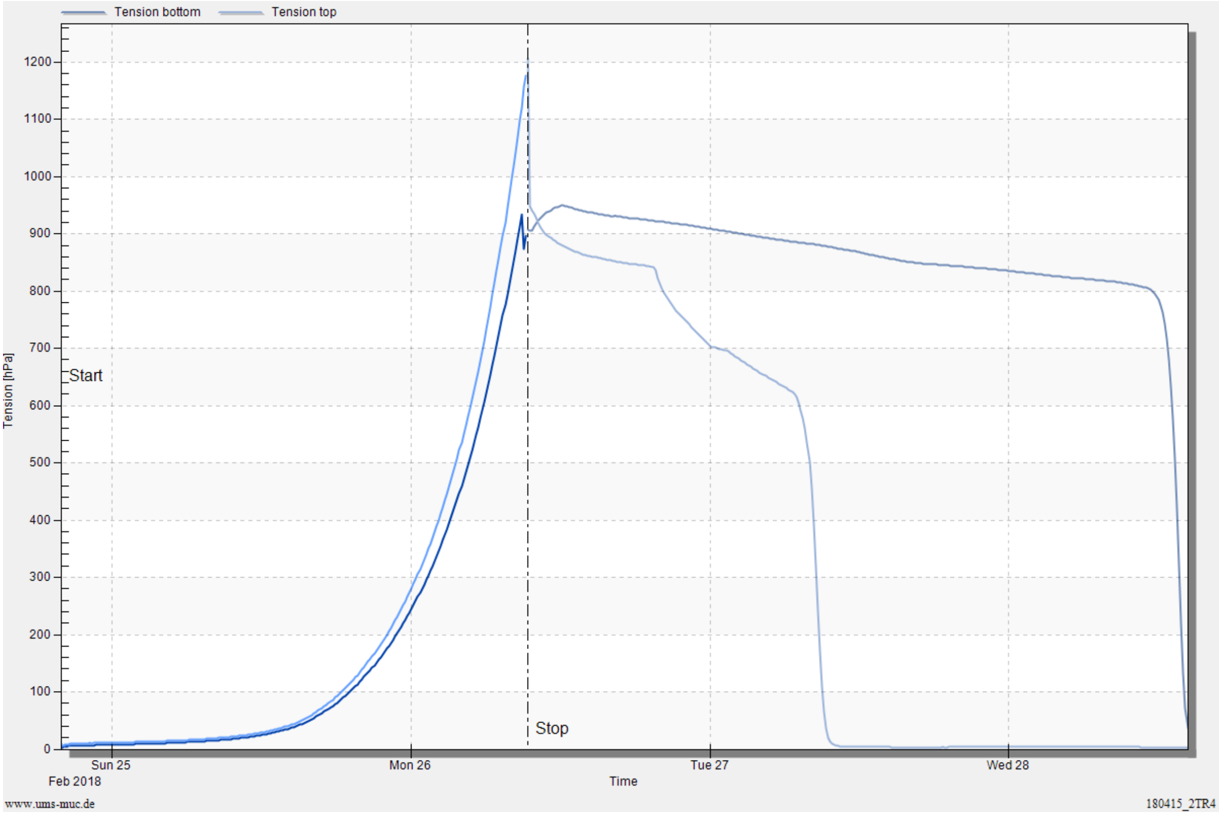


Weight
Weight [g]
440
430
420
410
400
390
380
370
Start
Stop
Fri 2
Sat 3
Sun 4
Mon 5
Tue 6
Feb 2018
Time
www.ums-muc.de
180415_2TR3

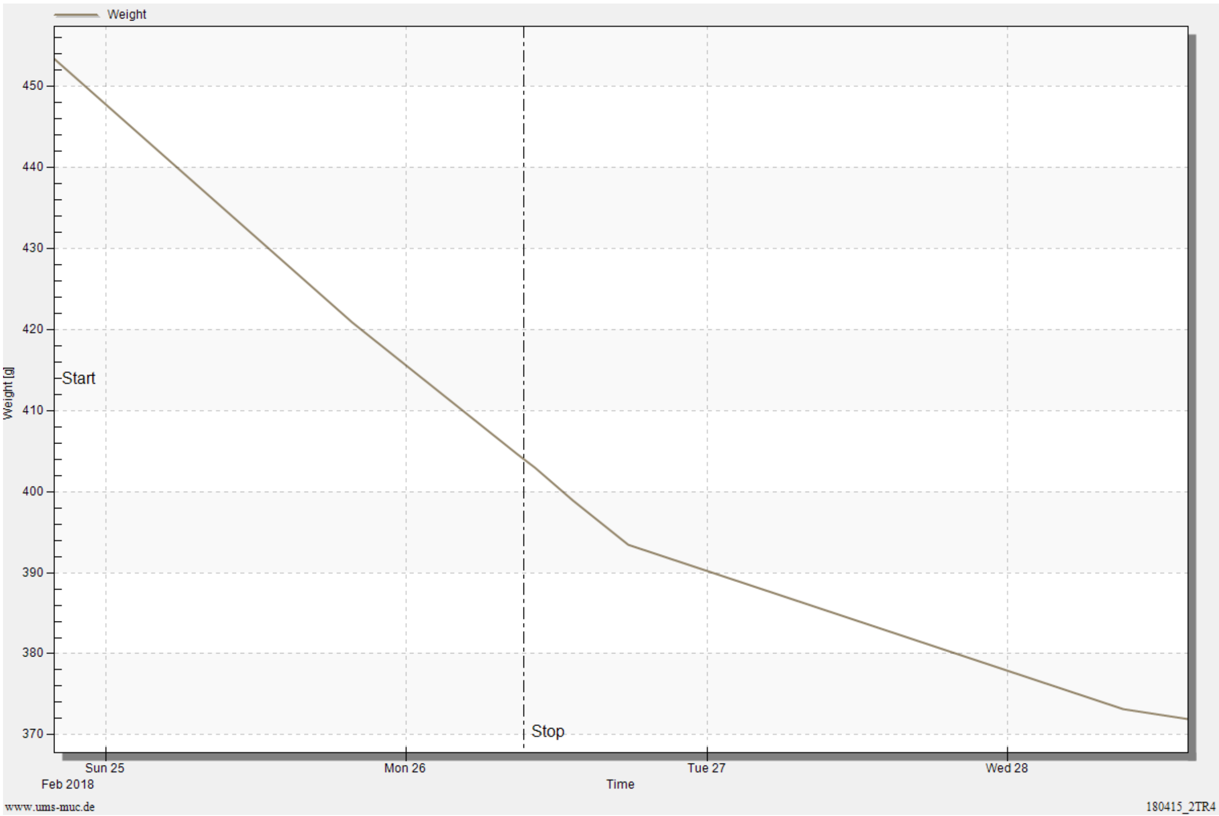
2TR4



Retention Θ(pF)
function
data
added data
vol. water content [%]
45
40
35
30
25
20
15
10
5
0
pF 4.2
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
pF [-]
www.ums-muc.de
180415_2TR4

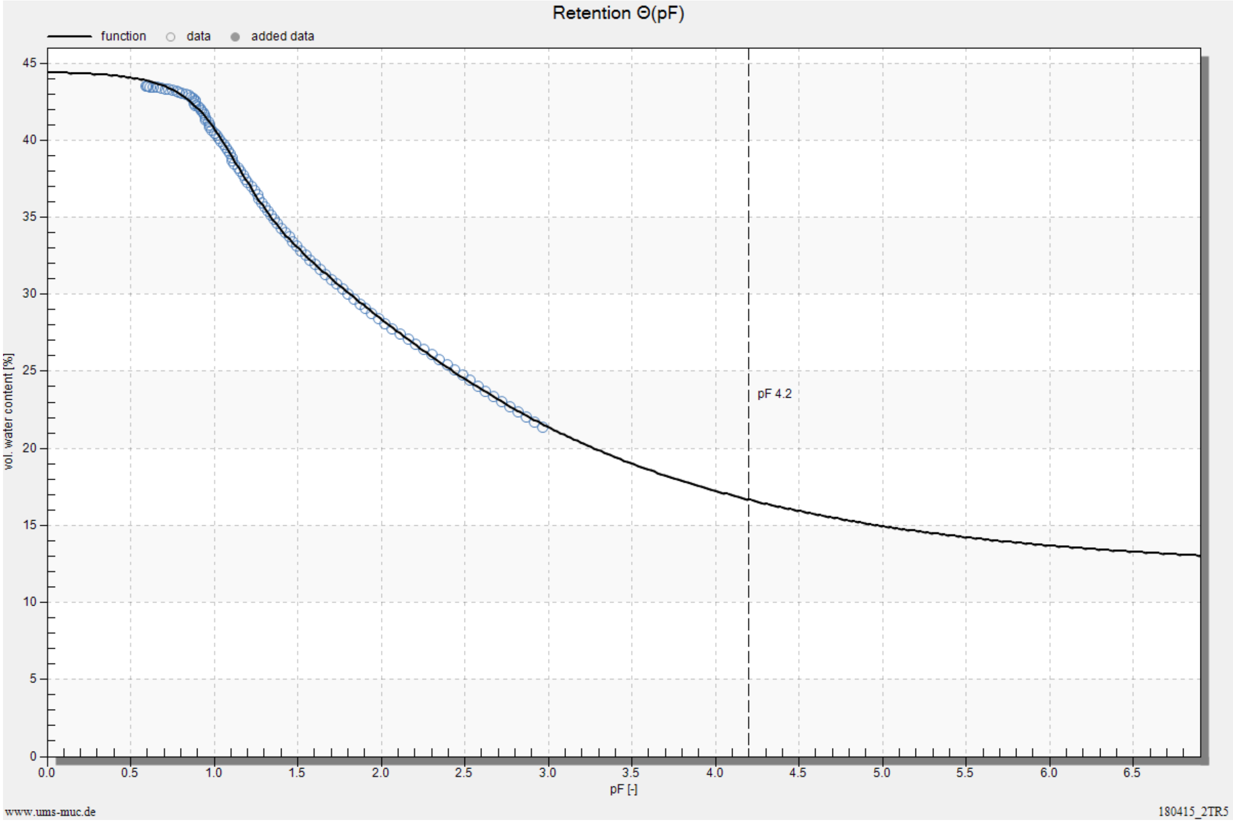


Tension bottom
Tension top
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Tension [hPa]
Start
Stop
Sun 25
Mon 26
Tue 27
Wed 28
Feb 2018
Time
www.ums-muc.de
180415_2TR4

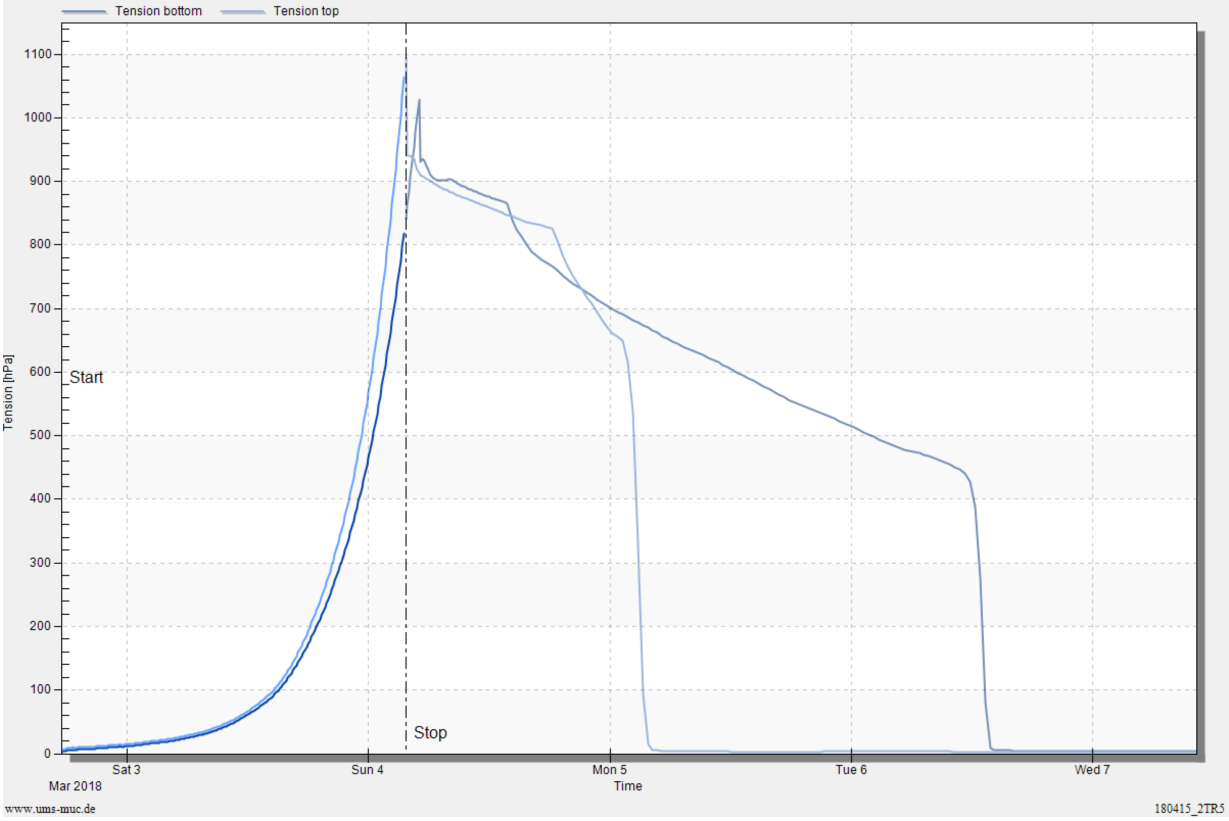


Weight
450
440
430
420
410
400
390
380
370
Weight [g]
Start
Stop
Sun 25
Mon 26
Tue 27
Wed 28
Feb 2018
Time
www.ums-muc.de
180415_2TR4

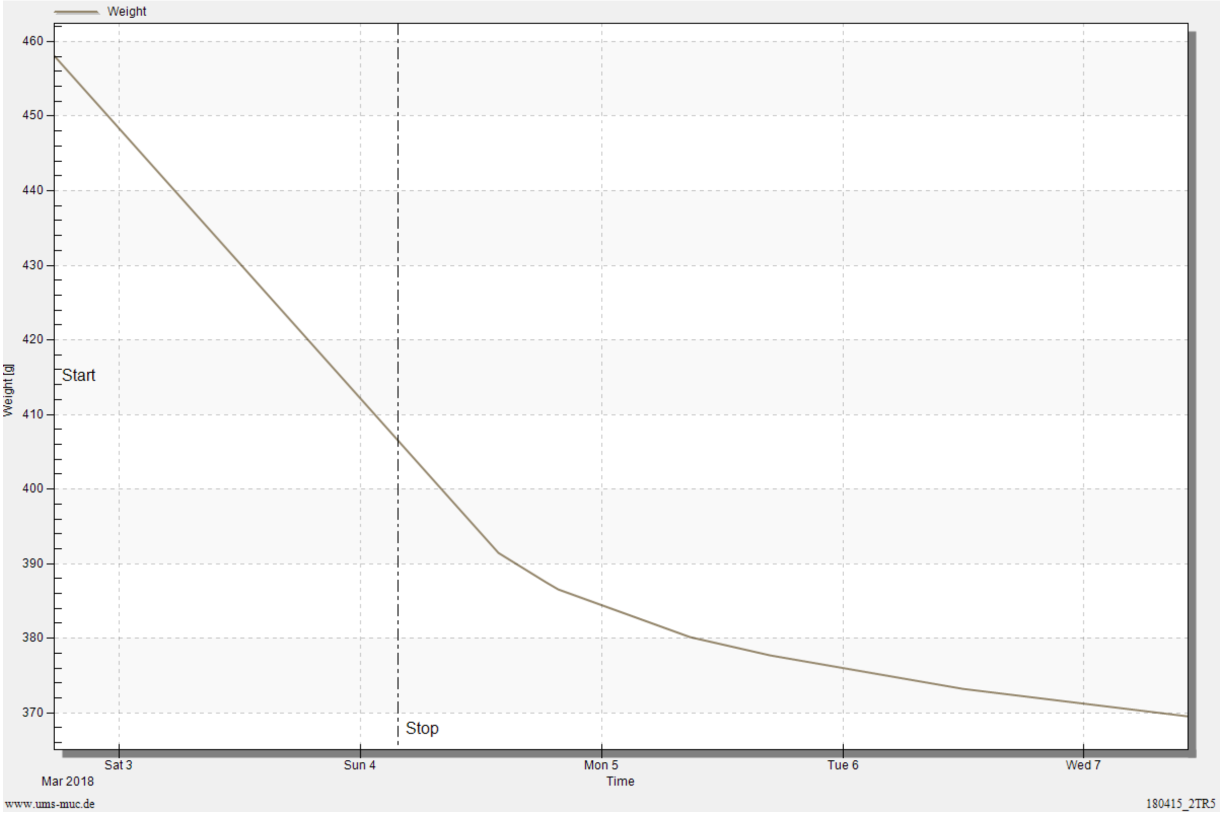
2TR5



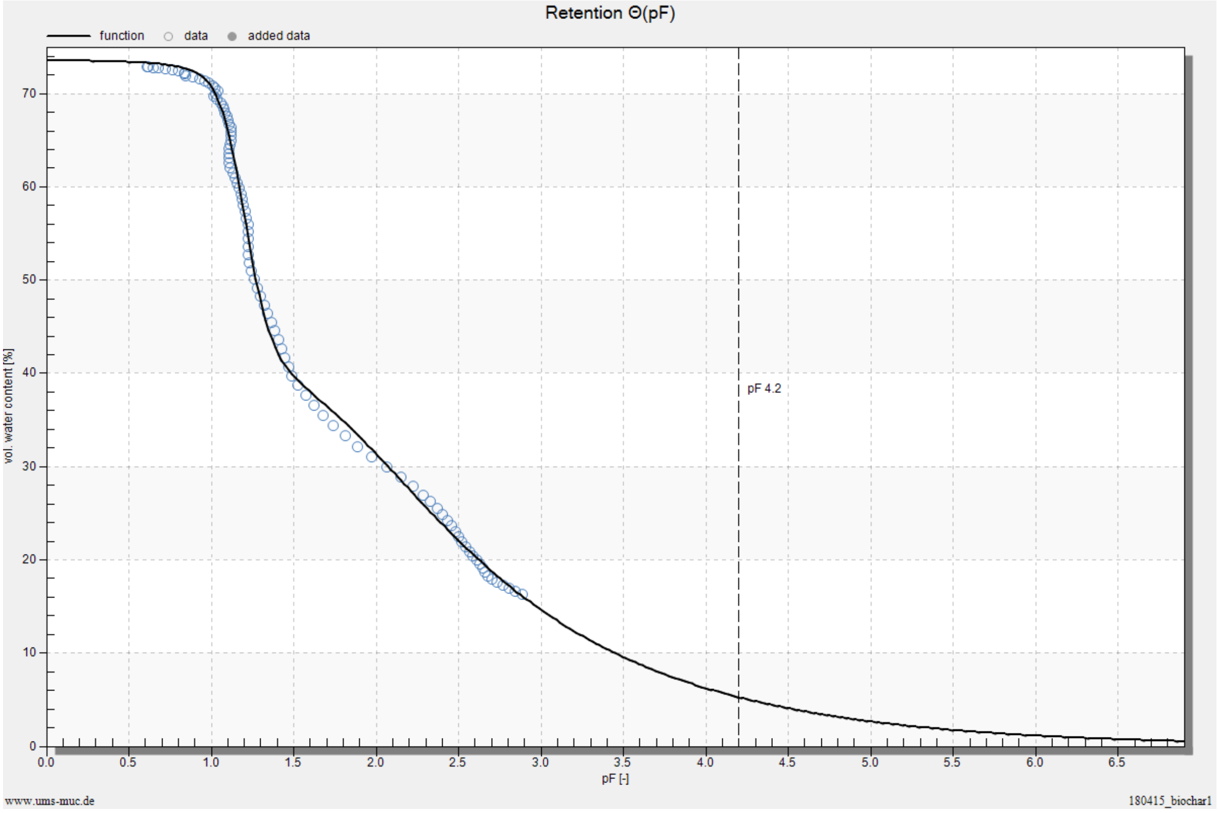
Retention Θ(pF)
function
data
added data
vol. water content [%]
pF 4.2
pF [-]
www.ums-muc.de
180415_2TR5

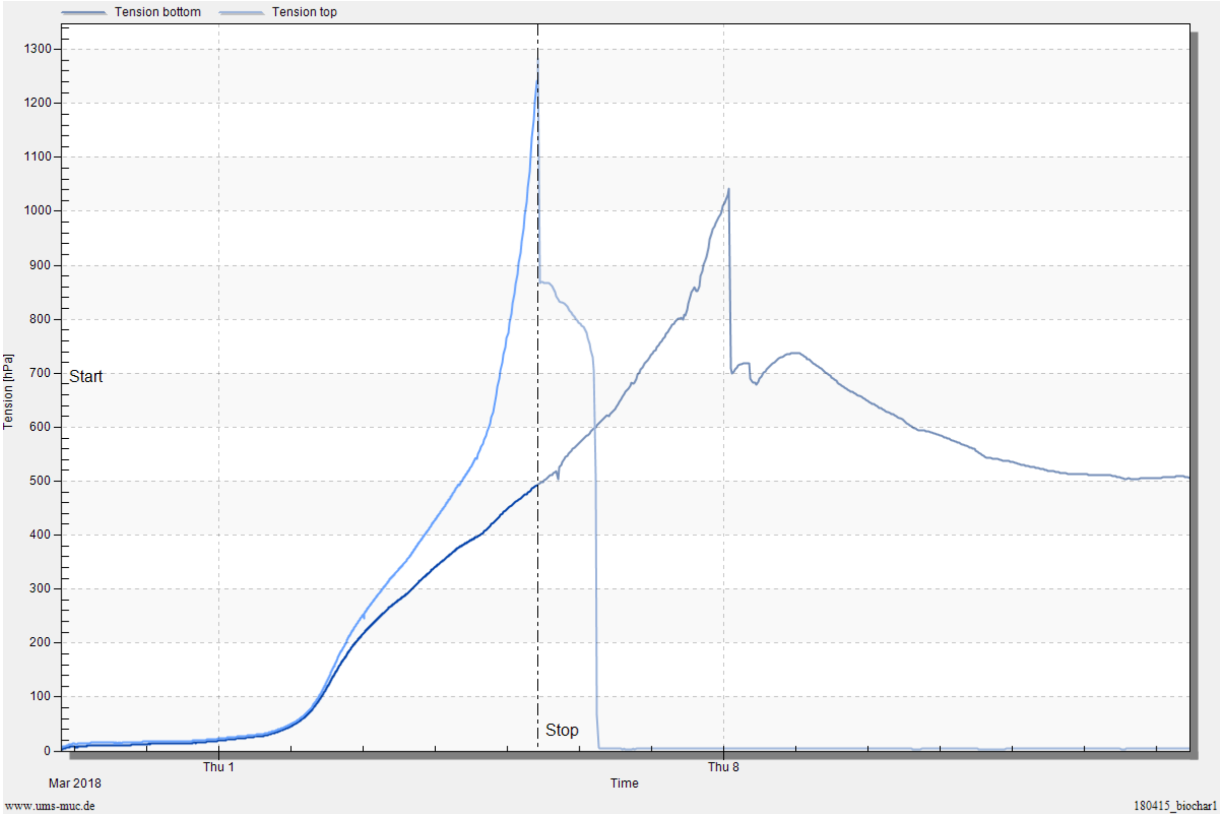


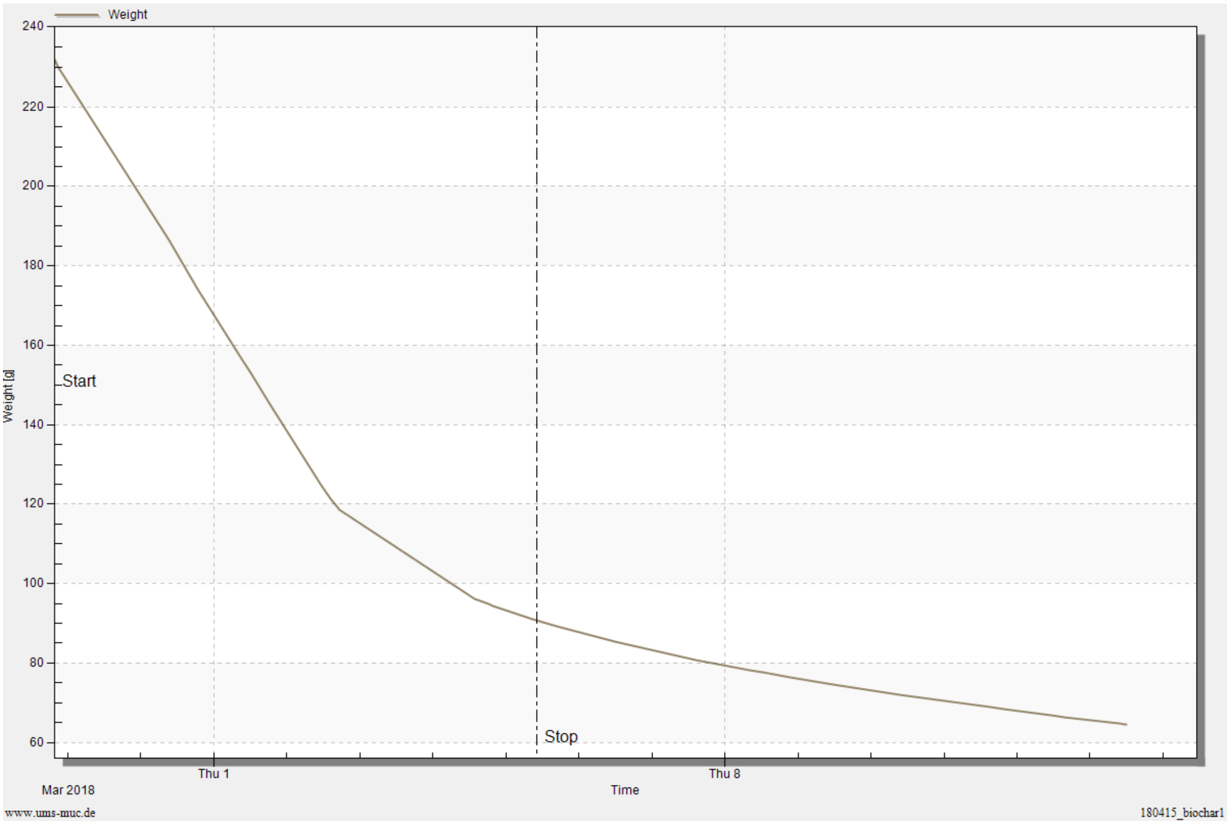
Tension bottom
Tension top
Tension [hPa]
Start
Stop
Sat 3
Sun 4
Mon 5
Tue 6
Wed 7
Mar 2018
Time
www.ums-muc.de
180415_2TR5


Weight
Weight [g]
Start
Stop
Sat 3
Sun 4
Mon 5
Tue 6
Wed 7
Mar 2018
Time
www.ums-muc.de
180415_2TR5

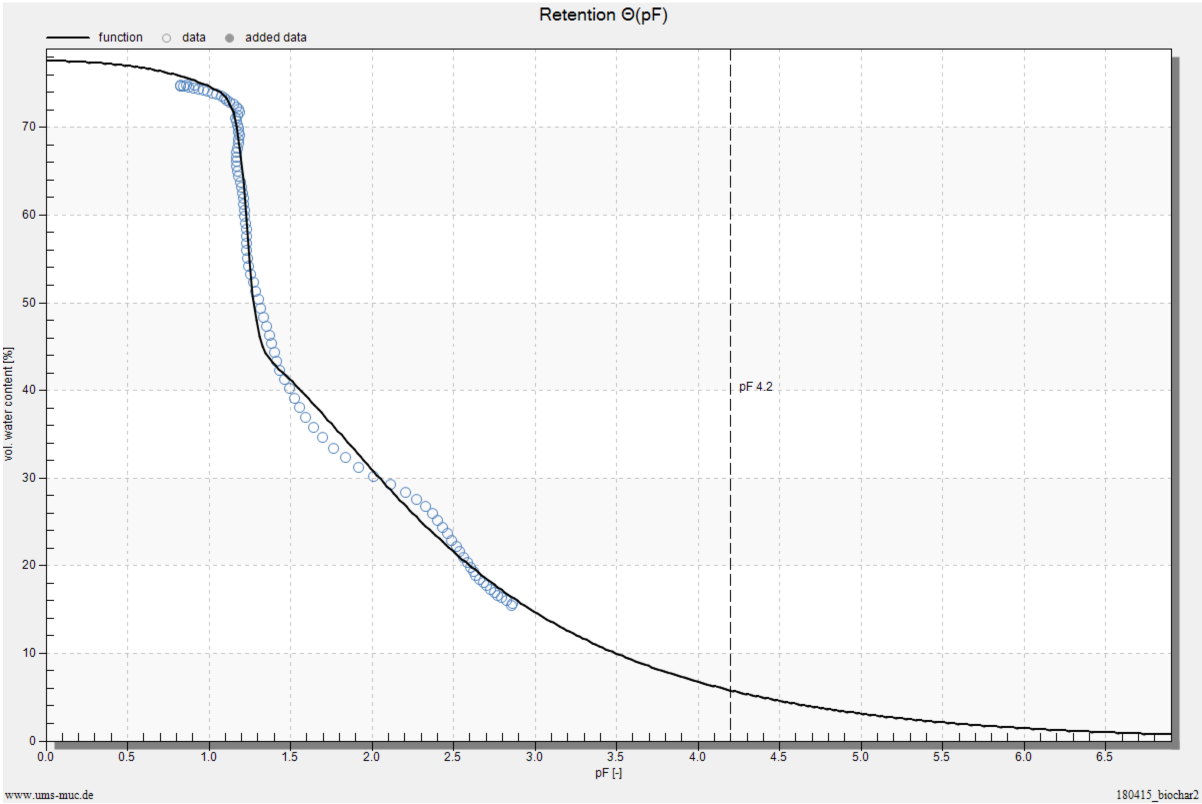
Biochar 1


Retention Θ(pF)
function
data
added data
vol. water content [%]
pF 4.2
pF [-]
www.ums-muc.de
180415_biochar1

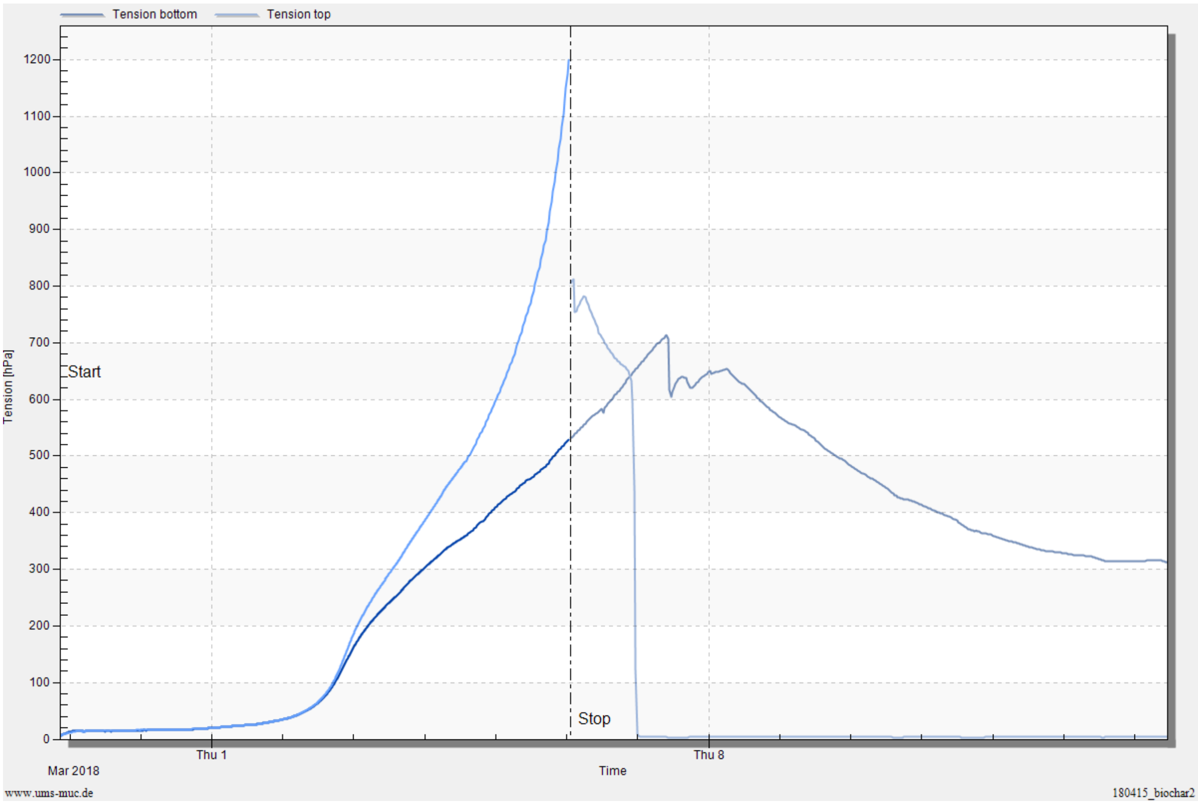

Tension bottom
Tension top
Tension [hPa]
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Start
Stop
Thu 1
Thu 8
Mar 2018
Time
www.ums-muc.de
180415_biochar1


Weight
Weight [g]
240
220
200
180
160
140
120
100
80
60
Start
Stop
Thu 1
Thu 8
Mar 2018
Time
www.ums-muc.de
180415_biochar1

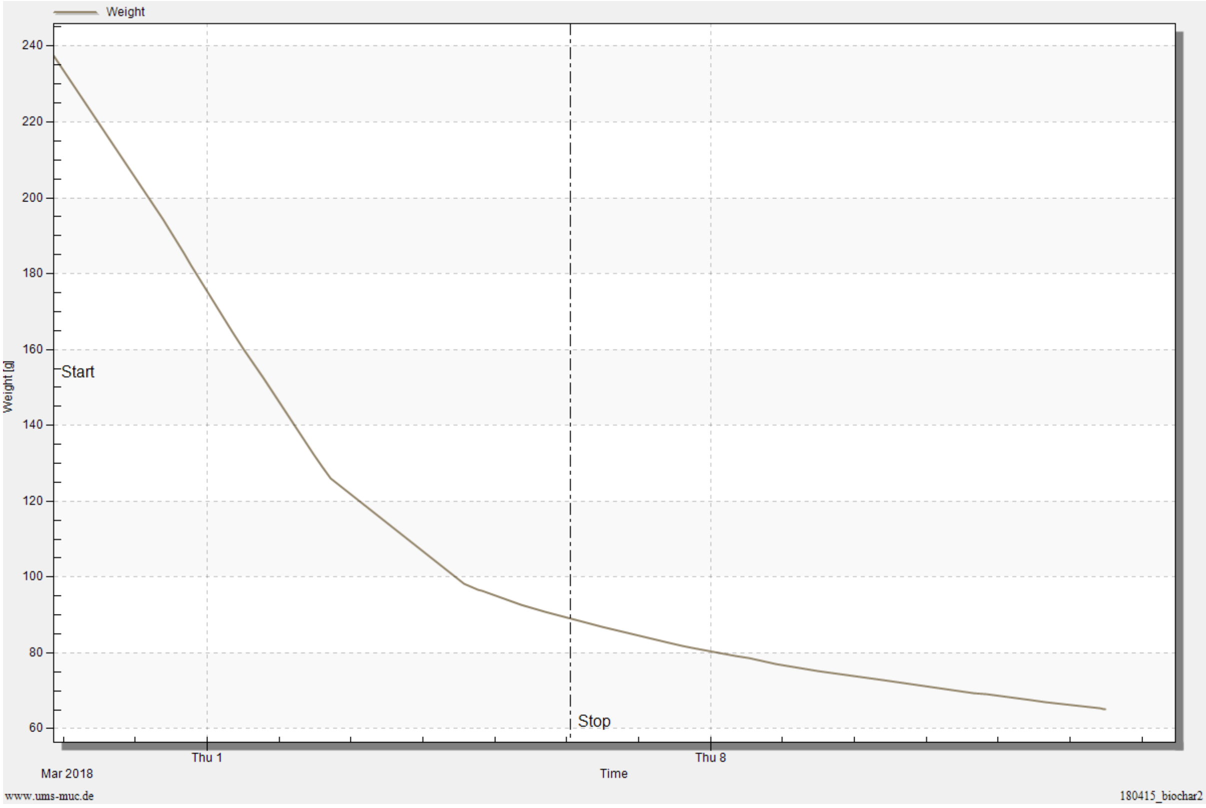
Biochar 2



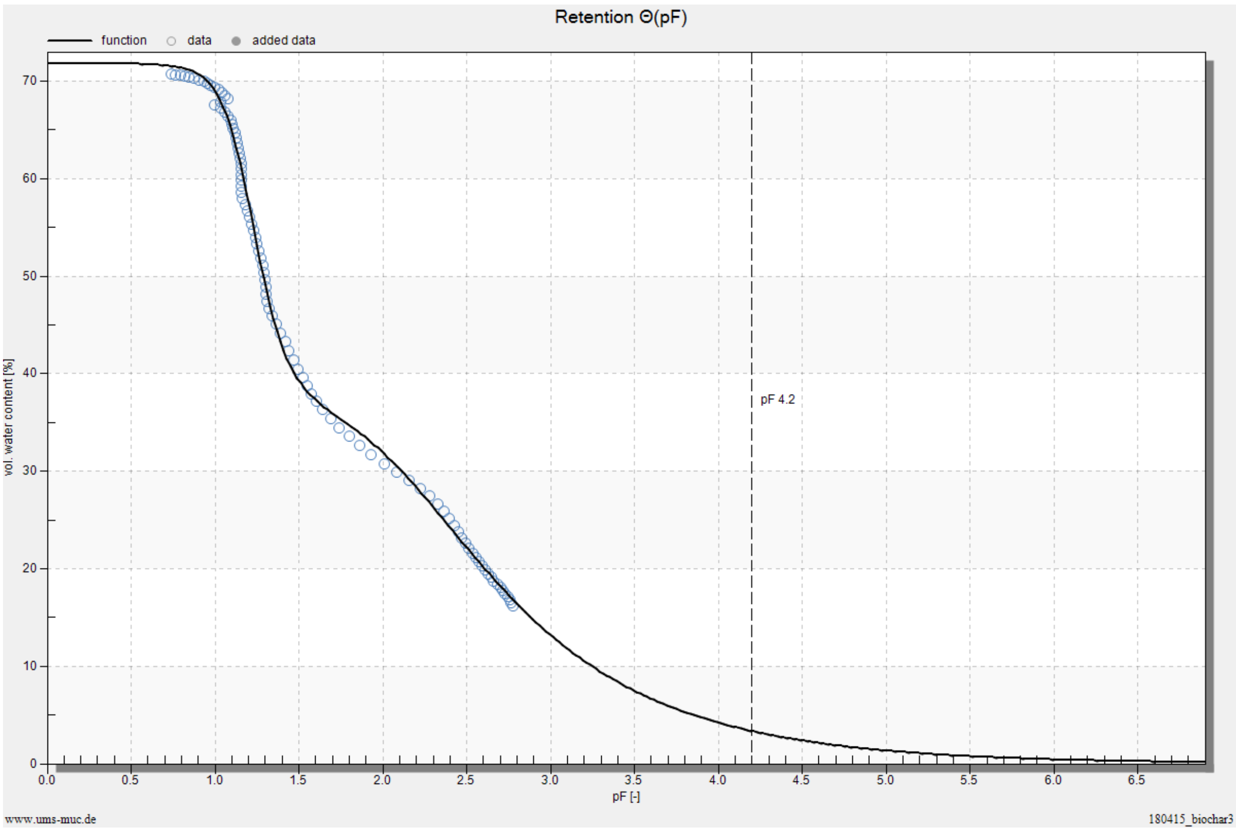
Retention Θ(pF)
function
data
added data
vol. water content [%]
pF [-]
pF 4.2
www.ums-muc.de
180415_biochar2

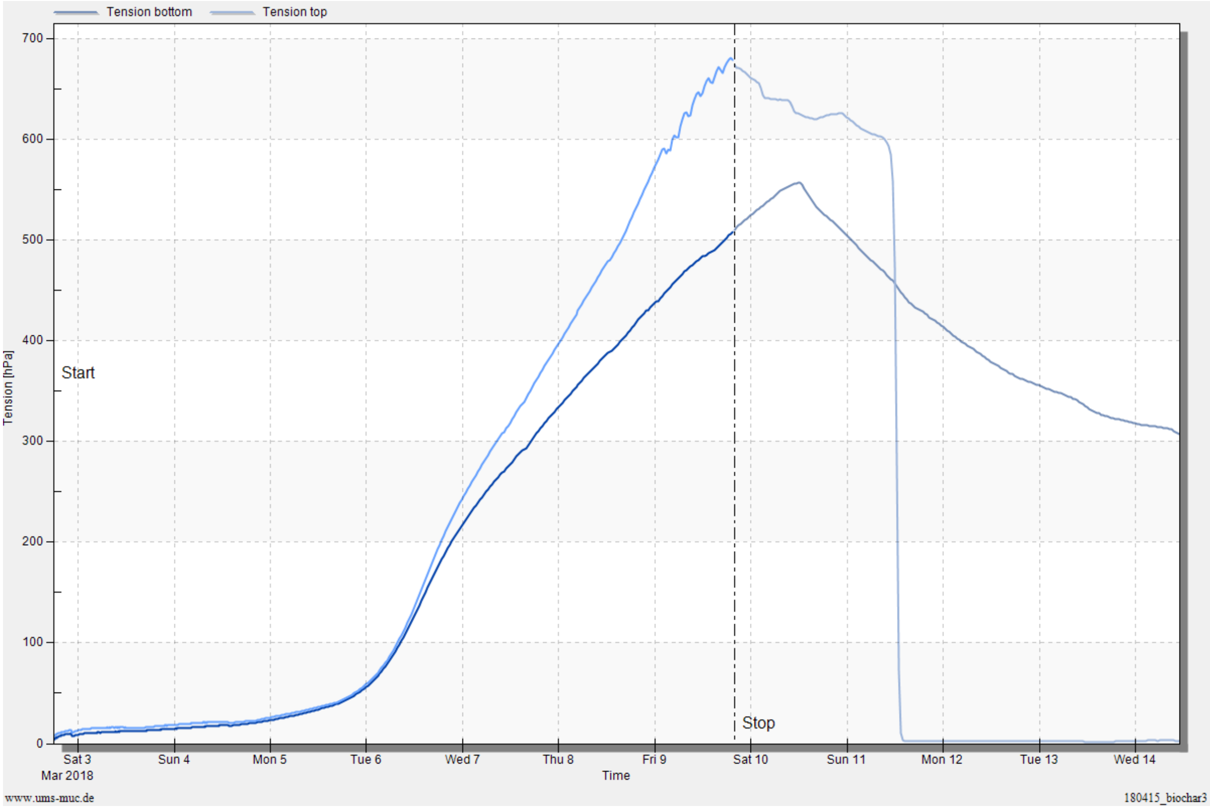


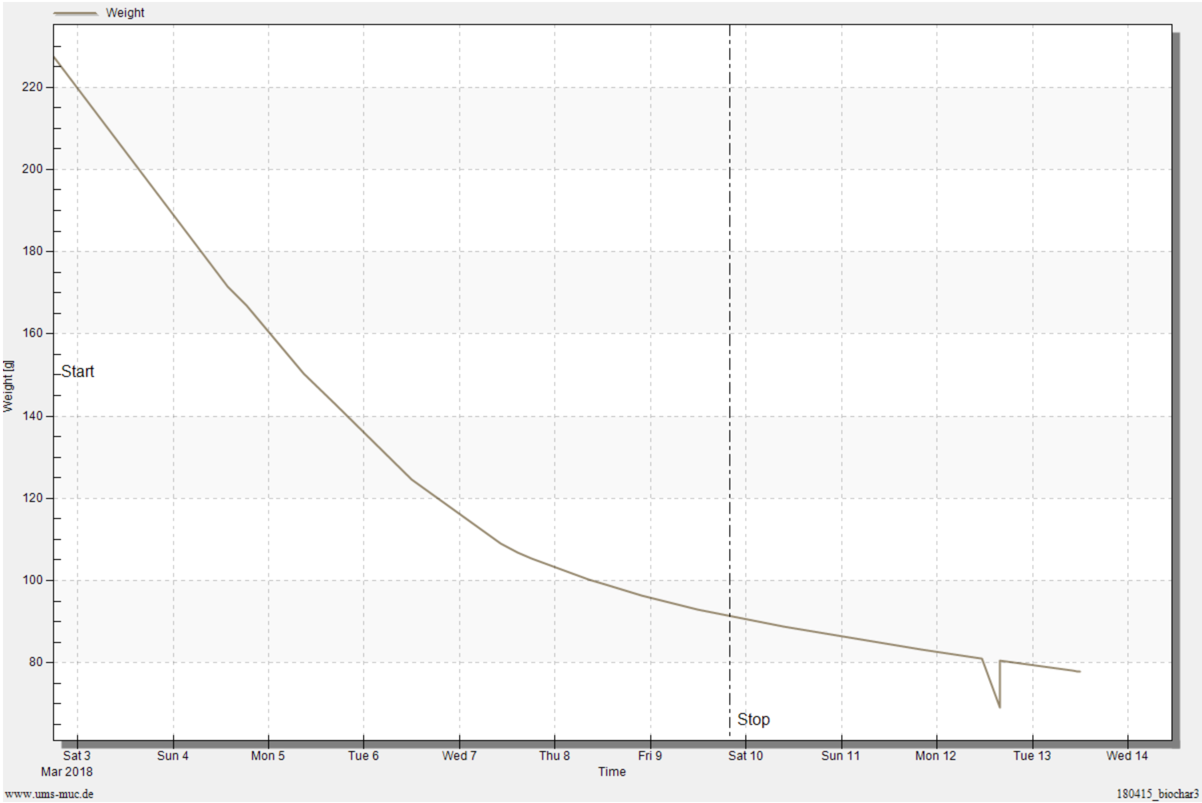
Tension bottom
Tension top
Tension [hPa]
Start
Stop
Thu 1
Thu 8
Mar 2018
Time
www.ums-muc.de
180415_biochar2


Weight
240
220
200
180
160
140
120
100
80
60
Weight [g]
Start
Stop
Thu 1
Thu 8
Mar 2018
Time
www.ums-muc.de
180415_biochar2

Biochar 3


Retention Θ(pF)
function
data
added data
70
60
50
40
30
20
10
0
vol. water content [%]
pF 4.2
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
pF [-]
www.ums-muc.de
180415_biochar3


Tension bottom
Tension top
Tension [hPa]
Start
Stop
Time
Sat 3
Mar 2018
Sun 4
Mon 5
Tue 6
Wed 7
Thu 8
Fri 9
Sat 10
Sun 11
Mon 12
Tue 13
Wed 14
www.ums-muc.de
180415_biochar3


Weight
Weight [g]
Start
Stop
Time
Sat 3
Mar 2018
Sun 4
Mon 5
Tue 6
Wed 7
Thu 8
Fri 9
Sat 10
Sun 11
Mon 12
Tue 13
Wed 14
www.ums-muc.de
180415_biochar3

Enclosure 4. Snapshot of running UMS KSAT software.