Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Bachelor Thesis

The effect of different plant litter on decomposition process in the alpine zone

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1 Introduction

This bachelor thesis is created within a four months period and about 300 hours of work as required by the Departement USYS of ETH Zurich to obtain the bachelor degree. I was supported by Dr. Stephan Zimmermann from the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL). The issue of this thesis is the decomposition of litter and the accumulation of soil organic matter (SOM) under two different plant species in the alpine zone. First of all, an introduction of decomposition processes in general and in alpine zone is given. Secondly, questions are formulated which give the research focus. Further, the location is described and the methods are presented. Finally, the results are presented and discussed.

1.1 Decomposition in general

In terrestrial ecosystems dead plant material is subject of different physical and biochemical breakdown mechanisms. The decay process of plant litter in soils is called decomposition (McClaugherty and Berg, 2011). Plant litters are highly variable in their chemical composition, but carbohydrates and lignins are the most abundant classes (McClaugherty and Berg, 2011). Sugars and low molecular-weight phenolic compounds are assimilated easily by microorganisms, though their existence time in soils is usually quite short. Parts of these compounds are mineralized and CO_2 is released to the atmosphere (Blume et al., 2016). Nevertheless some of these are stabilized in organo-mineral complexes, so their residence time in the soil is extended (Paul, 2016; Kögel-Knabner et al., 2008). In contrast, there is a large fraction of high-molecular weight phenolic compounds such as lignins, suberin and cellulose, which cannot be assimilated directly by microorganisms (McClaugherty and Berg, 2011). These recalcitrant compounds of plant litter are synthesized to metastable humic substances, transformed to low-molecular weight compounds by extracellular enzymes or accumulated directly in the soil (McClaugherty and Berg, 2011). The total of all substances (low molecular-weight and high molecular weight) that are not directly mineralized, are accumulated in the soil, building the soil organic matter (SOM). The accumulation and building of the soil organic matter respectively the mineralization rate and its dynamics depends on different **factors** (Gavazov, 2010; Bryant et al., 1998; Paul, 2016):

1. Physical conditions like temperature, moisture and solar radiation
2. The quantity and quality of the plant litter (depending on composition of plant material)
3. The composition of the soil biota community
4. The sorption of SOM on mineral surfaces depending on soil type respectively mineral compounds (see Kögel-Knabner et al. (2008))

For an overview see also figure 19 in appendix.

1.2 Alpine zone: Definition, conditions, soils and decomposition

In a plant-geographic sense we speak about "alpine" life zone above the natural altitudinal treeline. The life in the alpine zone is constrained by physical conditions (Körner, 2011). In the alpine zone the situations for plants are climatically rough and limited from a nutrient point of view. There is low atmospheric pressure, though a low CO_2 partial pressure, low atmospheric temperature, high solar radiation and high disturbance by wind and debris. Often there is a snowcover, what leads to a shortened vegetation period. The steep environmental climatic gradients in alpine regions leads to different and heterogenous conditions within a few meters (Körner, 2011). There are snow-bed communities in wet cold soil and hot desert microhabitats on rocky outcrops. Consequentially, the building processes of soils are very slow, hence alpine soils are often genetically young and low in nutrients. Next to the common factor of

pedogenesis in terrestrial ecosystems, the on site erosion of parent rock, gravity, sedimentation by water or snow and sedimentation by wind influence pedogenesis in alpine zone and the accumulation of fine mineral substrate (Körner, 2011). The soil organic matter has thus an important role regarding chemical, physical and biological properties of alpine soils. The activity of microorganisms is inhibited, hence the mineralization is reduced and an accumulation of SOM is the consequence. Körner (2011) showed that SOM content increases with altitude (until a certain altitude, then decreasing because there are less plants). The second important factor for decay rate respectively accumulation of SOM is the composition of plant material. Due to the specific litter quality of plant types the rate of decomposition is different. Based on plant species groups, Cornelissen (1996) made a classification on decomposition rates as follows: forbes > graminoids > decidous shrubs > evergreen shrubs. In the alpine zone shrubs are the most abundant group. So in alpine zone the climate and plant litter quality are very important factors for decomposition rate, which is inhibited strongly (Gavazov, 2010). Körner (2011) showed that in alpine zone more than 90% of total ecosystem carbon is stored in the soil organic matter, whereas only a few part of it is in the biomass. For comparison: the ratio biomass:soil of stored carbon is about 1:1 in mature forests (Chapin et al., 2002).
In this bachelor thesis, I focus on the effect of litter quality on decay processes, accumulation and quality of soil organic matter. Therefore I investigate the decay processes of *Dryas octopetala* and *Salix reticulata* representative for different litter quality. Both plants are abundant in the alpine zone above the tree line until altitudes of 3000 m a.s.l. (Favre, 1955).

1.3 Questions

The issue of this thesis is the decay process of plant material with different litter quality. To investigate this effect the two plants *Dryas octopetala* and *Salix reticulata* are compared to answer the following general question:

> **Is decomposition stronger inhibited under *Dryas octopetala* or *Salix reticulata*?**

1.3.1 Morphology

In the alpine zone the decomposition is accordingly inhibited due to different factors as explained in the introduction (page 5). The mineralization and the leaching of organic matter is smaller than the input of dead litter, hence there is an accumulation of soil organic matter and a development of an organic layer in the soil. The thickness and the amount of the organic layer depends on the composition of plant species material. The question therefore is:

> **Is the thickness of the organic layer under *Dryas octopetala* different from the one under *Salix reticulata*? Are there organic horizons (Of and Oh)?**

1.3.2 Soil parameter: pH value, C/N ratio, C_{org} content

By means of the analyses of pH value, CN ratio and C_{org} content, one can assess conditions regarding the decomposition state of soil organic matter. Due to humification and building of soil carbon, carboxylic and other acidic functional groups of SOM are built what brings acids to the soil (Conyers et al., 2012). In the same study Conyers et al. (2012) showed that there is a negative relationship between organic C and pH in soils. Although there were shown contrary effects in other studies (Murphy, 2015), pH value can be used as an indicator for SOM accumulation.

> **Can a lower pH value under one of the two plants be detected, due to the higher input of organic acids?**

The litter of different plant species has characteristic CN ratios. During decomposition (mineralization and humification) the CN ratio gets lower and can reach values of 10 (Blume et al., 2016). As long as sufficient nitrogen is available, microorganisms take up carbon and metabolize it to CO_2, what brings a decline of the CN ratio. The higher this ratio is, the stronger the decay is inhibited, because microorganisms need an additional input of nitrogen (Chapin et al., 2002).

> **Are there differences in the soil under the two plant species regarding CN ratio in the soil?**

A further indicator for inhibited decomposition is the content of organic carbon accumulated in the soil. Since only parts of the organic substances are mineralized and the rest is accumulated in the soil, one can say: the higher the organic carbon content the more the mineralization is inhibited.

> **Is there a difference in the content of soil organic carbon under *Dryas octopetala* and *Salix reticulata*?**

1.3.3 Lignin

Plants contain different chemical components such as lipids, proteins, polysaccharides and lignins, whereby the latter is one of the most abundant in plants (McClaugherty and Berg, 2011). Depending on the molecular weight and the complexity of the molecular structure, substances are decomposed differently. Lignin is a high molecular weight and complex molecule, consequently its decay is a slow process conducted mainly by white rot fungis (Blume et al., 2016). In the soil organic matter the occurrence of lignin is decisive for the decomposition rate of organic matter (Thevenot et al., 2010). Lignin concentration is often negatively correlated with decomposition (McClaugherty and Berg, 2011). The decomposition of lignin and its restructuring are dependent on vegetation and land-use, as well as on climate and soil character (Thevenot et al., 2010). According to plant origin and grade of decay of lignin, there are different components in the soil (Thevenot et al., 2010). The indicator single ring phenolic components of lignin are vanillyl (V), syringyl (S) and cinnamyl (C) with their acidic and aldehyde units. The amounts and ratios of these molecules are indicators for decay grade and origin of lignins (Thevenot et al., 2010). The sum of these phenols (V,S,C) is a quantitative measure for the soil lignin content (Thevenot et al., 2010). The acid to aldehyde ratio (Ad-to-Al ratio) of V and S compounds is an indicator for the state of lignin degradation and is increasing during decomposition process. S and C compounds are preferentially degraded compared to V units, what leads to a decrease of the S-to-V and C-to-V ratios.

> **Are there differences in lignin content in the soil under the two different plants indicated by a higher VSC-sum? Is decomposition more advanced under one plant species implied by a higher acid to aldehyde ratio?**

1.4 Hypotheses

In this bachelor thesis the effect of different plant litter on decomposition should be investigated. Therefore the soils, especially the organic matter under *Dryas octopetala* and *Salix reticulata* are analysed to understand the litter decay and its transformation to organic matter. I could observe that *Dryas octopetala* has a higher input of litter and its litter seems to be rougher. For those observational reasons I assume a potentially higher accumulation respectively an inhibition of decomposition of *Dryas octopetala* litter. Morphologically, this should be visible in a **thicker organic layer**. Further I expect a **higher C/N ratio and higher C_{org} content** in the profiles under *Dryas octopetala*. **The pH value might be lower under *Dryas octopetala*** due to a higher input of organic acids. Because some locations are calcareous, the fine earth is efficiently buffered and the pH value might not mirror these different loads of organic acids. The analyses of lignin content and components should give additional information about the decomposition of plant litter and the accumulation of organic matter. Lignin belongs to the most abundant components in plants and is mostly inhibiting the decomposition process (Thevenot et al., 2010). **I expect a higher lignin content hence a higher VSC-sum under *Dryas octopetala*.** I suggest a lower Ad-to-Al ratio and higher S-to-V and C-to-V ratios in soils under *Dryas octopetala*.

2 Materials and Methods

2.1 Study site

The study area was in the valley Val S-charl in the eastern Swiss Alps (see table 1). This valley is situated south of the lower Engadin at altitudes from 1800 m a.s.l up to 2300 m a.s.l. surrounded by mountains of about 3000 m a.s.l. The hillsides exposition varies from northeast to east respectively from southwest to west. The timber line is at about 2200 m a.s.l. For climatic situation in Val S-charl the nearby situated meteorological stations of Scuol (1304 m a.s.l.) and Buffalora (1968 m a.s.l.) were considered (see Appendix). The precipitation is around 700 to 800 mm per year (Scuol: 706 mm and Buffalora: 793 mm). The mean annual temperature can be compared with the temperatures of Scuol: 5.5°C and Buffalora: 0.7°C and estimated by a decrease of 1°C per 100 meter. In that case the mean annual temperature of the study sites is about - 2°C. The valley area at lower elevations is mostly covered by morainal material due to glacial drift. The parent rock material of the mountains around the area is constituted of gneissic rock and dolomite. The debris in the valley ground and hillsides are a mixture of these components. In the valley-area three different locations were chosen where *Dryas octopetala* and *Salix reticulata* are found side by side (see table 1).

Table 1: Locations

Location	**Exposition**	**Altitude/Coordinates**	**Description**
1	Northwest	2300 m a.s.l., 824 575/173 860, Valbella	This location is in the debris and close to a chute. It is above the treeline and is disturbed by material brought by the chute. The soil is accordingly shallow.
2	West	2135 m a.s.l., 823 800/174 300, Valbella	This location underneath location 1 is close to a brook and above the trail. Some trees (*Pinus cembra* and *P. mugo*) are found but still the area is quite in the debris.
3	East	2330 m a.s.l., 822 440/175 345, Schombrina/ Piz Mezdi	The location is an alp pasture during summer above the treeline. In contrast to the other two locations there are deeper soils and less disturbed by chute or debris.

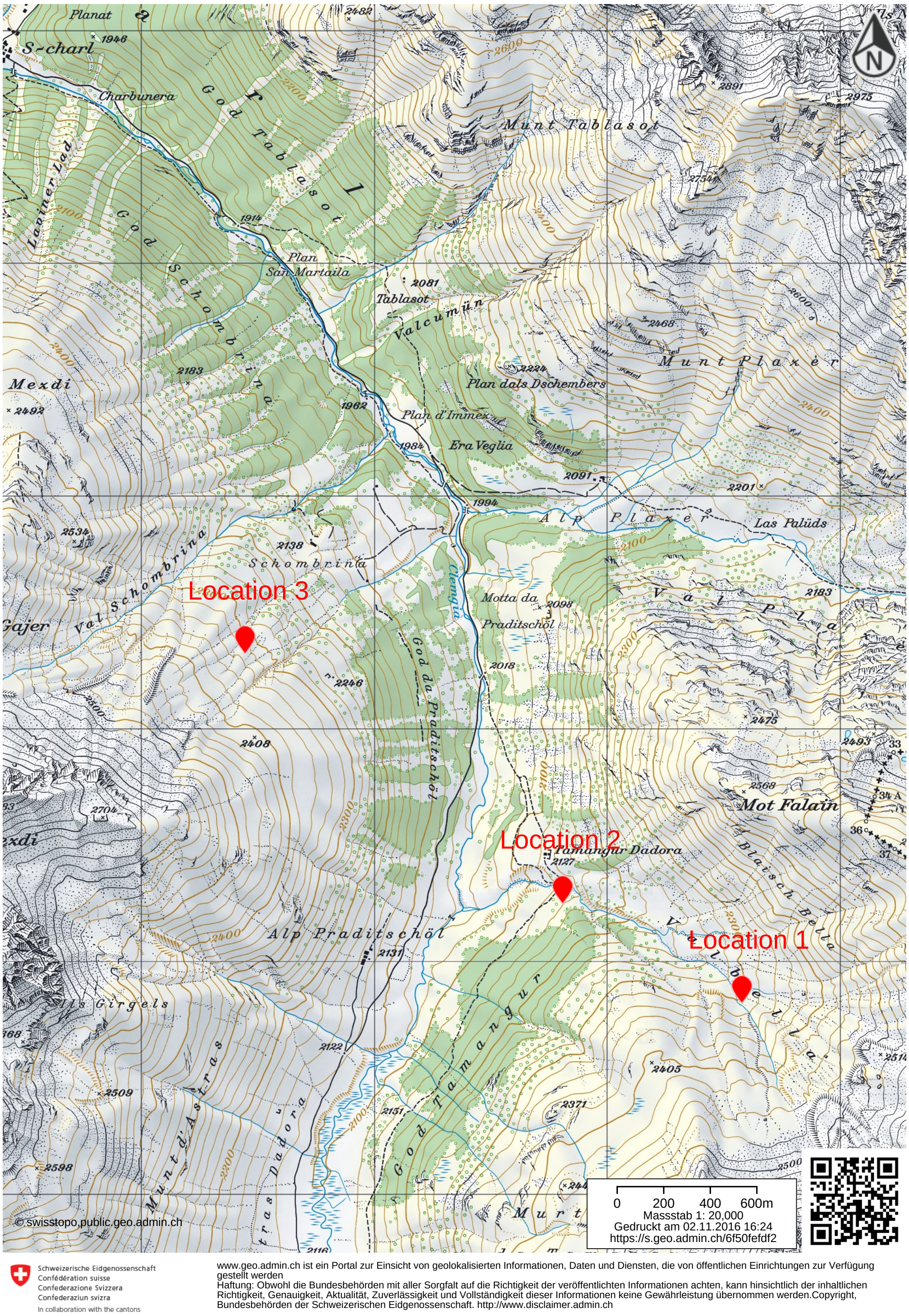

Figure 1: Map of study area

2.2 Properties of *Dryas octopetala* and *Salix reticulata*

In general, the two plants are highly frequent in alpine zone. Often they build surface groups, kind of carpets, because their branches are spread flatly. Both plants are perennial by building wood, thus contain lignin. They have associations with fungi and build mycorrhiza. Therefore, these plants are considered as micro-forest (Favre, 1955). *Dryas octopetala* is a dwarf shrub with branches up to 50 cm. The undivided leaves are 1-2.5 cm. The blossom is white with mostly 8 petals. It occurs in the whole alpine zone (see figure 3), especially in calcareous regions. It can bear low temperatures, high wind expositions and high light intensity. (All the plant information are from Konrad et al. (1996)).

Figure 2: *Dryas octopetala*

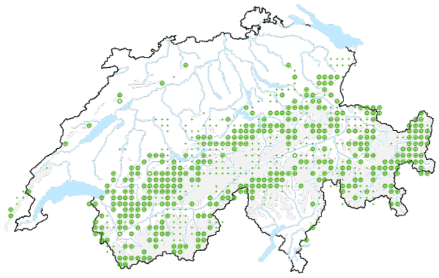

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Figure 3: Distribution of *Dryas octopetala* in Switzerland

Salix reticulata is a dwarf shrub and its branches are spread at ground. Its leaves are oval and between 1 to 4 cm. It appears mainly in the alpine zone (see Figure 5) in calcareous environments and is capable to endure low temperatures but occurs in contrast to *Dryas octopetala* in humid and less wind exposed locations (Favre, 1955). (All the plant information are from Konrad et al. (1996)).

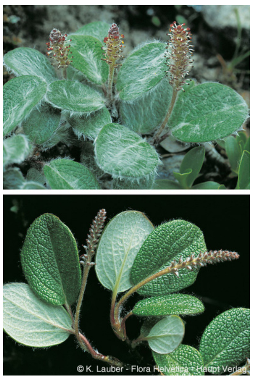

Figure 4: *Salix reticulata*

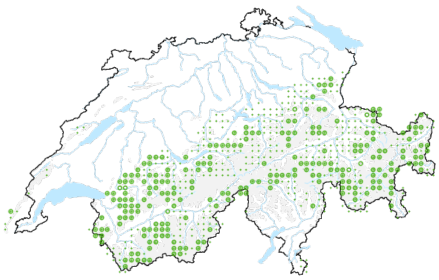

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Figure 5: Distribution of *Salix reticulata* in Switzerland

2.3 Analyses

On each of the 3 locations 4 plots were chosen, where *Dryas octopetala* and *Salix reticulata* are the main plant cover and are situated next to each other. So I made two profiles per plot (depth 6 to 20cm), one under *Dryas octopetala* cover and the other under *Salix reticulata* cover.

Every profile was analysed morphologically by using the "Kleines Aufnahmeprotokoll WSL" (see Appendix). Further I took 2-3 samples from every profile. Where clearly existing I took a sample from the organic matter, and always from the Ah-Horizon in depth 0-1 cm and from the Ah-Horizon in depth 1-4 cm. In total I collected 63 samples, which are used for analyses in the laboratory. For the different analyses it was necessary to prepare the samples. First of all, the soil samples were dried in the oven at 60°C for three days. By sieving the samples they were prepared for pH measurements. For the C/N ratio and C_{org} content measurements, fine material is necessary, hence the samples were milled. The pH was measured potentiometrically in 0.01 M $CaCl_2$ (10 g soil / 5 g organic layer in 20 ml CaCl2) with a glass electrode (Metrohm 691 pH meter, bioblock-electrode). The total content of C and N was measured on a CN-Analyzer (CE Instruments NC 1500). Organic C was determined after fumigation with HCl (Walthert et al., 2010) with the same CN-Analyzer. The Lignin components and quantity were determined with cupric oxide (CuO) oxidation method and gas-chromatographic analysis as proposed by Dignac and Rumpel (2006).

2.4 Statistics

In this thesis there are four response variables, namely pH value, CN ratio, C_{org} content and Lignin content (VSC-Sum). The main effect of the two species and potential effects of other factors on these responses are tested. Basically for every statistical analysis we need an appropriate experimental design with units and treatments. In this case the whole experimental design is based on a split-plot design. These designs are used when some factors are harder or more expensive to vary than others (Oehlert, 2010). Split-plots have more than one randomization and more than one idea of experimental unit (Oehlert, 2010).

In my experimental design data were collected at three different locations, which are different in exposition, parent rock material, altitude and land use. According to reduce variance of data one can use homogenous experimental units by introducing a block factor. In this model the block factor is 'location' with three levels for three different locations. This factor is chosen as block factor, because the values within each location are more alike than values at different locations. Fixed effects are unknown parameters that are tried to estimate. In my case these fixed factors are 'plant species' (factor with two levels: 'dryas' and 'salix') and 'horizon' (factor with 3 levels of 3 different soil depths). Random effects are appropriate, when some treatments are random samples from a population of potential treatments (Oehlert, 2010). We are though interested in the variance of the treatment population and not on the individual treatment effects to make a statement over decomposition differences of the two chosen plants in general. There are two random effects. There is the factor 'plot' (12 levels) with the paired plants (each with dryas and salix) and the factor 'plant' (24 levels) for every single plant. The plots and the plants are randomly selected within the three locations and should give information about differences in plant species in general. To estimate the main effect of species and probable other effects on the response, I fitted the following mixed effects model:

$$y \sim location|_3 + species|_2 \times horizon|_4 + (1|plot|_{12}) + (1|plant|_{24}) \tag{1}$$

To avoid false model assumptions residual analyses (qqplots and Tukey-Anscombe Plots) were considered for every response and eventually the model was adjusted by logarithmising the response variable. All statistical calculations were conducted with the software R. The linear mixed model is fitted by restricted maximum likelihood method (REML), which corrects the degree of freedom (see (Zuur, 2009) for more informations). T-tests were done by using Satterthwaite approximations to degrees of freedom (in R: lmerMod) (see (Zuur, 2009)). Model fitting is based on R packages "lmerTest" and "lme4" using the function "lmer". The figures were effectuated using the package "ggplot2".

3 Results

3.1 Morphology

The morphological observations are compiled in table 'Summary morphological analyses' in the Appendix. All the observed profiles are very shallow, though a depth between 6 to 20 cm. In all profiles there is a A-Horizon with a following C-Horizon and different sizes of coarse parent rock material. The horizons are in the sequence of Ah-AC-C. So the pedogenesis is not advanced, which means that soils are genetically young. The soils are disturbed by different factors such as wind, debris and pasture and have character of soil type Rendzina. In 16 profiles (71%) I found an organic layer. In 9 profiles under *Dryas octopetala* there is an organic layer, whereas under *Salix reticulata* I found 8 profiles with an organic layer (see page 33). These organic layers are in average about 5 cm and have L and Of horizons and only one of them had a distinct Oh horizon. The horizon boundaries at location 1 and 2 are often not very clear, because there is a lot of movement of debris and sediments in the area covering and mixing the soil. The horizon boundaries at location 3 - with an alpine pasture - are clearer and seemed more developed having first indications of a cambic horizon or a Cv-Horizon, respectively. The soils at location 3 are tendentially darker what signify a higher humus content. The humus content is estimated to be about 20-30%, whereas at location 1 and 2 the humus content is about 5-15%.

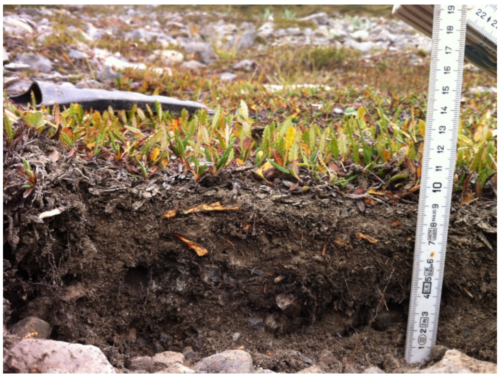

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Figure 6: Profile under *Dryas octopetala* at location 1

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Figure 7: Profile under *Dryas octopetala* at location 3

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Figure 8: Profile under *Salix reticulata* at location 1

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Figure 9: Profile under *Salix reticulata* at location 2

3.2 pH[1]

Before testing the data with the mixed effects model, I did explorative analyses of the data. In figure 10 there is a tendency that in total the samples under *Dryas octopetala* have a lower pH. Further one can see that there is lowest pH value in organic horizon (0) and the pH increases with depth. Figure 11 shows that all the samples at location 3 (rectangular signs) have a lower pH value. Between the other two locations there are no differences. Further there are two organic matter samples under *Dryas octopetala* of location 2 (red triangular signs) having a very low pH.

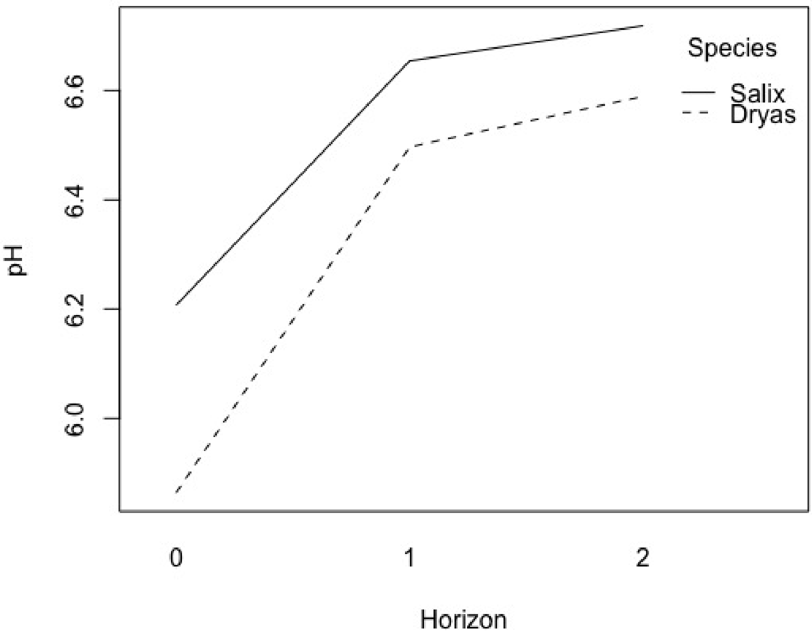

Figure 10: Interactionplot, pH value

This tendency is tested, considering the different explaining variables of the model and their impact on pH. There we can get a more detailed view, the relevance and the factors effects on the response variable pH.

The test results confirm the tendency of species on pH seen in the illustrations above, but show no significant effect of species. The pH value of soils under *Salix reticulata* is estimated 0.28 higher than the one of *Dryas octopetala* but p-value is not significant (0.12). Contrary, there is a significant effect of location. Location 3 has a smaller pH value than the other locations, as shown in table 2. The samples at location 3 have an estimate value of 1.59 smaller than the samples at location 1. Further we can see a tendency of increasing pH with depth (Horizon 1: 0.17, Horizon 2: 0.27). Standard deviations of random effects, though plant and plot are 0.09, 95%-CI: (0, 0.25) respectively 0.17, 95%-CI: (0, 0.28). Error standard deviation is 0.32, 95%-CI: (0.25, 0.38).

[1] The data used for the pH value is summarized in table 'Summary of parameter measurements' on page 34.

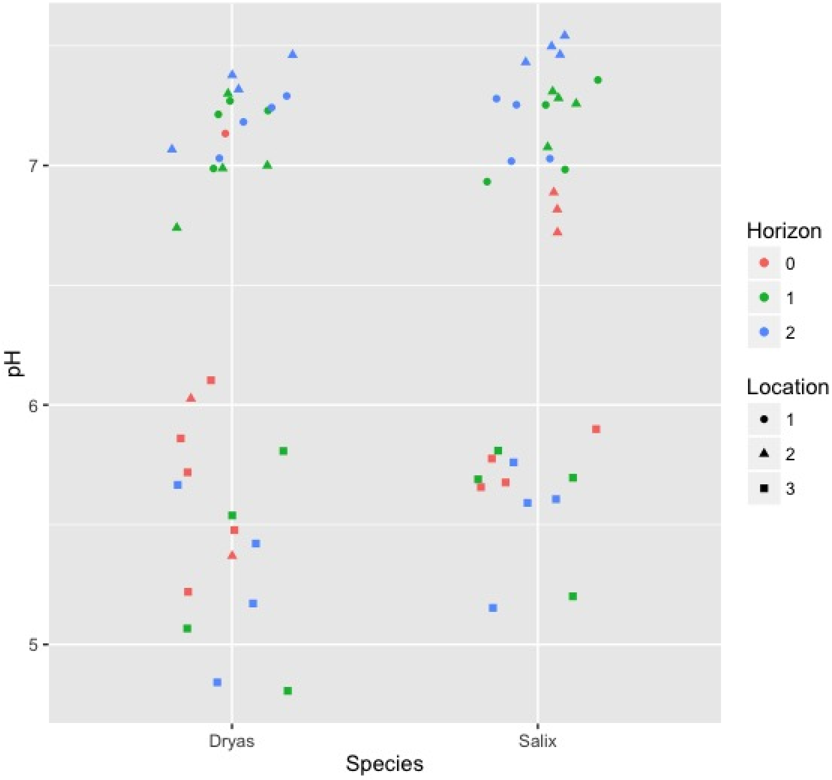

Figure 11: Data distribution, pH value

Table 2: Description of model for pH

Variable	Fixed effects			Random effects
	Estimate	SE	P	SD
Intercept	6.88	0.17	$2e^{-}16^{***}$	
Location 2	-0.08	0.17	0.64	
Location 3	-1.59	0.17	$1.88e^{-}6^{***}$	
Species Salix	0.28	0.18	0.12	
Horizon 1	0.17	0.15	0.26	
Horizon 2	0.27	0.15	0.09	
Species Salix : Horizon 1	-0.12	0.22	0.57	
Species Salix : Horizon 2	-0.15	0.22	0.48	
Plant (Intercept)				0.09
Plot (Intercept)				0.17
Residual error				0.32

Significance level: $*** \leq 0.001$, $** \leq 0.01$, $* \leq 0.05$

3.3 C/N ratio[2]

In figure 12 we can see that CN ratio is lower in deep soil horizons. At the same time CN ratio is slowly higher in soils under *Dryas octopetala*, what is especially due to some values under *Dryas octopetala* that are higher in the upper horizons (more values between 20 and 25). In lower horizons there is even a tendency of higher CN ratio in soils under *Salix reticulata*. In figure 13 we can not see any tendencies for location. The effect of horizon as seen in the interactionplot is seen in 13 that blue points are at lowest and red points at highest.

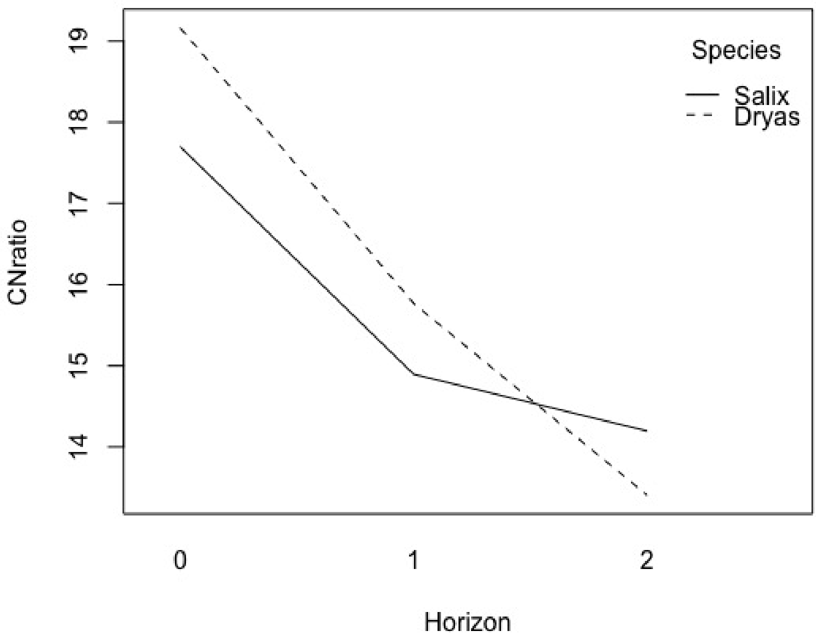

Figure 12: Interactionplot, CN-ratio

The test results show an estimate value of 1.48 lower for *Salix reticulata* but it is not significant (p-value: 0.15). Location 3 has a significantly lower CN ratio. The tendency seen in explorative statistics of lower CN ratio with soil depth is confirmed (by significance for horizons) in the test. CN ratio of horizon 1 is 4.77 lower respectively horizon 3 is 7.13 lower than horizon 0. The standard deviation of plant is 0, 95%-CI: (0, 1.04) and the one of plot is 1.87, 95%-CI: (0.91, 2.71). Error standard deviation is 1.94, 95%-CI: (1.54, 2.27).

[2]The data used for CN ratio is summarized in table 'Summary of parameter measurements' on page 34.

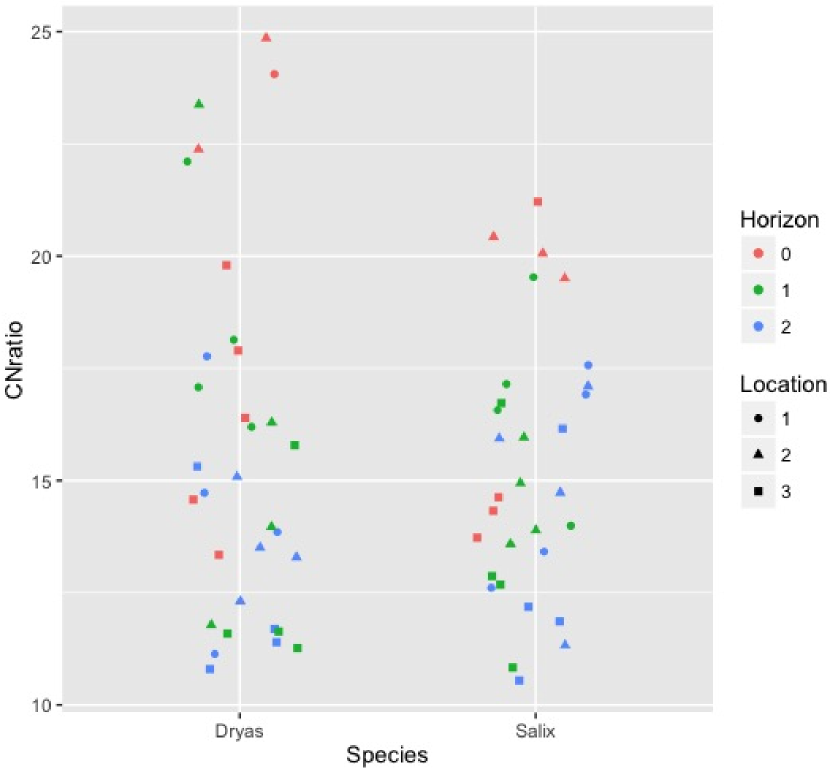

Figure 13: Data distribution, CN-ratio

Table 3: Description of model for C/N-ratio

Variable	Fixed effects			Random effects
	Estimate	SE	P	SD
Intercept	22.31	1.28	$1.56e^{-}13^{***}$	
Location 2	−1.07	1.47	0.49	
Location 3	−4.25	1.47	0.02^{*}	
Species Salix	−1.48	1.47	0.15	
Horizon 1	−4.77	0.92	$4.3e^{-}6^{***}$	
Horizon 2	−7.13	0.92	$5.79e^{-}10^{***}$	
Species Salix:Horizon 1	0.61	1.29	0.64	
Species Salix:Horizon 2	2.27	1.29	0.09	
Plant (Intercept)				0
Plot (Intercept)				1.87
Residual error				1.94

Significance level: $*** \leq 0.001$, $** \leq 0.01$, $* \leq 0.05$

3.4 C_{org} content[3]

C_{org} content is obviously smaller the deeper in the soil (see figure 14). Especially from organic soil horizon (0) to mineral soils 1 and 2 there is a big difference. The interaction plot (14) shows that soils under *Dryas octopetala* have a slightly higher C_{org} content in particular in organic soil horizons. The interaction plot does not show the individual measurements, so I hereafter consider figure 15. The points are quite similar distributed in the range of C_{org} content 1 and 20. There are some outliers for soils under *Dryas octopetala*. The observation that in organic soil horizons the C_{org} content is higher, is confirmed and seen by the red points at the top. Location does not seem to play an important role.

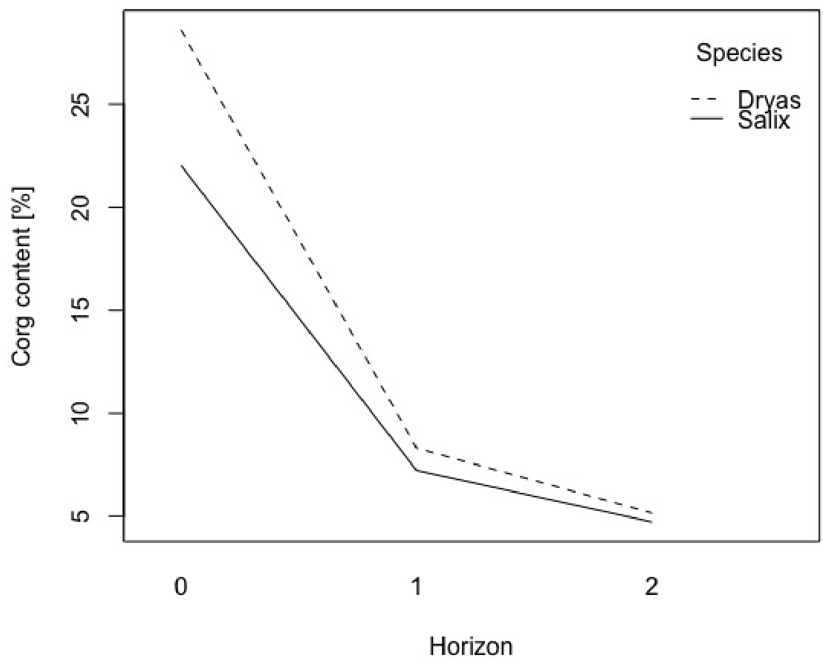

Figure 14: Interactionplot, C_{org} content

For testing the effects on C_{org} content I fitted a log linear mixed modell to comply with the assumptions that residuals are normal distributed (QQ-Plot, see figure 20) and their variances are constant (TA-Plot, see figure 21). The estimate value of the intercept is 3.19, 95%-CI: (2.81, 3.58) though an estimated C_{org} content of 24.29 ($e^{3.19}$). The following output shows that there is no significant difference in C_{org} content between species. There are significant effects of both horizons as predicted in explorative statistics (see p-values). In horizons 1 the estimate value is 1.18, 95%-CI: (-1.51, -0.85) smaller compared to the intercept, though an estimated C_{org} content of 7.46 ($e^{2.01}$). Estimate value of horizons 2 is 1.73, 95%-CI: (-2.06, -1.40) than the intercept estimate value, consequentially a C_{org} content of 4.36. We can recognize a significant effect of location 2 for which the estimate value is -0.51, 95%-CI: (-0.92, -0.10). Location 3 has no significant effect (p-value: 0.09) but we see that the estimate value is 0.42 higher than intercept. So I assume that at location 3 there is the highest C_{org} content, followed by location 1 and location 2 with the lowest C_{org} content.

[3]The data used for C_{org} is summarized in table 'Summary of parameter measurements' on page 34.

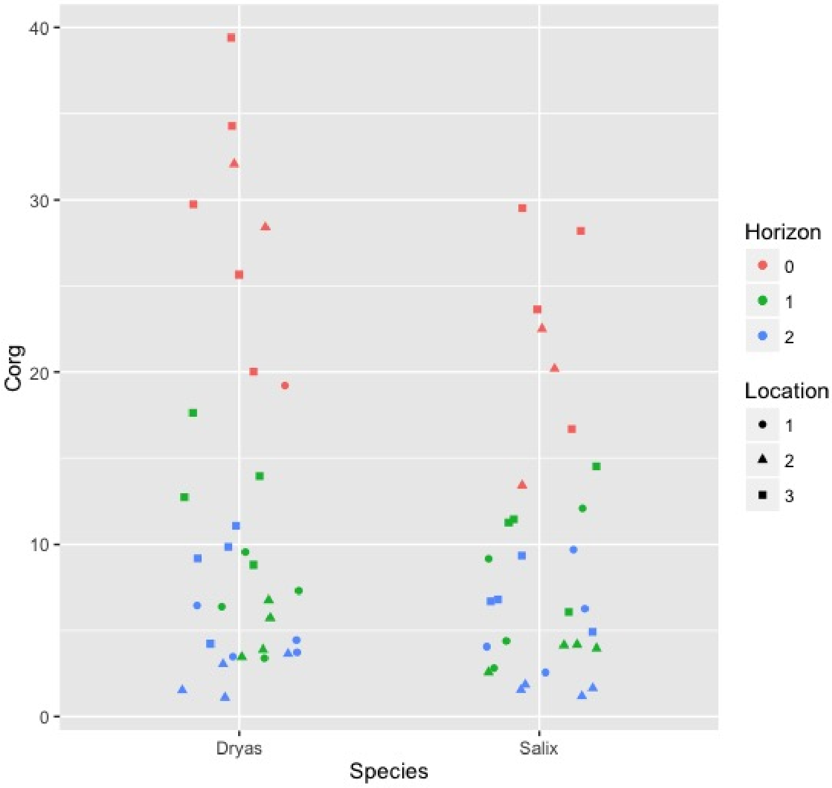

Figure 15: Data distribution, C_{org} content

Table 4: Description of model for C_{org} content

Variable	Fixed effects			Random effects
	Estimate	SE	P	SD
Intercept	3.19	0.21	$3.33e^{-}14^{***}$	
Location 2	-0.51	0.22	0.05^{*}	
Location 3	0.42	0.22	0.09	
Species Salix	-0.18	0.19	0.36	
Horizon 1	-1.18	0.17	$3.44e^{-}8^{***}$	
Horizon 2	-1.73	0.17	$2.1e^{-}12^{***}$	
Species Salix:Horizon 1	0.01	0.24	0.97	
Species Salix:Horizon 2	0.06	0.24	0.80	
Plant (Intercept)				0.06
Plot (Intercept)				0.26
Residual error				0.37

Significance level: $*** \leq 0.001$, $** \leq 0.01$, $* \leq 0.05$

3.5 Lignin[4]

The analyses on the lignin are additional and are not the focus of this thesis. The data sample is only from location 2, so the dataset is too small to do statistical tests. I did in the following some plots to illustrate the data. VSC sum between the species does not show clear differences (see figure 16). In the same figure one can see that type gruen (green plant litter) has higher VSC sum than type duerr (brown plant litter). The smallest values are found in soil samples. Regarding the Ad-to-Al ratios one can see that *Salix reticulata* has tendencially higher Ad-to-Al ratios, whereas the ones for *Dryas octopetala* are smaller and much closer together (see figure 17). For all measurements the Ad-to-Al ratio of Syringil compound is higher than the one of the Vanillin compound and soil samples have the highest Ad-to-Al ratios. In figure 18 the ratios of C-to-V and S-to-V are shown. For both species the ratios are similar, but *Dryas octopetala* has higher S-to-V values. The soil samples have a high C-to-V ratio, whereas type duerr und gruen have a smaller C-to-V ratio.

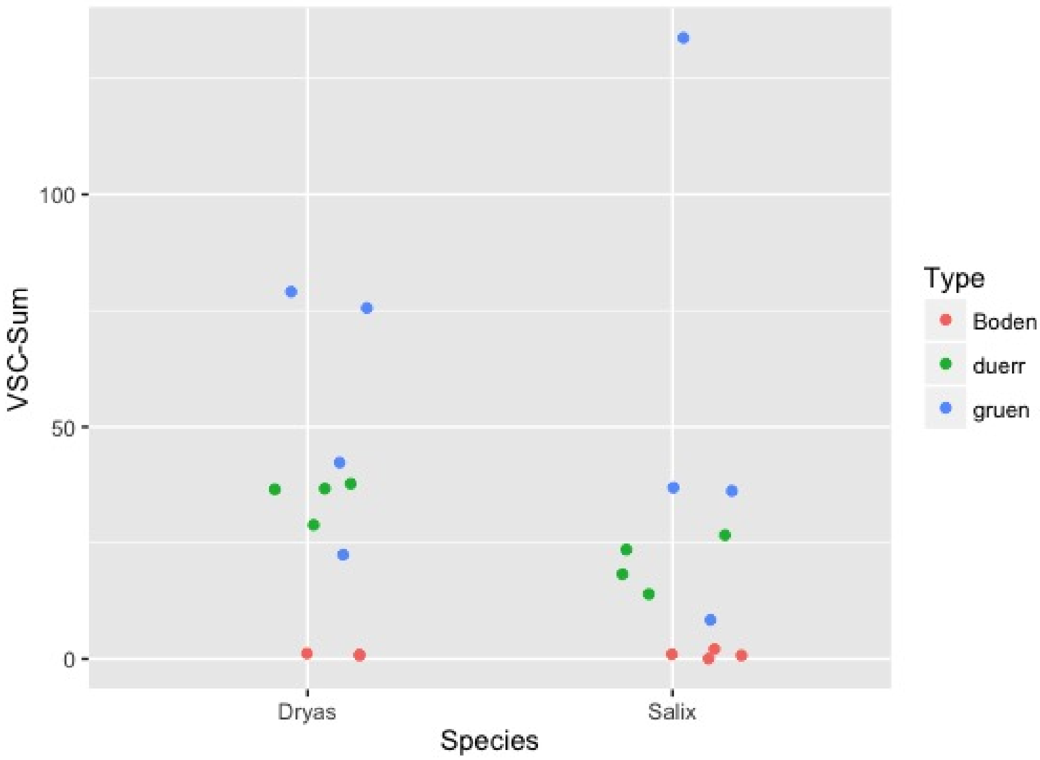

Figure 16: VSC sum of different species

[4]The data used for Lignin analyses is summarized in table 'Lignin values (potential regression)' on page 35.

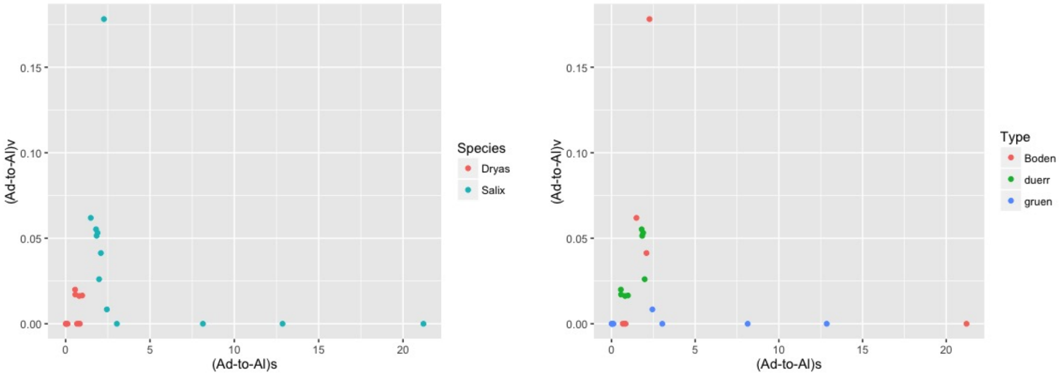

Figure 17: Acids to Aldehyde ratios of Syringil and Vanillin

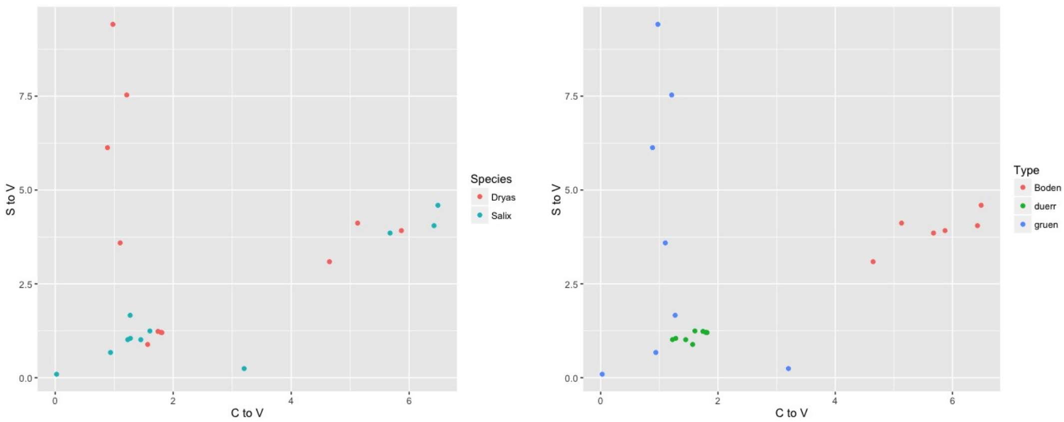

Figure 18: Ratios of C-to-V and S-to-V

4 Discussion

In this section hypotheses are evaluated and checked for compliance with the results. The general hypothesis that the litter of *Dryas octopetala* is decomposed worse than the one of *Salix reticulata*, was checked by analyses of different indicator parameters (see chapters 1.3 and 1.4). By using the described mixed effects model (see chapter 2.4), none of the analyzed parameters showed significance (significance level 5%) regarding the two different plant species. However there are tendencies, which all support the general hypothesis. Although there is no statistical significance I give the tendencies a high relevance and discuss them for every parameter (see below). The lack of significance comes on one side from the small sample size. It should have been larger to get more statistical power, but in the extent of this thesis this was not possible. On the other side locations where samples were taken, are very heterogenous, what made significance of species difficult. In the following I discuss the results of all parameters and give further possible answers why the suggested hypothesis is not significant. Then other significant factors such as 'location' and 'horizon' are discussed. At last, I do a general discussion and point out some difficulties of the experiment.
Morphologically, there was an apparent difference between the two species concerning the litter accumulation. Under *Dryas octopetala* there was more litter accumulated, thus a clear litter horizon L was visible. Organic layers were found under both species indicating the inhibited decomposition for both plants. A clearly visible difference was observed between locations assumingly due to different exposition, different altitude, different land-use and different disturbance factors.

4.1 pH value

Although the expected tendency is showed in the interaction plot (figure 10), the expected lower pH value under *Dryas octopetala* is not significant. The tendency can be slightly seen in the test (see table 2) by comparing the estimate values. Nevertheless, the difference between the two species is small, what might have different reasons. As already mentioned location 1 and 2 are calcareous, hence the added protons from the organic acids are buffered there very well. The buffer effect of silicates and variable charge in the pH range of location 3 can comply this function as well. The difference of the amount of included protons to soils is not high enough to cause a clear different pH value between the species. In this case analyses about the general acidity of the soils such as measuring of CEC should be done. Further, input from plant litter during decomposition is not the only source of organic acids. There are inputs from roots and microorganisms to absorb cations. So the question is what the contribution of plant litters organic acids really is. Additionally, in a recent review paper by Adeleke et al. (2017) it was shown that the acidifying effect of organic acids in soils is widely discussed. A significant effect we can see for location 3. pH value for the measurements of all horizons is clearly in the acid range due to a lack of limestone as buffer system.

4.2 CN ratio

The hypothesis of a higher CN ratio in soils under *Dryas octopetala* that was suggested, is not significantly confirmed. There is a slight tendency, but even then the difference is very small (estimate value of *Salix reticulata* is only 1.48 smaller than the one of *Dryas octopetala*). Therefore one can give different explanations. It might be that initial CN ratio of both plants is not different and though there is no difference in the soil neither. This should be checked by determining CN ratio from senescent leaves of both plants. Assuming there is a clear difference in CN ratio of the initial leaves but no difference in soils (especially in deeper soil horizons), there is following suggestion. Decomposition is influenced by different factors (see chapter 1), which can play a more or less important role at different moments. Melillo et al. (1989) divided decomposition in two phases. In the first phase there is a constant mass loss especially of carbohydrates and for microorganisms easily accessible compounds. Therefore decisive factors are litter quality and environmental conditions. In the second phase there is a very slow mass loss because recalcitrant compounds of the litter are left and only environmental conditions play a role. In such a manner one can speak of an adjustment of organic compounds in the soil as a first step of decomposition. Thereby the CN ratio is getting smaller at a first step due to the respiration of microorganisms and only the recalcitrant compounds with a specific CN ratio are remaining. This kind of homogenization of the remaining components in decomposition would explain the quite similar CN ratio found under both plant species. There are significant effects for soil depth. Namely, the deeper in the soil, the smaller the CN ratio is (for both species). This phenomenon is seen in other studies (Oades, 1988; Callesen et al., 2007), where it is explained that organic matter in deeper soil horizons is older and though more humified. Further on, location 3 has a significantly lower CN ratio. At location 3 humification is more progressed due to climatic factors or the more intensive land-use of pasturing what could bring an additional input of nitrogen.

4.3 C_{org} content

The hypothesis for higher C_{org} content in soils under *Dryas octopetala* can not be confirmed. Even the tendency is only very slightly seen. There again it is possible that there is no big difference in leave composition between the two species. Although figure 15 shows that in organic horizon (red points) there is a tendency of higher C_{org} content for *Dryas octopetala*) and is getting more homogenous in horizon 1 and 2. So this would support the suggestion done for CN ratio, that microorganisms firstly use carbon for respiration to get an appropriate CN ratio to build microbial biomass. For this parameter we need to pay attention because it is measured in gram per 100 gram soil, so the comparison of organic horizon with mineral horizon can lead to false interpretations. On the basis of this aspect one should compare the both species once for organic layer and once for mineral horizons. Even if there is a lack of data, t-test was done for organic horizon and the tendency of higher mean of *Dryas octopetala* litter (mean of 28.6 and mean of 22) is confirmed but not significant (t-value: 2, df: 13, p-value: 0.07). So this higher amount of organic carbon would show that fresh organic matter of *Dryas octopetala* litter has more recalcitrant compounds. The deeper in the soil (mineral soil) the less C_{org} content differentiate between species. At the same time the deeper in the soil, the lower C_{org} content is. An important source for organic carbon are roots and the effect of litter is weaker in deeper soil horizons. The locations differentiate by having the highest C_{org} content at location 3, followed by location 1 and location 2. An explication could be that there are less favorable conditions for mineralization at location 3 with its more acidic conditions. Oades (1988) stated that a calcareous environment accelerates the initial states of the decomposition process, but later when mixing with mineral compounds the process is inhibited the more basic the soil texture is. Another explication could be that there is a higher biomass production at location 3 caused by more favorable climatic conditions, which leads to higher carbon input. Further the different land-use should not be neglected.

4.4 Lignin

All the results from the lignin analyses should be treated with caution, because this method is completely new installed at WSL and for this kind of investigation it has never been used. So there is a lack of experience concerning the methods plan and especially the basic concept of quantifying the phenolic components with a mixture of standards has to be optimized yet. Further I removed two data points, because they were particularly high and distort the graphics (for complete data see table 'Lignin values (potential regression)' on page 35). In figure 16 one can see that there is a tendency of decreasing VSC sum the more degraded the material is. This would mean that lignin is quickly decomposed and is not as recalcitrant as it was assumed. This could be supported by studies that claim that the recalcitrance of lignin has been overestimated (Schmidt et al., 2011; Stevenson, 1994). The problem is, that VSC sum is measured in gram per 100 gram soil, respectively per 100 gram leave foliage. The comparison of these two types is thus inappropriate. Further the leaves of type 'duerr' could be stuck together with mineral soil components, what leads to a distortion. Considering ratios are in that case more appropriate (see figures 17 and 18). The Ad-to-Al ratios are increasing with decomposition state (Thevenot et al., 2010). *Dryas octopetala* samples have lower Ad-to-Al ratios what would confirm the hypothesis of lower degradability of that species. The results for C-to-V and S-to-V ratios are in accordance with the theory: Both species are angiosperm plants, which produce more Siringyl than Vanillin compounds (Hedges and Mann, 1979) and both are woody plants, so the production of Cinnamyl and Vanillin is reduced (Hedges and Mann, 1979). S and C compounds are preferentially degraded compared to V units, what leads to a decrease of the S-to-V and C-to-V ratios during decomposition process (Thevenot et al., 2010). The highest S-to-V ratio is found in *Dryas octopetala* samples. Apparently, lignin decomposition is influenced by many different aspects such as nitrogen content of the soil, clay content and other mineral phases, temperature and precipitation as well as land-use (Thevenot et al., 2010). Further on, the soil biota especially the fungi plays an important role as they are considered to be the only lignin mineralizer.

4.5 General conclusion

The lower quality and degradability of *Dryas octopetala* litter than the one of *Salix reticulata* could be confirmed by the analyses only by tendency and not by significance. In the following I discuss some general points concerning my experiment and draw a final conclusion.
In the alpine zone there are within a few meters very different microclimates due to the slope and the terrain. So for doing investigations it is a very heterogenous field. Within some meters, snow can remain at a side much longer than at other sides. Snowpack cover leads to a shorter vegetation period (less biomass production) but at the same time it protects the side from high solar radiation and drought. So the decay rates can be different within a few meters. Surface decay rates are highest in moist and wet meadow habitats (Bowman et al., 2001). The collected data represent a natural situation *in situ* and is not a completely isolated experimental setup. As a consequence this investigation gives less an answer on differences of leave decomposition but rather a difference of decomposition between the species in their habitats. Especially, *Salix reticulata* was found often in combination with sedges or weeds or even other shrubs. Here some critical points of the procedure are listed. The separation of organic matter and mineral parts needed for making statements I have already appealed. Further on, it is probable that there is a certain mixing of the organic and mineral part, because the limits are not exactly linear, what made it difficult while soil sampling. Another point is that in this thesis the focus was on leave litter. But there is the decomposition of roots, which makes a considerable part of SOM. For investigating substrate quality one could include other parameters. For example Bowman et al. (2001) proposed nitrogen content or Melillo et al. (1989) the lignocelluloseindex (LCI).
In summary I can state that statistically (significant) there is no difference between *Dryas octopetala* and *Salix reticulata* soil habitats concerning litter decomposition and organic matter. However there are morphological differences and clear tendencies in all parameters. Therefore I suggest the leaves of these plants are different in composition and thus *Dryas octopetala* leaves are decomposed harder. I assume that there is an additional effect that *Dryas octopetala* has a higher amount of biomass input, which leads to an apparent higher accumulation of *Dryas octopetala* litter. *Dryas octopetala* seems to grow quicker and produces more biomass. However this quantitative effect was not part of this thesis and further experiments should be done. The higher biomass production of *Dryas octopetala* is a different life strategy what leads to the plant physiological question how that better growth is possible. Decomposition is a complex process where many factors play at different times a more or less important role. Identifying influence factors of decomposition is the one but quantifying them seems even more difficult. This bachelor thesis focussed on the plant litter quality in a environment, where climatic conditions are limiting and though dominating decomposition process. The importance of the climatic conditions lead to the question how climate change is influencing the alpine zone in the future. The two open questions at the end show that this bachelor thesis could be extended, can be brought in a larger context and leads to further research questions.

5 Summary

The effect of litter quality on decomposition is the main focus of this bachelor thesis. The decomposition of plant material is an important process in the carbon cycle and is influenced by environmental factors, soil properties and litter quality. In the alpine zone, where soils are often very shallow, soil organic matter (SOM) makes a big part of the soil and has different important functions. The experimental side of this bachelor thesis is in Eastern Swiss Alps in the valley Val S-charl. Thereby two in the alpine zone widely spread plants *Dryas octopetala* and *Salix reticulata* have been chosen to investigate their decomposition. Morphological differences in litter accumulation between the two plants could be seen and their effects on different soil properties were analyzed. The different analyses of soil properties, namely pH value, CN ratio, C_{org} content and lignin analyses were indicators for decomposition state and degradability of the two species. The general hypothesis that the litter of *Dryas octopetala* is harder decomposable than the one of *Salix reticulata* was tested by the indicator analyses. For the statistics a mixed effects model was chosen, where the effect of species was tested and further factors such as location and horizon were included. Species did not show significant effects on any indicator parameter, but partially clear tendencies. pH value tended to be lower under *Dryas octopetala*, whereas CN ratio and C_{org} content were slightly higher. Even the additional analyses of Lignin indicators support the general hypothesis. The locations are very different and also soil depth showed a significant effect. The final conclusion is - although only showed with tendencies - that there is a higher accumulation in *Dryas octopetala* habitats due to input of lower litter quality. The effect of higher input of bad quality plant litter is restrained by different harsh environmental conditions in the alpine zone.

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7 Appendix

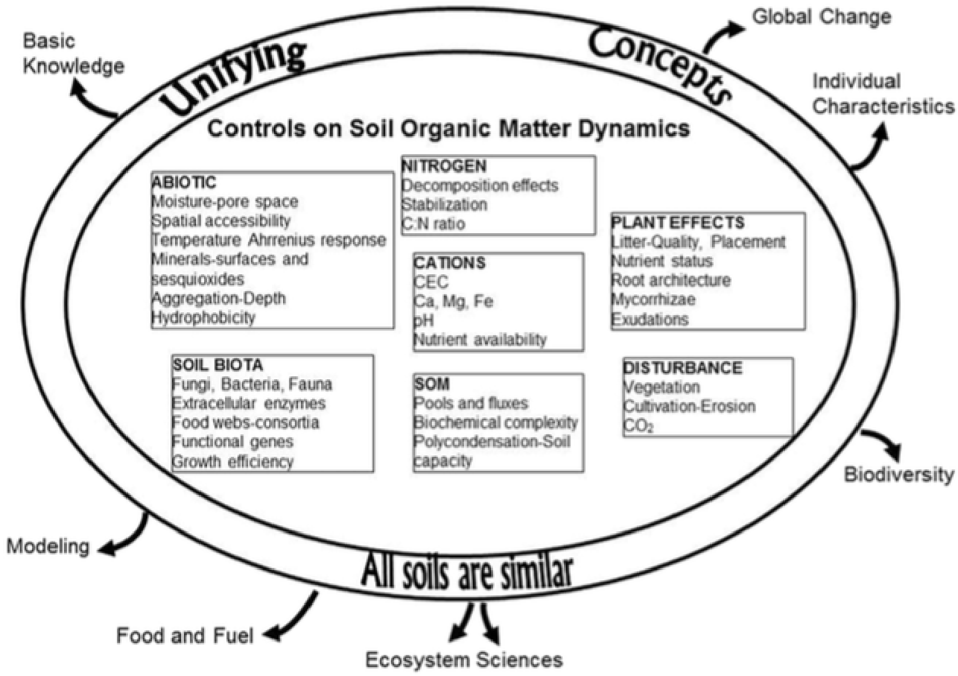

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Figure 19: The factors on soil organic matter formation

Klimanormwerte Buffalora

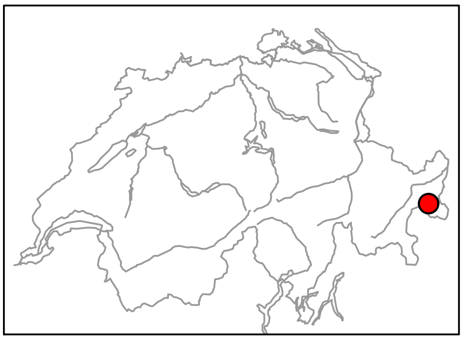
Normperiode 1981−2010

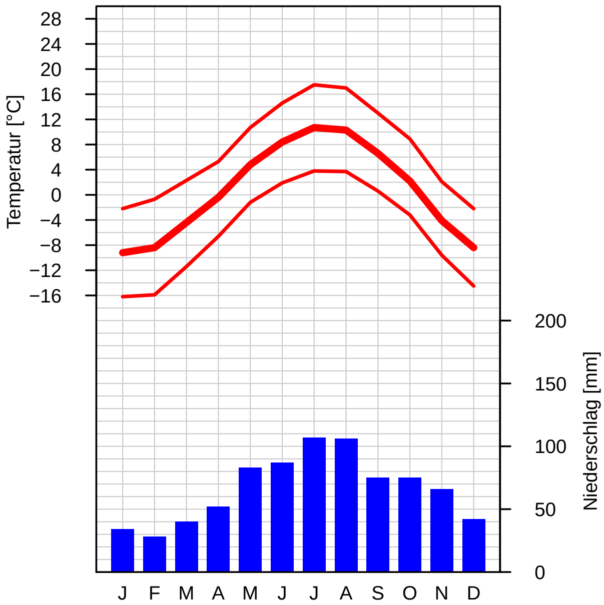
Höhe ü.M.: 1968 m

Geogr. Koord.: 46.65 N / 10.27 O

CH−Koord.: 816494 / 170225

Klimaregion: Engadin





	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez	Jahr	Periode
Temperatur [°C]	−9.2	−8.4	−4.4	−0.4	4.8	8.4	10.7	10.3	6.6	2.2	−4.1	−8.4	0.7	1981−2010
Maximumtemp [°C]	−2.2	−0.7	2.3	5.3	10.7	14.6	17.5	17.0	13.0	8.9	2.1	−2.2	7.2	1981−2010
Minimumtemp [°C]	−16.2	−15.9	−11.4	−6.6	−1.2	1.9	3.8	3.7	0.6	−3.2	−9.6	−14.5	−5.7	1981−2010
Eistage [Tage]	20.6	15.8	9.9	3.3	0.1	0.0	0.0	0.0	0.0	1.4	9.0	20.3	80.4	1981−2010
Frosttage [Tage]	31.0	28.2	30.7	28.7	20.0	9.1	4.0	3.4	12.6	24.4	29.2	31.0	252.3	1981−2010
Sommertage [Tage]	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.3	0.0	0.0	0.0	0.0	0.8	1981−2010
Hitzetage [Tage]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1981−2010
Relative Feuchte [%]	77	74	72	72	72	69	69	72	74	76	80	80	74	1981−2010
Niederschlag [mm]	34	28	40	52	83	87	107	106	75	75	66	42	793	1981−2010
Niederschlag [Tage]	7.0	5.8	7.4	9.1	11.2	11.3	11.3	11.0	8.8	8.3	8.1	7.4	106.7	1981−2010
Neuschnee [cm]	65.1	44.7	50.9	54.8	18.0	5.1	1.7	2.8	6.2	24.6	54.1	73.5	401.5	1981−1998
Neuschnee [Tage]	9.1	7.2	8.2	7.8	3.0	0.6	0.2	0.3	1.0	3.1	6.8	8.5	55.8	1981−1998
Schneedecke [Tage]	31.0	28.2	30.3	24.0	9.9	0.8	0.2	0.2	1.2	5.5	18.8	30.0	180.1	1981−1998
Sonne [h]	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sonne [%]	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Heitere Tage [Tage]	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Trübe Tage [Tage]	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Eidgenössisches Departement des Innern EDI
Bundesamt für Meteorologie und Klimatologie MeteoSchweiz

MeteoSchweiz

Klimanormwerte Scuol

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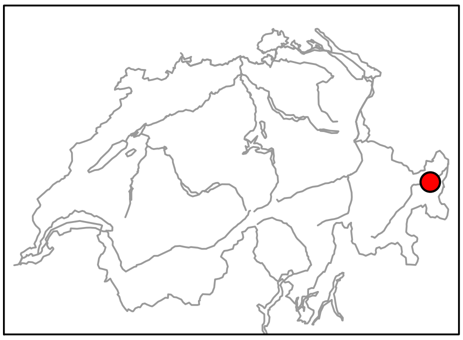
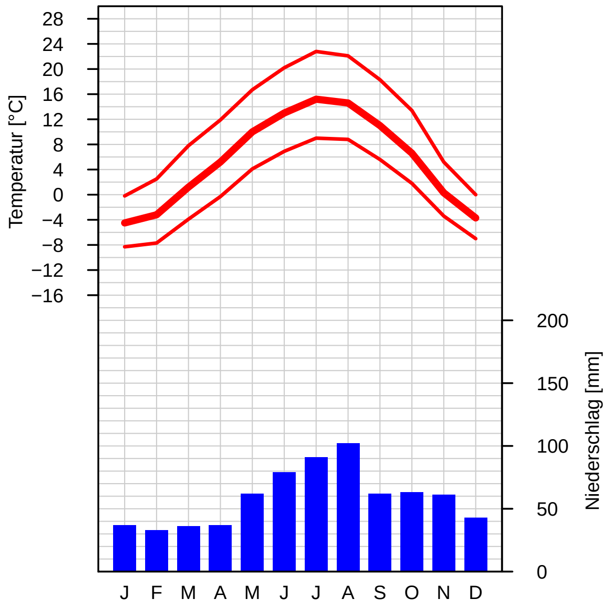
CH−Koord.: 817135 / 186393

Klimaregion: Engadin





	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez	Jahr	Periode
Temperatur [°C]	−4.5	−3.2	1.2	5.2	10.0	13.0	15.2	14.6	11.0	6.6	0.3	−3.7	5.5	1981−2010
Maximumtemp [°C]	−0.2	2.5	7.8	11.9	16.7	20.2	22.8	22.1	18.3	13.4	5.2	0.0	11.7	1981−2010
Minimumtemp [°C]	−8.3	−7.7	−3.9	−0.3	4.1	6.9	9.0	8.8	5.6	1.8	−3.4	−7.0	0.5	1981−2010
Eistage [Tage]	15.3	8.4	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	4.5	15.0	45.5	1981−2010
Frosttage [Tage]	30.7	27.7	26.1	15.6	3.0	0.4	0.0	0.0	0.9	9.0	24.1	30.1	167.6	1981−2010
Sommertage [Tage]	0.0	0.0	0.0	0.0	0.9	6.1	11.7	10.2	1.8	0.0	0.0	0.0	30.7	1981−2010
Hitzetage [Tage]	0.0	0.0	0.0	0.0	0.0	0.3	1.3	1.1	0.0	0.0	0.0	0.0	2.7	1981−2010
Relative Feuchte [%]	75	70	65	63	65	66	67	71	72	75	78	78	70	1981−2010
Niederschlag [mm]	37	33	36	37	62	79	91	102	62	63	61	43	706	1981−2010
Niederschlag [Tage]	5.6	5.1	5.6	6.3	9.2	10.1	10.5	11.1	7.5	7.6	7.2	6.8	92.6	1981−2010
Neuschnee [cm]	50.6	43.2	20.6	10.3	2.2	0.2	0.0	0.0	0.2	2.5	28.1	43.3	201.2	1981−2010
Neuschnee [Tage]	7.7	6.5	4.9	3.0	0.4	0.1	0.0	0.0	0.0	0.4	5.0	7.4	35.4	1981−2010
Schneedecke [Tage]	29.7	27.6	21.0	4.9	0.5	0.1	0.0	0.0	0.0	0.6	10.9	25.2	120.5	1981−2010
Sonne [h]	97	119	157	163	173	181	215	195	165	144	93	77	1779	1981−2010
Sonne [%]	56	56	53	48	44	45	53	53	53	56	50	50	51	1981−2010
Heitere Tage [Tage]	13.0	12.0	10.4	7.8	5.8	5.7	7.9	9.0	9.5	12.2	11.2	11.2	115.7	1981−2010
Trübe Tage [Tage]	10.3	8.5	8.3	9.2	9.6	8.5	6.1	7.2	8.0	8.9	11.0	12.0	107.6	1981−2010

climsheet 1.4.0 / 26.04.2016, Stand: 2016

1. Allgemeine Daten

Projekt	Landeskarte 1:25'000 Blatt-Nr.	Koordinaten	Datum	Wetter (Code)

Codes Wetter

1 schön
2 zeitweise sonnig
3 leicht bewölkt
4 stark bewölkt
5 unbeständig
6 Regen; Schneefall
7 Nebel

Aufnahmegruppe

Kanton

Gemeinde

Eigentümer

Photodokumentation

Film Nr. Photo Nr.

.... Bestand ....

.... Krautschicht ....

.... Profil ....

.... Oberboden ....

Übriges ....

....

....

....

....

2. Bodenbildungsfaktoren

Höhe ü. Meer (m)	Exposition	Hangneigung (%)	Relief (Code)	Mikrorelief (Code)

Codes Relief

Relief
1 ebene Fläche
2 Kuppe Oberhang
3 Mittelhang
4 Hangfuss, Mulde
5 unbestimmt

Mikrorelief
1 gleichmässig
2 mässig variabel
3 stark variabel

Geologie

Einheit Bodeneignungskarte

Bodenoberfläche ☐ roh ☐ mit Skelett ☐ mit Blöcken

Vorgänge unter der Bodenoberfläche

☐ stabil ☐ leicht schiefe Bäume
☐ stark schiefe Bäume ☐ zu bewegt für Bäume
☐ .... ☐ ....

Vorgänge an der Bodenoberfläche

☐ bewegtes Skelett ☐ bewegte Feinerde
☐ Steinschlag ☐ Blöcke (in Bewegung)
☐ Streuverlagerung ☐ Rinnenerosion

3. Angaben zur Vegetation

Waldgesellschaft nach ELLENBERG und KLÖTZLI (1972) ....

Klassierungsgrundlage der Waldgesellschaft

☐ Standortskarte
☐ Vegetationsaufnahme und Vegetationsschlüssel
☐ Standortansprache mit Vegetations- und Bodenschlüssel
☐ Schätzung aufgrund Vegetationsaspekt
☐ Schätzung aufgrund Vegetationsaspekt und Bodenmerkmalen

Bestandesbeschreibung

Baumarten und -anteile (%): ....

Baumhöhen und -alter: ....

Waldstruktur: ....

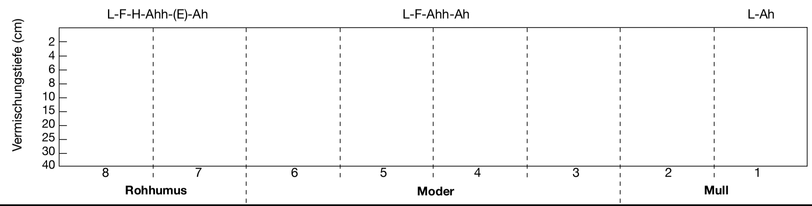
Deckungswerte Baumschicht .... % Strauchschicht .... % Zwergsträucher .... %

Krautschicht .... % Moosschicht .... %

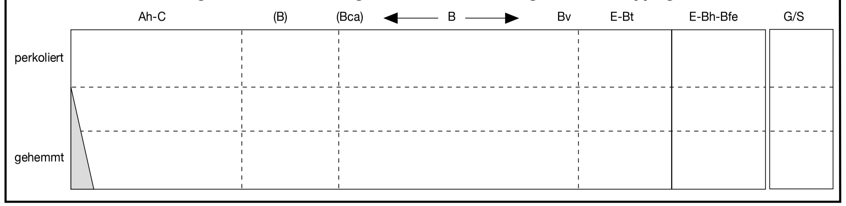
Bewirtschaftung heute .... früher ....

....

4. Variabilität der Humusform im Bestand



5. Profildifferenzierung sowie Vernässungstendenz mit Eintrag ins Oeko-Typogramm Mineralerde:



6. Bemerkungen (insbesondere Störungen)

7. Lageskizze des Bodenprofils

8. Nachbereitung

	Datum	Inhalt	Visum
Kontrolle			
Korrekturen			

Kleines Aufnahmeprotokoll

Zürcherstrasse 111, CH-8903 Birmensdorf, Schweiz FE Waldböden und Biogeochemie, Tel: 044-739 22 66

Dies ist ein wissenschaftliches Dokument.
Bitte senden Sie es an die genannte Adresse. Vielen Dank.

1 Aufschlussart	2 Bodenart (profilrelativ)	Profilnummer / Profilbezeichnung	3 Horizontierung	4 Wechsel Geologie/Substrat	5 Obergrenze (cm)	6 Skelettklasse	7 Skelettgrösse	8 Feinerde	9 Gefügeform	10 Aggregatstruktur (dominant)	11 Lagerungsdichte	12 Hydromorphie	13 Vernässung durch	14 aktuelle Bodenfeuchtigkeit	15 Humusgehalt	16 Bodenorganismen	17 pH-Hellige	18 Skelett / Feinerde — Karbonat	19 Kalkgrenze (cm)	20 Limite Wurzelraum	21 Farbe (Standard Soil Color Charts)	22 Sackprobe

Profilskizze

[cm] 20, 15, 10, 5, 4, 3, 2, 1, 0, 2, 4, 6, 8, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120

23 Humusformindex $\frac{Ah}{F+H+Ahh+Ah}$:

24 Humusform (Beilage 9):

Variante:

25 Horizontfolge:

26 Bodentyp (Beilage 10):

27 Vernässungsgrad (Beilage 11):

28 Bemerkungen zum Profil:

Codes zur Profilbeschreibung:

1 Aufschlussart
1 Profil
2 Bohrkern
3 Sticher
4 Spatenstich

4 Wechsel Geologie/Substrat
0 kein Wechsel
1 Gesteinswechsel (II)
2 Textur-, Strukturwechsel (2)
3 begraben

6 Skelettklassen
siehe Beilage 4
1 0– 5 %
2 5–10 %
3 10–20 %
4 20–50 %
5 50–75 %

7 Skelettgrösse
1 >75 % Feinskelett FS (0,2–5 cm)
2 >50 % FS, >25 % GS
3 >50 % FS, >25 % BL
4 >75 % Grobskelett GS (5–20 cm)
5 >50 % GS, >25 % FS
6 >50 % GS, >25 % BL
7 >75 % Blöcke BL (>20 cm)
8 >50 % BL, >25 % FS
9 >50 % BL, >25 % GS

8 Feinerde
Code siehe Beilage 1

9 Gefügeform
siehe Beilage 5
1 Einzelkorngefüge
2 Kohärentgefüge
3 Aggregats- /Segregatsgefüge

10 Aggregatsstruktur
siehe Beilage 5
1 krümelig (1– 10 mm)
2 polyedrisch (2– 50 mm)
3 subpolyedrisch (5– 30 mm)
4 prismatisch (30–300 mm)
5 plattig (1– 50 mm)
6 bröckelig (30– 50 mm)
7 klumpig (>50 mm)
8 Häute (Ton/Humus)

11 Lagerungsdichte
siehe Beilage 6
1 sehr locker (<0,8 g*cm–3 (org. Mat.))
2 locker (0,8–1,2 (Oberboden))
3 mittel (1,2–1,4 (B-Horizont))
4 dicht (1,4–1,8 (verdichtet))

12 Hydromorphie
siehe Beilage 7
0 keine
1 Konkretionen schwarz
2 Diffus-Rostflecken
3 Kontrast-Rostflecken
4 Fahl-Rot-Färbungen (Marmorierungen)
5 Reduktionsfarben (grau/blau/grün)
6 Buntfärbungen

13 Vernässung durch
1 Hangwasser
2 Grundwasser
3 Stauwasser

14 Aktuelle Bodenfeuchte
1 trocken 4 nass
2 frisch 5 gesättigt
3 feucht

15 Humusgehalt
siehe Beilage 8
0 humusfrei
1 humusarm <2 %
2 schwach humos 2–5 %
3 humos 5–10 %
4 stark humos 10–15 %
5 humusreich/anmoorig 15–20 %
6 sehr humusreich 20–30 %
7 organisch >30 %

16 Bodenorganismen
0 nicht sichtbar 2 Würmer
1 Pilzmyzel 3 Schnecken

18 Karbonat (Reaktion mit HCl)
0 kein Aufbrausen
1 schwaches " (hörbar)
2 mittleres " (schäumend)
3 starkes " (stark schäumend)

20 Limite Wurzelraum
1 offen
2 limitiert durch Fels
3 limitiert durch Verdichtung
4 limitiert durch Vernässung

21 Farbe
Code siehe Farbtafeln

24 Humusform
Codes siehe Beilage 9

25 Varianten
0 normale Ausprägung
1 Xero...
2 Feucht- oder Hydro....

Summary morphological analyses

Profil	Spezies	Horizonte	Tiefe [cm]	org. Auflage	Mächtigkeit [cm]	Humusgehalt	Bemerkung
1	Dryas	(L-)Ah-C	10	Nein	-	10 - 15 %	Mehrschichtig, da immer wieder von Geröll überdeckt
2	Salix	(L-)Ah-C	8	Nein	-	10 - 15 %	Mehrschichtig, da immer wieder von Geröll überdeckt
3	Salix	(L-)Ah-C	13	Nein	-	10 - 15 %	Steiles Gelände, Nähe zu Rinne
4	Dryas	L-Of-Ah-C	12	Ja	3	10 - 15 %	Steiles Gelände, Nähe zu Rinne, L, Of
5	Salix	(L-)Ah-C	13	Nein	-	5 - 10 %	viele Gräser, viele Feinwurzeln
6	Dryas	(L-)Ah-C	10	Nein	-	10 - 15 %	
7	Salix	L-Of-Ah-C	11	Ja	1	15%	sehr steinig, viele Gräser, viele Feinwurzeln
8	Dryas	(L-)Ah-C	10	Nein		10 - 15 %	
9	Dryas	L-Of-Ah-C	8	Ja	2	10 - 15 %	flachgründig, stark durchwurzelt im Skelett
10	Salix	L-Of-Ah-Cv-C	10	Ja	2	10 - 15 %	
11	Dryas	L-Of-Ah-Cv-C	11	Ja	3	10 - 15 %	
12	Salix	L-Of-Ah-Cv-C	12	Ja	3	10 - 15 %	grosse Felsblöcke
13	Dryas	L-(Of-)Ah-C	16	Ja	0.5	10 - 15 %	sehr schwache organische Auflage
14	Salix	L-Of-Ah-(B-)C(v)	14	Ja	2	10 - 15 %	Dryas vorkommend, erste Anzeichen eines B Horizonts
15	Salix	L-(Of-)Ah-C	18	Nein	-	5 - 10 %	
16	Dryas	L-Of-Oh-Ah-C	11	Ja	2	10 - 15 %	schwache organische Auflage
17	Salix	L-Of-Oh-Ah-C	10	Ja	8	20 - 30 %	mächtige organische Auflage, sehr dunkel, stark durchwurzelt
18	Dryas	L-Of-Oh-Ah-C	8	Ja	11	20 - 30 %	mächtige organische Auflage, sehr dunkel, stark durchwurzelt, viel Gras, Anzeichen einer Verbraunung
19	Salix	L-Of-Oh-Ah-C	11	Ja	4	20 - 30 %	sehr wenig Salix
20	Dryas	L-Of-Oh-Ah-C	10	Ja	5	20 - 30 %	Kuhweide
21	Dryas	L-Of-Oh-Ah-C	9	Ja	9	20 - 30 %	stark ausgeprägter Of, Ah ist sehr humos
22	Salix	L-Of-Oh-Ah-C	15	Ja	4	15 - 20 %	sehr spärlich mit Salix durchsetzt, viel Moos
23	Salix	L-Of-Oh-Ah-C	9	Ja	4	20 - 30 %	sehr wenig Salix, Dryas gerade oberhalb, sehr steinig
24	Dryas	L-Of-Oh-Ah-C	10	Ja	5	20 - 30 %	Skelett und OS vermischt

Summary table of parameter measurements

Profil	Spezies	Standort	Plot	Höhe	Koordinaten	Horizont	pH	Corg	C:N
P1_1	Dryas	1	1	2296	824572/173870	1	7.21	3.39	17.08
P1_2	Dryas	1	1	2296	824572/173870	2	7.18	3.74	14.72
P2_1	Salix	1	1	2296	824572/173870	1	7.25	4.38	13.99
P2_2	Salix	1	1	2296	824572/173870	2	7.25	2.56	12.61
P3_1	Salix	1	2	2296	824576/173872	1	6.98	9.15	17.15
P3_2	Salix	1	2	2296	824576/173872	2	7.03	6.26	13.42
P4_1	Dryas	1	2	2296	824576/173872	0	7.13	19.23	24.05
P4_2	Dryas	1	2	2296	824576/173872	1	7.27	6.38	16.19
P4_3	Dryas	1	2	2296	824576/173872	2	7.29	3.48	11.14
P5_1	Salix	1	3	2301	824571/173840	1	7.36	2.8	16.57
P5_2	Salix	1	3	2301	824571/173840	2	7.28	4.06	16.92
P6_1	Dryas	1	3	2301	824571/173840	1	7.23	7.29	18.13
P6_2	Dryas	1	3	2301	824571/173840	2	7.24	4.44	13.85
P7_1	Salix	1	4	2309	824589/173858	1	6.93	12.08	19.53
P7_2	Salix	1	4	2309	824589/173858	2	7.02	9.69	17.57
P8_1	Dryas	1	4	2309	824589/173858	1	6.99	9.56	22.10
P8_2	Dryas	1	4	2309	824589/173858	2	7.03	6.45	17.77
P9_1	Dryas	2	5	2130	823838/174318	0	5.37	32.072	22.38
P9_2	Dryas	2	5	2130	823838/174318	1	6.74	6.756	13.97
P9_3	Dryas	2	5	2130	823838/174318	2	7.07	3.048	12.31
P10_1	Salix	2	5	2130	823838/174318	0	6.72	22.51	20.43
P10_2	Salix	2	5	2130	823838/174318	1	7.08	4.178	13.59
P10_3	Salix	2	5	2130	823838/174318	2	7.46	1.856	14.73
P11_1	Dryas	2	6	2137	823862/174290	0	6.03	28.407	24.85
P11_2	Dryas	2	6	2137	823862/174290	1	6.99	3.895	16.30
P11_3	Dryas	2	6	2137	823862/174290	2	7.46	1.101	15.08
P12_1	Salix	2	6	2137	823862/174290	0	6.89	13.421	19.51
P12_2	Salix	2	6	2137	823862/174290	1	7.31	2.578	14.94
P12_3	Salix	2	6	2137	823862/174290	2	7.50	1.172	15.94
P13_1	Dryas	2	7	2136	823863/174297	1	7.00	5.732	11.78
P13_2	Dryas	2	7	2136	823863/174297	2	7.38	3.655	13.29
P14_1	Salix	2	7	2136	823863/174297	0	6.82	20.191	20.06
P14_2	Salix	2	7	2136	823863/174297	1	7.26	4.141	13.90
P14_3	Salix	2	7	2136	823863/174297	2	7.43	1.655	11.33
P15_1	Salix	2	8	2142	823876/174277	1	7.28	3.958	15.96
P15_2	Salix	2	8	2142	823876/174277	2	7.54	1.548	17.10
P16_1	Dryas	2	8	2142	823876/174277	1	7.30	3.46	23.38
P16_2	Dryas	2	8	2142	823876/174277	2	7.32	1.527	13.51
P17_1	Salix	3	9	2321	822471/175360	0	5.90	23.637	14.63
P17_2	Salix	3	9	2321	822471/175360	1	5.81	11.273	12.68
P17_3	Salix	3	9	2321	822471/175360	2	5.61	6.695	12.18
P18_1	Dryas	3	9	2321	822471/175360	0	5.48	29.735	16.39
P18_2	Dryas	3	9	2321	822471/175360	1	5.07	8.808	11.59
P18_3	Dryas	3	9	2321	822471/175360	2	5.17	4.234	11.40
P19_1	Salix	3	10	2337	822433/175336	0	5.78	28.199	14.33
P19_2	Salix	3	10	2337	822433/175336	1	5.70	11.462	10.84
P19_3	Salix	3	10	2337	822433/175336	2	5.76	6.807	10.55
P20_1	Dryas	3	10	2337	822433/175336	0	5.72	25.653	14.58
P20_2	Dryas	3	10	2337	822433/175336	1	5.54	12.743	11.27
P20_3	Dryas	3	10	2337	822433/175336	2	5.67	9.861	11.70
P21_1	Dryas	3	11	2334	822429/175336	0	6.10	39.409	19.79
P21_2	Dryas	3	11	2334	822429/175336	0	5.86	20.016	13.35
P21_3	Dryas	3	11	2334	822429/175336	1	5.81	13.958	11.64
P21_4	Dryas	3	11	2334	822429/175336	2	5.42	9.176	10.80
P22_1	Salix	3	11	2334	822429/175336	0	5.68	16.686	13.73
P22_2	Salix	3	11	2334	822429/175336	1	5.69	6.068	12.87
P22_3	Salix	3	11	2334	822429/175336	2	5.59	4.918	11.86
P23_1	Salix	3	12	2331	822426/175340	0	5.66	29.51	21.21
P23_2	Salix	3	12	2331	822426/175340	1	5.20	14.537	16.73
P23_3	Salix	3	12	2331	822426/175340	2	5.15	9.345	16.15
P24_1	Dryas	3	12	2331	822426/175340	0	5.22	34.291	17.89
P24_2	Dryas	3	12	2331	822426/175340	1	4.81	17.647	15.78
P24_3	Dryas	3	12	2331	822426/175340	2	4.84	11.07	15.31

Lignin values (potential regression)

Plot	Type	Species	VSC-sum	C/V	S/V	(Ac/Al)V	(Ac/Al)S
1	duerr	Dryas	36.6927467	1.570025208	0.88570142	0.016536903	0.98351275
2	duerr	Dryas	37.7292334	1.743951345	1.23293139	0.017093822	0.57196149
3	duerr	Dryas	36.5307041	1.795192398	1.20668164	0.019969799	0.56032099
4	duerr	Dryas	28.8597268	1.812837888	1.20293233	0.016253988	0.80975889
1	duerr	Salix	18.2767804	1.449433567	1.01282696	0.053187059	1.89041636
4	duerr	Salix	23.5618858	1.276984674	1.04818708	0.051430612	1.83471639
3	duerr	Salix	13.9842252	1.605648153	1.24421677	0.055237	1.80351193
2	duerr	Salix	26.6542673	1.226745719	1.01387186	0.026059624	1.98263954
1	gruen	Dryas	75.5441837	1.214219552	7.53103563	1.59373E-09	0.04011693
2	gruen	Dryas	22.4296099	1.102424649	3.59029383	2.12585E-09	0.11518857
3	gruen	Dryas	79.0949654	0.974887266	9.41199693	1.38727E-09	0.00996255
4	gruen	Dryas	42.2930825	0.884181566	6.12739777	6.40684E-10	0.02768747
1	gruen	Salix	8.38131888	1.268282535	1.66115946	1.57413E-10	8.13795138
2	gruen	Salix	36.1773412	3.203880861	0.24326008	0.008401307	2.44356562
3	gruen	Salix	36.9164391	0.939851407	0.67109795	8.56214E-10	3.03623397
4	gruen	Salix	133.714834	0.025282498	0.0931242	1.88266E-08	12.859118
1	Boden	Salix	2.16617682	6.423173666	4.04930864	0.061901894	1.48985617
2	Boden	Salix	1.01378983	5.679129434	3.8526975	0.04134954	2.08877459
3	Boden	Salix	0.76910062	6.486097856	4.59217479	0.178141568	2.27072442
4	Boden	Salix	0.096917	2.005442871	41.9467372	8.92426E-32	21.2104552
1	Boden	Dryas	0.5166897	1.31051E-05	2.4456E-05	139083.3269	1.20459736
2	Boden	Dryas	1.17088943	4.648702285	3.08920515	2.11562E-05	0.84251894
3	Boden	Dryas	0.84486115	5.128840598	4.11748639	1.77024E-05	0.67432715
4	Boden	Dryas	0.87283642	5.870297936	3.91718834	2.95358E-05	0.76544663

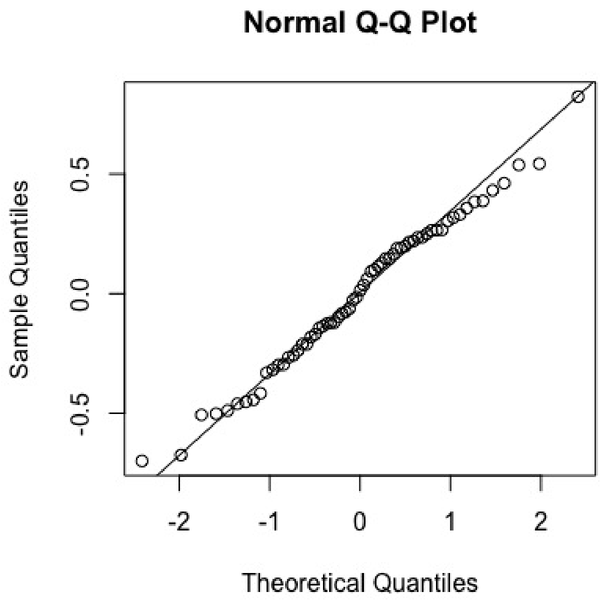


Figure 20: QQ-Plot of C_{org} data

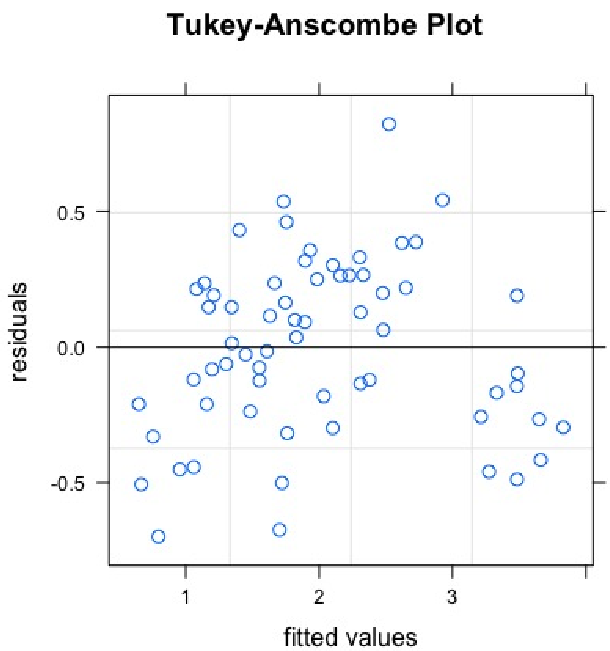


Figure 21: TA-Plot of C_{org} data

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Eigenständigkeitserklärung

Die unterzeichnete Eigenständigkeitserklärung ist Bestandteil jeder während des Studiums verfassten Semester-, Bachelor- und Master-Arbeit oder anderen Abschlussarbeit (auch der jeweils elektronischen Version).

Die Dozentinnen und Dozenten können auch für andere bei ihnen verfasste schriftliche Arbeiten eine Eigenständigkeitserklärung verlangen.

Ich bestätige, die vorliegende Arbeit selbständig und in eigenen Worten verfasst zu haben. Davon ausgenommen sind sprachliche und inhaltliche Korrekturvorschläge durch die Betreuer und Betreuerinnen der Arbeit.

Titel der Arbeit (in Druckschrift):

The effect of different plant litter on decomposition process in the alpine zone

Verfasst von (in Druckschrift):

Bei Gruppenarbeiten sind die Namen aller Verfasserinnen und Verfasser erforderlich.

Name(n):	**Vorname(n):**
Muheim	Luis

Ich bestätige mit meiner Unterschrift:

- Ich habe keine im Merkblatt beschriebene Form des Plagiats begangen.
- Ich habe alle Methoden, Daten und Arbeitsabläufe wahrheitsgetreu dokumentiert.
- Ich habe keine Daten manipuliert.
- Ich habe alle Personen erwähnt, welche die Arbeit wesentlich unterstützt haben.

Ich nehme zur Kenntnis, dass die Arbeit mit elektronischen Hilfsmitteln auf Plagiate überprüft werden kann.

Ort, Datum	**Unterschrift(en)**
Zürich, 23.01.17	L. Muheim

Bei Gruppenarbeiten sind die Namen aller Verfasserinnen und Verfasser erforderlich. Durch die Unterschriften bürgen sie gemeinsam für den gesamten Inhalt dieser schriftlichen Arbeit.