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Carbon stocks in sight



Carbon stocks in sight:

High-resolution vertical depth profiles to quantify carbon reservoirs in the NOBV research sites

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Abstract

Carbon stocks in sight: high-resolution vertical depth profiles to quantify carbon reservoirs in the NOBV research sites

When studying carbon emissions from peatlands and the effectiveness of different mitigation measures it is essential to scale the observed fluxes (net emissions) to the available soil carbon (C) stocks. In this study we present high resolution carbon profile data for all NOBV research locations to quantify their total carbon stock. We determined the botanical composition, measured the bulk density, organic matter content and composition and the degree of degradation using extraction techniques and stable isotopes of N and C. Based on these data we gained insight in the total carbon pool sizes, the variance in chemical composition of the peat layers and the peat degradation stage along the depth profiles. We combined these C stock data with the site-specific groundwater dynamics and divided the carbon stocks into different risk classes for aerobic decomposition, depending on the number of days that they were above the actual groundwater level. Average carbon stocks were 87 kg/ m² based on a usual soil profile depth of 120cm. Strikingly, carbon stocks in a peaty soil were similar to a relative undisturbed peat due to the higher density of the organic matter in degraded soils. Carbon stocks in plots with water infiltration measures were generally in the same order of magnitude as stocks in the reference counterpart plots, apart from Zegveld, where the water infiltration plot had a substantially lower carbon stock than the reference plot. Overall, water infiltration measures resulted in lower amounts of carbon exposed to aerobic conditions for most days of the year (>245 days) and lower amounts exposed during dry summer months (<30 days) but slightly higher permanently oxidized carbon stocks in the topsoil, due to drainage in wet winter months.

Research highlights

- 1) Carbon stocks ranged from 66-128 kg/m² based on a 120 cm soil profile and from 100-180 kg/m² based on a soil profile depth of 200 cm. In peaty soils, C stocks can be in the same order of magnitude as those of relatively undisturbed peat soils due to the higher density of organic matter.
- 2) In general, we found an average carbon content of 47% for organic matter in Dutch peat soils, which is substantially lower than the commonly used parameter of 50-58%. We need to consider if differentiated percentages are needed for different clastic layers and peat degradation classes in the SOMERS model.
- 3) Field plots with water infiltration systems have lower carbon contents which are exposed for most days of the year (>245 days) and during dry summer months (<30 days). In contrast these measures result in slightly higher permanently oxidized carbon contents in the top of the profile due to winter drainage.
- 4) Degradation proxies largely followed the hydrological gradient with a clear decrease in $\delta^{15}\text{N}$ with depth and shifts in ratios between acid soluble to acid insoluble organic fractions indicating a specific preservation of lignin type of substrates in anoxic peat layers.
- 5) C:N ratios are strongly affected by botanical origin of the peat

1 Introduction

The Dutch National Research programme on Greenhouse Gases in Peat Meadows (NOBV) quantifies greenhouse gas fluxes (emissions and uptake) from organic soils in the Netherlands. The main objective of the project is to assess the effects of emission mitigation measures as water infiltration systems (WIS) and paludiculture, to diminish greenhouse gas emissions (CO_2 , CH_4 and N_2O) and reduce associated land subsidence.

In this context carbon fluxes refer to the amounts of C that are exchanged between soils and the atmosphere. The overall balance between carbon uptake through photosynthesis and soil emission (CO_2 and CH_4) determines if an organic soil can be considered a source or a sink of carbon (Tiemeyer et al., 2016; Lee, et al., 2017). This in turn determines its contribution to the atmospheric CO_2 concentration leading to enhanced radiative forcing (Günther et al 2020). The size of the outgoing carbon flux depends (amongst several other factors) on the amount of carbon present in the soil profile (i.e. the carbon stock), the resistance of carbon compounds to microbial decomposition and the exposure of this carbon to aerobic conditions.

Peat soils in the Netherlands vary widely both in composition and stratification. Peat layers differ for instance in density (degree of compaction), organic matter content and origin, and mineral admixture (Van Asselen 2011; Erkens et al., 2016). For the NOBV project it is important to gain insight in the total amount of carbon stored in peat soils in order to compare carbon reservoirs of peat soils with humic mineral soils, podzols and peaty soils and to relate the observed emissions (C-fluxes) to the size of these carbon pools. The total carbon pools in peatlands are highly variable due to the large differences in thickness of the peat deposits ranging from 6-10 meter in the Western peat district to generally <1 meter in the Northern peat area. Peat thickness is mapped in detail for the Province of Utrecht (Stouthamer et al., 2008) and for the Netherlands by the WUR (De Vries et al., 2014). Regular updates of these maps are needed because organic layers in drained peat soils are getting thinner due to peat decomposition which may even lead to a declining area where soils meet the peat definition.

When quantifying net carbon emissions from peatlands and the effectiveness of mitigation measures to decrease net emissions, it is essential to gain insight in the soil carbon stock that is vulnerable to decomposition over time. The size of the vulnerable carbon stock can be an additional determinant of emissions next to measured emissions. When studying carbon stocks, we need to consider three important aspects, which are further explained in sections 1.1 to 1.3; **1)** the C content and density of the organic matter in different peat layers, **2)** the quality, chemical composition and degradation stage of the organic material and **3)** the position of the C relative to the groundwater levels as a proxy for exposure to aerobic conditions. Additionally, numerical models used to predict effects of measures on CO_2 emissions from organic soils distinguish between the different carbon pools (e.g. Peatland-VU;), or focus on one pool (e.g. SOMERS; Erkens et al., 2022). For the calibration and validation of these models we need to gain insight in the carbon stocks from field sites and couple them to field flux measurements. This chapter presents a first descriptive exploration of the carbon profile data. Future analysis will include a more in-depth (statistical) data analysis. A next substantive step will be the addition of temperature profiles and oxygen demands of specific peat layers will be included to connect insights in peat carbon profiles, peat exposure and peat degradation stage to inform and improve national emission registration models.

1.1 Carbon content and density of organic matter in peat soils

In the Dutch soil classification, peat is defined as material with an organic matter percentage of > 22 (if 0% clay) to >55% (if clay contents are 45%) on weight basis (De Vries et al., 2014). Peaty material (moerig materiaal) is defined as material with at least 15% organic material (at 0% clay) to 30% organic material (if clay contents are 70%) (De Vries et al., 2014).

Peat soils contain peat material within the 0- 80 cm layer with a thickness of at least 40 cm. Peaty soils have peaty material in the topsoil of up to 40 cm thickness or an interlayer of 5 to 40 cm thickness within 40 cm from the soil surface. The bulk density and carbon concentration of organic matter can vary based on the degree of degradation, porosity, botanical peat type, compaction and mineral admixture. This will in turn affect the carbon stock and potential for carbon emissions from peat soils. Erkens et al., (2016) calculated the average organic matter density in peat soils to be 103 kg/m³ with a lower and upper estimated average of 80 - 150 kg/m³ respectively. The range of samples used for their analysis comprised some extreme samples of deep peat deposits and peat layers underneath dikes. These peat deposits are not relevant for soil-atmosphere exchange. Here we limit ourselves to the analysis of relatively shallow peat layers (up to 2 m depth) under seminatural and agricultural land use to obtain more directed data for the evaluation of emission mitigation measures.

Generally, C contents of peat are derived directly from organic matter contents using a conversion factor; the Soil Organic Carbon/Soil Organic Matter ratio (SOC/SOM). A general conversion factor used in soil science for all soils combined (organic and inorganic) is 0.58 (Buringh 1984). Although we know that organic matter in mineral soils differs greatly from organic matter in peat soils in terms of composition, chemical complexation and degree of degradation, the same factor is used in the peat map of Europe (Montanerella et al., 2006). In contrast, Kuikman et al., (2003) used a lower conversion factor of 0.5 for stocks of C in Dutch soils to estimate CO₂ emissions. Klingenfuss et al., (2014) focussed on peat soils and suggested differentiating between peat types with 0.58 for peat from vascular plants, 0.5 for Sphagnum based peat and 0.41 for amorphous peat and humic sands (although this latter category shows a large variability). As the carbon content of organic matter is a crucial parameter in our national GHG inventory model instruments, we wanted to determine whether it would be necessary to use different conversion factors for different peat regions or botanical peat types.

1.2 Chemical composition of the organic material as a proxy for the degree of decomposition

The chemical composition of peat layers along a depth profile provides information on the peat origin and its microbial processing. As peat that is decomposed by microbial activity releases C in gaseous form (CO₂ and CH₄) to the atmosphere while N remains largely in the profile, the C:N ratios in organic matter generally decreases with the degree of degradation and age.

Consequently, the C:N ratio is often proposed as a proxy for degradation status in homogenous peat soils (Kuhry & Vitt 1996). However, C:N ratios in the peat profile are also governed by the botanical composition and can even be influenced by N deposition, fertilisation and hydrological conditions. This complicates the interpretation of C: N as a proxy for peat degradation (Leifeld et al., 2020). Stable isotopes $\delta^{15}\text{N}$ -nitrogen and $\delta^{13}\text{C}$ -carbon are other well-known proxies for the degree of peat decomposition (Hobbie et al., 2017, Drollinger et al., 2019, Groß-Schmolders et al., 2022). Because there is an isotopic discrimination taking place during biogeochemical/microbial transformations (preference for the lighter isotopic), accumulation of the heavier isotopes occurs in the bulk soil as compared to newly formed peat. Hence, a higher $\delta^{15}\text{N}$ indicates a higher degree of degradation. Direct interpretation of the isotopic signature is hampered, however, by the fact that the initial isotopic signature can differ between peat forming vegetation types and the conditions as a result of microbial degradation and isotopic fractionation during photosynthesis (Hobbie et al., 2017, Drollinger et al., 2019). Although microbial processing of SOM is the dominant driver of $\delta^{15}\text{N}$ in pristine peat, organic fertilizer and compost application in agricultural systems can substantially alter the stable isotope ratios in the bulk soil (Shearer, et al 1974).

Peat is built up of organic compounds, which can generally divided into five compound groups, differing in molecular structure and complexity: lignin, hemicellulose, cellulose, sugars and waxes. Microbial transformation shifts the relative amount of these groups in peat through preferential consumption. Microbes (mostly fungi) degrade lignin under oxic conditions, while lignin

degradation is very limited under the anoxic conditions in deeper peat layers. Hence, the proportions of polysaccharides (i.e. hemicellulose, cellulose) generally decrease with depth while the proportions of lignin increase due to a lower degradation rate of aliphatic- and phenolic-rich material under anoxic conditions (Serk et al., 2022, Hayes et al., 2015; Freeman et al., 2004). The relative proportion of groups of organic compounds is obtained using sequential carbon extractions. The relative proportions of organic compounds vary between the botanical peat composition. Fen peats, which mainly consists of vascular plants and woody material, are characterized by high lignin and high protein content (60-75 % of the bulk) and N contents of 2-4%. Conversely, bog peats dominantly consist of Sphagnum moss, which has higher hemicellulose and cellulose contents and low <2% N-content. Botanical origin also influences the type of lignin and aromatic compounds. (Waksman, 1937).

1.3 The position of the carbon stock relative to the groundwater level

In this chapter, we quantified the C stocks in the top 200 cm of the soil as we assume that this - in geological terms “shallow” - layer is subject to climatic and anthropogenic changes, whereas deeper layers are assumed to remain preserved. Additionally, C stocks are presented in separate figures for the top 120 cm as this is the usual soil depth for profile descriptions and matches the profile depth in the emission registration models and literature. The carbon depth and density profiles combined with detailed groundwater monitoring data provide information on the exposure time to unsaturated soil conditions. Unsaturated conditions facilitate oxygen intrusion, which in turn promotes high rates of microbial breakdown of the peat substrate through heterotrophic respiration (Freeman et al., 2001). Based on the combined carbon profile data and site-specific groundwater dynamics, we divided the site-specific carbon stocks into different risk classes depending on the number of days that they were above the groundwater level.

1.4 Objectives, main research questions and hypothesis

The aim of this study is to determine the current carbon stocks and peat degradation status of peat soils in the NOBV monitoring sites and identify the size of the carbon stock that is at risk of microbial degradation as it is exposed to unsaturated soil conditions. We focus on the carbon content and density of the organic matter, the chemical composition and the degree of degradation with this information, we aimed to answer the following research questions:

- What is the effect of mineral admixture, degree of peat degradation and bulk density on the size of the carbon stocks?
- What is the carbon content in peat organic matter (SOC/SOM ratio) and is there a need to discriminate SOC/SOM conversion factors for different botanical peat types?
- Do peat degradation proxies show clear pattern with depth and groundwater dynamics?
- Are carbon stocks comparable between NOBV research locations and within locations between mitigation measure vs control plots)?
- Does the size of the unsaturated carbon stock (carbon at risk of oxidation) decrease with water infiltration measures?

We hypothesize that peat soils with a clay cover or mineral soils that originate from peat soils that have been subjected to excavation or extensive drainage, have significant lower total carbon stocks in the depth profile compared to more pristine peat profiles. We also expect that specific SOC/SOM conversion factors are needed for soils with a high mineral admixture and peaty soils with degraded organic matter as this organic matter is expected to have lost C during degradation. Finally, peat degradation proxies (C:N, Stable isotopes, C fractionation) are expected to show lower peat degradation levels in peat that is permanently saturated compared to the unsaturated layer.

2 Methods / study area

2.1 Field methods

Between June 2021 and November 2022, peat profiles were collected at each of the NOBV locations (Table 1.1). Detailed descriptions of the NOBV research plots are described in Kruijt et al., in prep Van Asselen et al., in prep). Peat profiles were sampled up to 2 m down to the permanently saturated zone of the Holocene sequence, or to the underlying Pleistocene deposits when the Holocene sequence was shallower than 2 metres. For this purpose, a peat column was extracted by hand coring using a 1-meter-long gouge (6 cm diameter) and using extension rods to be able to sample up to 2 metres depth. Generally, we sampled in one single borehole without overlapping depth intervals unless peat samples showed disturbance effects or when cores were incomplete. When disturbance effects were visible additional overlapping cores were taken within centimetres or decimetres of the original borehole. To ensure that the column was representative of the site, a hand coring was carried out prior to core sampling, and was described in the field according to the standard soil and peat description protocol (Erkens et al., 2013). Compaction during coring was avoided and checked regularly by measuring the extracted core length and the depth of the borehole. The profile was compared with previous geological and soil profile descriptions at the study site. If similar the carbon core was obtained at the same location (a few decimetres away from the bore hole used for core description). In the field, the core was wrapped in foil, PVC tubes and a tailor-made plastic bag directly after extraction to minimize exposure to air which might cause evaporation and peat oxidation, and transported horizontally to the laboratory.

In some cases, additional undisturbed bulk density samples were taken from the topsoil as coring force sometimes distorted the loose topsoil. These bulk density samples were taken using a foil sampler, root auger, 20 cm diameter PVC rings or 100cc bulk density rings depending on the density of the rooting zone and peat consistency.

2.2 Laboratory methods

In the laboratory, cores were cut open longitudinally using a thin steel wire. The inner, least disturbed part of the core was sampled at a 5 cm interval with a 1 x 1 x 5 cm sampling apparatus (Van Asselen, 2011). For each sample/depth interval we determined the field bulk density using a fixed volume (5 cm³), gravimetric moisture content based on fresh weight-dry weight difference (oven dry soil 70 degrees for 48 hours), organic matter content using the loss on ignition method by weighing the dried soil material (5-10 g) in a porcelain crucible and combusted to constant mass in 5 hours in an annealing furnace at 550 °C (Heiri et al., 2001). The carbon (C) and nitrogen (N) content of homogenised dried soil was determined by analysis on a CNS elemental analyser (Vario Micro Cube, Elementar). Stable isotope ratios of ¹⁵N: ¹⁴N and ¹³C: ¹²C were analysed by coupling a CNS elemental analyser (EA NA1500, Carlo Erba) to an IRMS (Delta V Advantage IRMS, Thermo Fisher Scientific) via a ConFlo III interface (Thermo Fisher Scientific). Total phosphorus (P), iron (Fe) and sulphur (S) contents were determined by digesting 200 mg of homogenised soil with 5 mL 65% HNO₃ and 2 mL 30 mL H₂O₂ in a microwave (Milestone microwave type mls 1200 mega of Ethos Easy). Samples were subsequently analysed using inductively coupled spectrometry (ICP-OES ARCOS, Spectro Analytical Instruments, Germany). Besides the above mentioned physical and chemical parameters, carbon fractionation was carried out with a Soxhlet extraction technique on a selection of the samples. Using this method, four fractions of organic matter can be determined, namely the nonpolar extractives, the water-soluble fraction, the acid-soluble fraction and the non-acid-soluble fraction (Ryan et al. 1990). This method assumes that nonpolar extractives consist of fats, oil and wax, the acid-soluble fraction is representative for the cellulose and hemicellulose type of compounds, and the non-acid-soluble

fraction is indicating the lignin, cutin and suberin compounds. In short, 1 g of dried soil samples (70°C for 48 hours) weighed and transferred to labelled Ankom filter bags (F57). This is followed by four separate extraction drying and weighing steps. Extractions were performed with dichloromethane (CH₂Cl₂), heated demineralised water and sulphuric acid. To determine the remaining mineral fraction the bags were combusted at 550°C for 5.5 hours. The acid insoluble carbon is defined as the organic matter fraction that is lost during the final loss on ignition step.

Table 2.1. NOBV Sample areas for the carbon profiles

Locatie	Type perceel	Number of profiles
Aldeboarn (ALD)	Reference and treatment	2
Rouveen (ROV)	Reference and treatment	2
Assendelft (ASD)	Reference and treatment	2
Ankeveen (ANK)	Paliduculture <i>Typha</i> spp.	1
Zegveld (ZEG)	Reference, treatment, managed high GWL, <i>Miscanthus</i> , Clay-addition.	5
Weerribben (KAL)	Floating peat raft and baulk	2
Vlist (VLI)	Reference and treatment	2
Lange Weide (LAW)	Managed high GWL	1
Demmerik (DEM)	Unmanaged high GWL	1
Vegelingsoord (VEG)	Peaty soil	1
Ilperveld (ILP)	Paliduculture <i>Sphagnum</i> spp.	1
TOTAL		20

2.3 Data analysis

Groundwater classes with boundaries of at least 355, 245, 30 and 7 days above groundwater level were determined based on daily groundwater level data obtained for a selection of the NOBV-research sites (Van Asselen et al in prep). Next, based on the groundwater classes, we calculated the carbon quantities exposed to unsaturated conditions for respectively 7, 30, 245, or 355 days

The graphs with the continuous cumulative groundwater data are given in the appendix (Figure A1). Cumulative carbon stocks were based on bulk density data and carbon concentrations for each depth interval. For shorter profiles (i.e. Ankeveen and Vegelinsoord) the carbon data of the missing layers were assumed to be the same as the deepest sampled sand layer. Cumulative carbon stocks include these sand layers to a depth of 2 metres. Cumulative carbon data for all NOBV site with depth are shown in Appendix (Figure A2).

3 Results

3.1 Soil carbon profiles

Figure 1 presents carbon concentration trends with depth. Trends are comparable between the measure and reference plots at one location (blue vs orange lines) except for Zegveld, where the carbon content of the plot with a measure is lower than the reference plot.

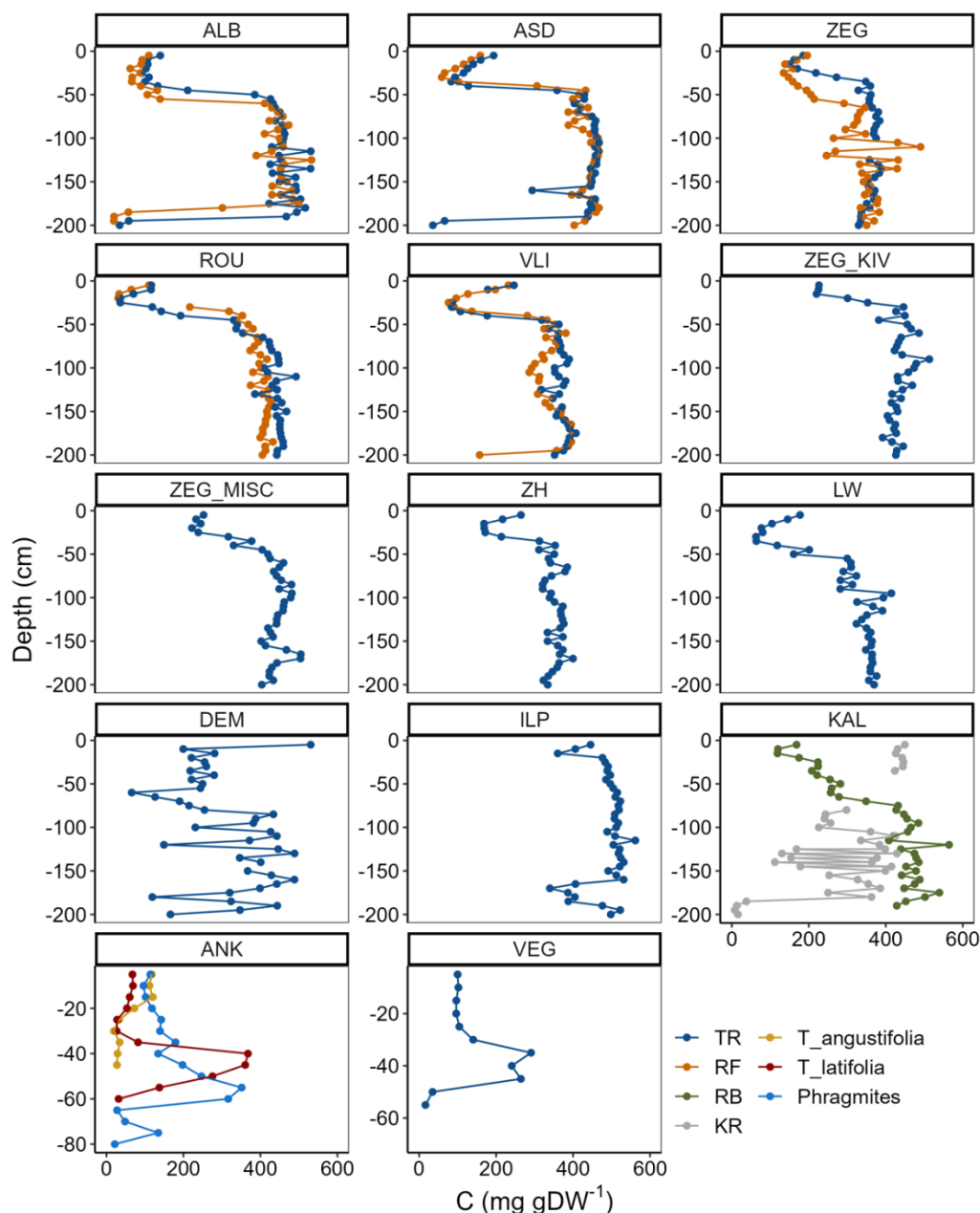


Figure 1. Carbon concentration (mg C g/DW) along a depth gradient at the sample locations. For abbreviations of study sites names see table 1.1. Blue lines represent sites with a measure as treatment (TR; infiltration, raised ditch water levels or paludiculture, while orange lines represent reference sites (RF; conventional agricultural parcels). In ANK, profiles were collected in each of the alternative crops (*Typha latifolia*, *T. angustifolia* and *Phragmites*), while in KAL, both baulk (RB) and floating peat raft (KR; water layer between 50 and 100 cm depth) were sampled.

At most sites carbon concentrations are lower in the top 20-50 cm due to accumulation of mineral components and clastic material. Below this depth, the carbon concentration is rather stable over depth for most sites. This clastic material originates either from riverine or marine (mostly clay) deposits and can accumulate over time when peat decomposes. The accumulation of mineral material in the aerobic highly decomposed layers is derived from decomposed peat layers that disappeared over centuries as a consequence of intensive drainage. This can be illustrated by the coinciding pattern of accumulating minerals as Fe, P, S and N (appendix Figures A3-A6). In some locations the higher mineral built-up is caused by anthropogenic addition as can be seen in the contrast between the topsoil of the baulk (legakker) and the topsoil of the floating peat raft (kragge). Clear banding patterns were observed in deeper soil layers of the floating peat raft are not anthropogenic but indicate that the site was regularly flooded. A comparable spikey pattern was observed in the carbon profile of Demmerik. From all sites the carbon concentrations are highest in the topsoils of the floating peat rafts and paludiculture *Sphagnum* spp. site in Kalenberg and IJperveld. The highly disturbed peat areas (peaty soils and excavation site with paludiculture Ankeveen) have a carbon rich layer around 40-60 cm. The Ankeveen site has a very heterogeneous soil and the sampled profiles show some variation between sampling locations.

3.2 Bulk densities, organic matter, and carbon contents in organic matter

The bulk density of the NOBV peat soils generally decreased over depth and with increasing organic matter content (Figure 2). For this analysis soil samples were depicted from distinctly different zones 1) Top soil or root zone (generally 0-10 cm) 2) oxidized building zone is layer below the root zone with generally amorphous peat (20-30 cm), 3) exchangeable moisture layer is the oxidation-reduction zone (about 50-80 cm) and 4) the zone below the groundwater, reduced zone >120-150 cm). The exact depths in centimetres of these zones are site specific and depend on the groundwater dynamics. The samples were classified in such a way as to maximise comparability with sampled layers from sites as described in the respiration chapter (Weidner et al). Peat in the oxic layers (green circles in figure 2) generally contained higher fractions of mineral material and was in some cases even classified as clay. Generally, this 20-30 cm layer consisted of degraded peat and peat residues of otherwise completely decayed peat layers. Permanent exposure to oxygen leads to decomposition, shrinkage and aggregation of peat material, which can contribute to the higher density in contrast to peat layers deeper in the profile in the fluctuating and saturated zone. These predominantly saturated peat layers generally have lower bulk densities (0.2 kg DW/l) and contain higher percentages of organic matter (>70%) compared to the topsoil and oxic layers. The top layer (10 cm, depicted in black in Figure 2) is deviating from the general pattern as it is higher in organic material compared to some of the oxidized peat layers due to the presence of recent plant material. These root zones are enriched with coarse organic matter that consists of short-cyclic carbon (root remains, leave litter and microbial material). This carbon is not part of the long-cyclic carbon dynamics (fossil peat) and emission from this short-cyclic carbon fraction by definition does not contribute to a net increase in CO₂ concentration in the atmosphere.

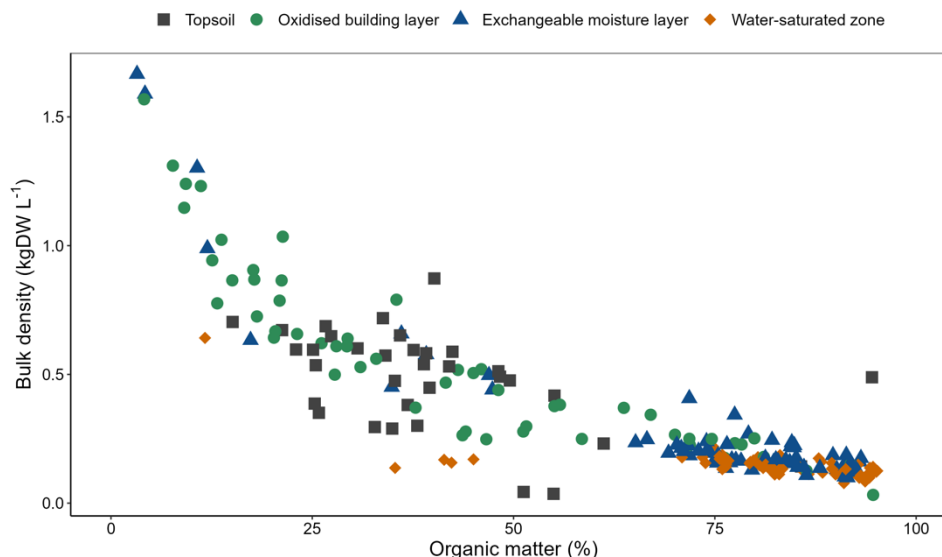


Figure 2. The variation in soil density (in kg DW/L soil) plotted against organic matter content. Different depths below ground level are presented in different colours. black: topsoil (0-10 cm); green: oxidised building layer (20 - 30 cm); blue: exchangeable moisture layer, (about 50 - 80 cm, depending on the site); orange: water-saturated zone, > 120-150 cm (permanently below groundwater).

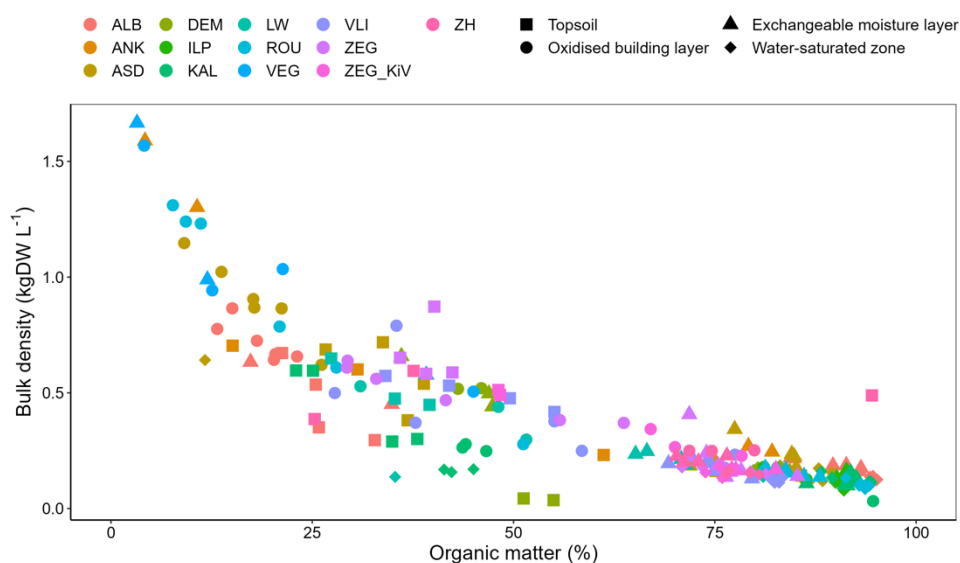


Figure 3. The variation in soil density (in kg DW/L soil) plotted against organic matter content. Different colours indicate the NOBV locations and symbols show discriminate between distinct hydrological zones squares topsoil/root zone (0-10cm), circles oxidized zone under root zone(20-30 cm), triangle: exchangeable moisture layer, (about 50 - 80 cm - mv, depending on the site); diamond water-saturated zone, > 120-150 cm - mv (permanently below groundwater).

In figure 3, the data from Figure 2 are presented differently, now highlighting the different NOBV research sites and hydrological zones. High bulk densities (> 1 kgDW/l) are observed in sites with clastic layers (Rouveen) and clay rich peat (Assendelft) or in predominantly mineral soil profiles as found in peaty soils (Vegelinsoord) and in previously excavated sites (Ankeveen). It is noteworthy that the clastic toplayers in Aldeboarn and Vlist generally have a somewhat lower bulk density in comparison to Rouveen and Assendelft. The high bulk densities coincide with low

organic matter percentages <20% and can by definition not be considered as peat. On the other side of the spectrum, we see soils with a density around 0.2 kg DW/l with high (>70%) organic matter. These densities occur at almost all study sites, primarily in zones with permanently or temporarily water saturated conditions. Lowest densities were observed in the saturated subsoils of Rouveen (0.08 kg DW/l). Comparable bulk densities were in some cases also found in topsoil layers dominated by Sphagnum moss in Kalenberg and Ilperveld. An exception is the low bulk density in oxic zones in the Zegveld site, where a clay addition treatment was applied (ZEG KIV).

3.3 Conversion factors from soil organic matter (SOM) to soil organic carbon (SOC)

When the SOC/SOM ratio is calculated for all NOBV samples including the mineral layers we get a SOC/SOM of 0,467. However, we did observe clear differences between peat samples with and without mineral admixture., with some organically rich clays with substantial lower SOC/SOM ratio of 0,23 compared to organic sand layers with significantly higher SOC/SOM ratio of 0.58. When only “pristine” peat samples were analysed without the clay rich peat, we observed a dichotomy with high slopes (0.49-0.59) for Aldeboarn, Assendelft, Rouveen and Ilperveld and contrasting low slopes (0.33-0.39) for Zegveld, Zegveld High Water, Langeweide and Kalenberg (data not shown) Figure 4 shows the conversion factor SOC/SOM for organic matter in peat soils under agricultural use (excluding clay and other mineral soil layers). This parameter can be used in the emission registration model SOMERS (Erkens et al.,2022) as a general average. When all data are taken together including the mineral layers and peaty soil, we get a slightly lower fraction of 0.47 (slope 0.467).

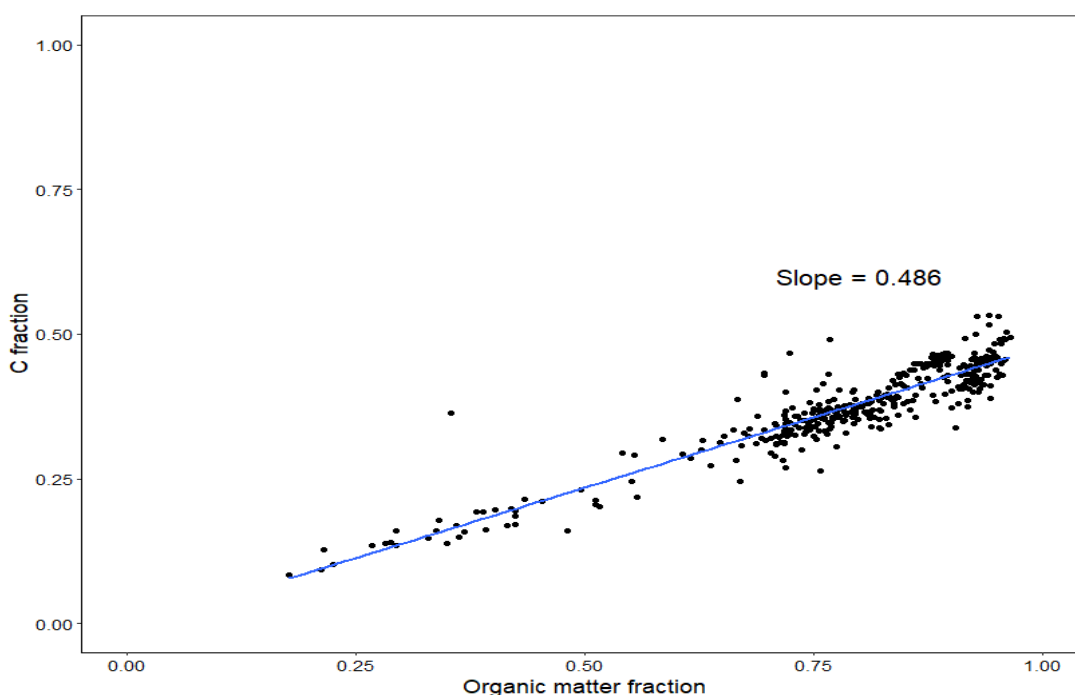


Figure 4. The soil organic carbon fraction plotted against organic matter content fraction for all peat profiles under agricultural use Zegveld, Langeweide, Vlist, Aldeboarn, Assendelft, Rouveen. The slope indicates the SOC/SOM ratio.

In Figure 5, the carbon content in relation to the organic matter content is presented for peat from the different NOBV locations (excluding the mineral layers). Ratios (slopes) are different between sites but no clear differences could be observed based on botanical origins, when comparing for

instance Shagnum peat from Ilperveld and Kalenberg (0.595 vs 0.394) or wood peat from Zegveld and Langeweide (0.478 vs 0.507).

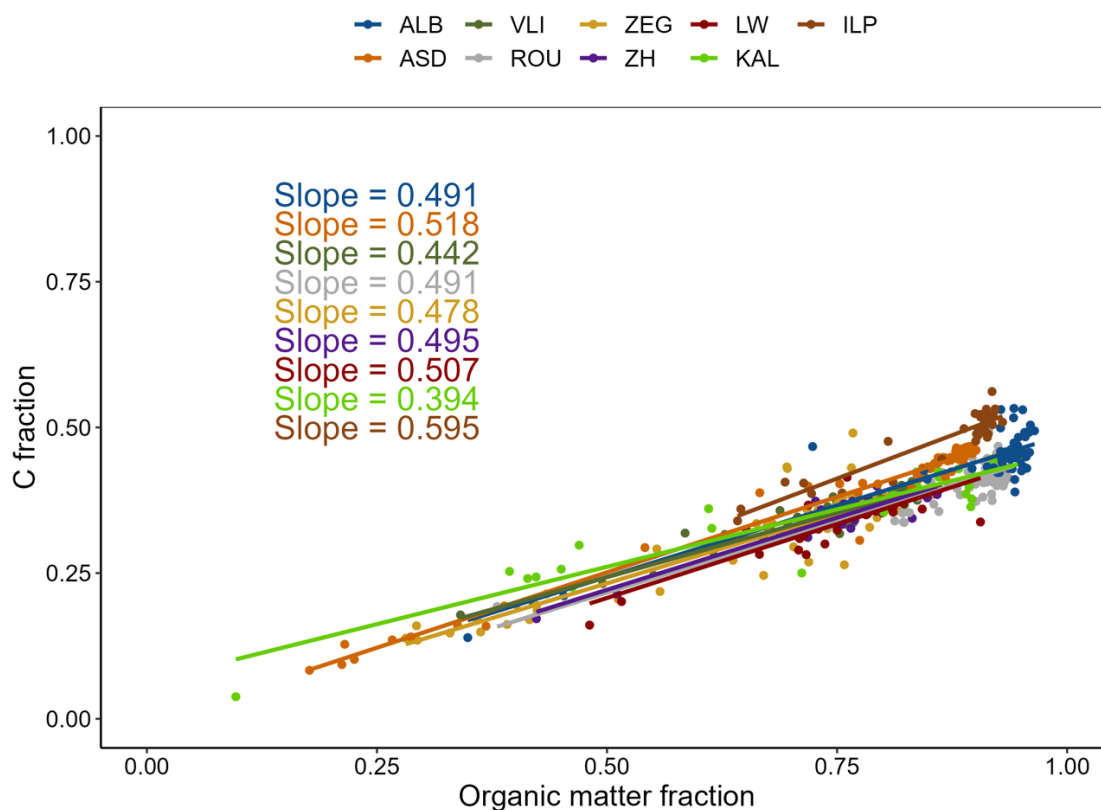


Figure 5. The variation in soil organic carbon fraction plotted against organic matter content fraction. Different colours represent different locations, with each slope indicating the SOC/SOM ratio for that location.

3.4 Peat degradation proxies and peat composition pattern in depth profiles

3.4.1 Carbon fractionation

The sequential organic matter fractionation performed with the Soxhlet extraction technique results is presented in pie diagrams that show the relative proportions of the different compound groups. The non-polar extractives (NPE) represent fatty acids and waxes, the water-soluble compounds (WS) represent all dissolved organic molecules such as soluble phenolics, sugars, enzymes and nutrients. The acid soluble extractives (AS) represent the complex carbohydrates cellulose and hemicellulose. The acid insoluble fraction (AIS), represents lignin, citin and suberin. The mineral fraction is the Ash content after combustion and represents mainly sand, silt, clay particles and metal hydroxides (amongst other Fe and Al compounds). Data are not all analysed yet. Data are available for the sites Zegveld, Langeweide, Kalenberg, Assendelft, Vlist, Rouveen and Ankeveen

A general pattern that can be observed in most studied profiles is depicted in Figure 6 A and B. There is a shift from dominant proportion of (hemi)cellulose (acid soluble) compounds in organic matter in the oxic soil layers (Figure 6A) and a dominance of lignin-type (acid insoluble) compounds in the saturated zone (figure 6B). Another general trend in the studied soil profiles is the higher mineral fraction in the oxidized layers due to the accumulation of mineral remains from

former overlying peat layers, anthropogenic additions and clastic deposits. This is in agreement with the observed lower C concentration in the carbon concentration profiles. In figure 7 and appendix A5-A6, small size pie diagrams with the same colour coding are presented along the depth profile for a selection of sites. Peat samples from Zegveld had relatively high acid insoluble fractions in the upper layers of the peat profile in comparison to other peat profiles (appendix Figure A8). High acid insoluble fractions indicate a high lignin content. This high lignin content is presumably derived from the large wood fragments which are present in this wood peat.

. Another noticeable deviation is the higher water-soluble carbon fraction in the saturated layers of Assendelft (Appendix Figure A8). Overall, with the present data and at a first glance, no significant differences could be observed in AS/AIS ratio between sites with distinctly different botanical peat types (Appendix Figure A7) Kalenberg (moss peat) Langeweide (wood peat), Rouveen (sedge peat). This might change once sample numbers increase as more data are available for all NOBV locations.

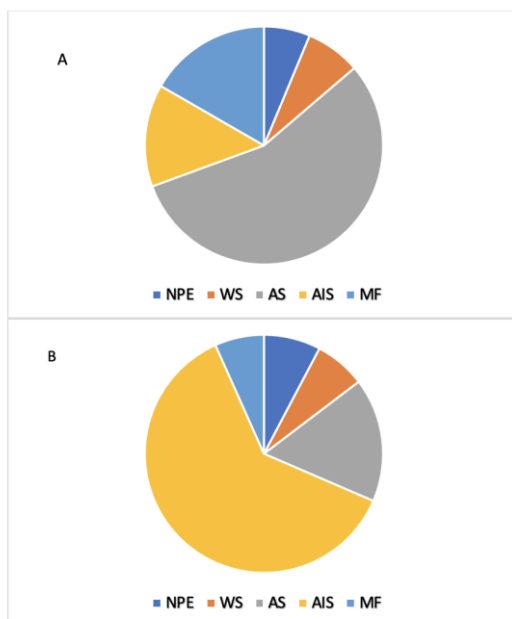


Figure 6 Example of data from the sequential organic matter extraction using Soxhlet, with A) a degraded oxidized peat layer and B) a permanently reduced peat layer. Legend abbreviations are: NPE= non polar extractives; WS= water soluble extractive; AS= acid soluble extractives; AIS =acid insoluble fraction; MF= mineral fraction.

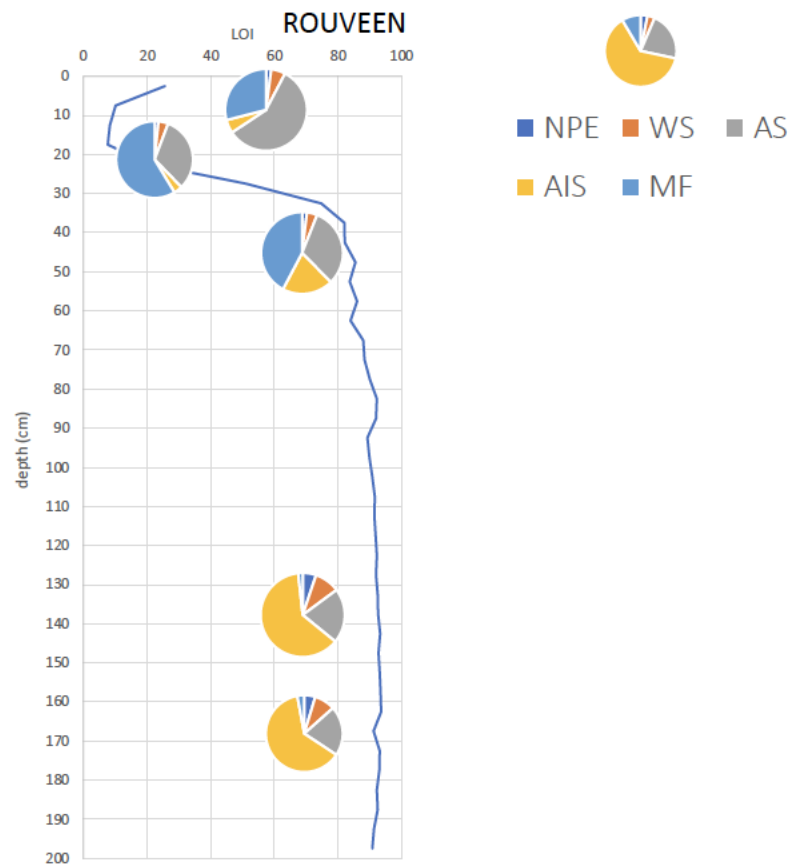


Figure 7 Sequential organic matter data along a depth profile in Rouveen. Legend abbreviations are: NPE= non polar extractives; WS= water soluble extractive; AS= acid soluble extractives; AIS =acid insoluble fraction; MF= mineral fraction.

3.4.2

15N:14N ratios

In all NOBV sites under agricultural use, a clear pattern was observed with higher $\delta^{15}\text{N}$ in the top 40 to 50 cm (Figure 7). In deeper peat layers more balanced stable isotopes ratios were found. A different pattern is observed for Assendelft, which shows a more variable pattern in deeper layers and an increase in $\delta^{15}\text{N}$ around 190-200cm. The more natural area in KAL shows an opposite pattern, with negative $\delta^{15}\text{N}$ values in the shallow layers of the floating raft (Figure 7).

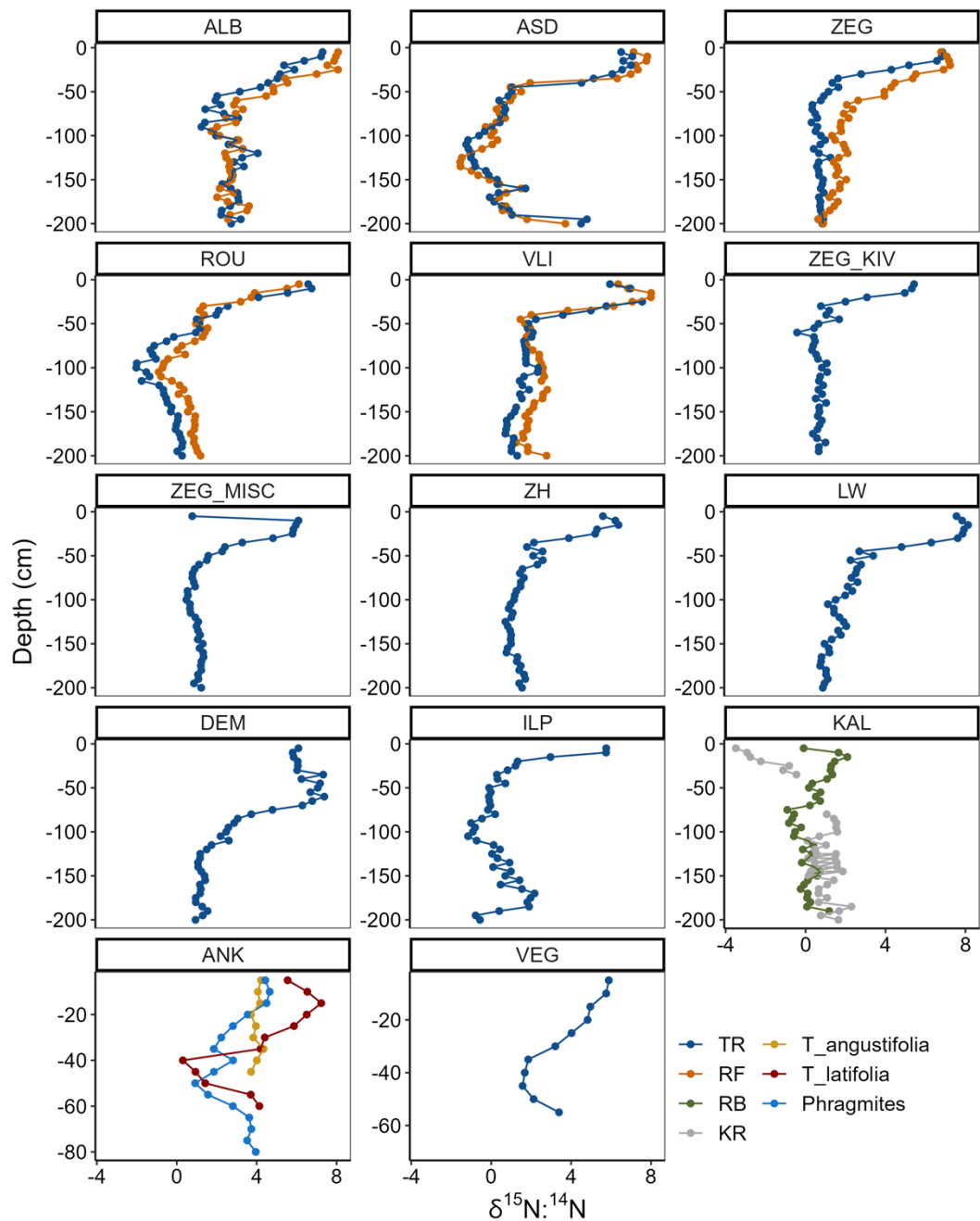


Figure 7: $\delta^{15}\text{N}$ (delta15N: 14N) ratios along a depth gradient in all NOBV sites. Blue lines represent sites with a treatment (TR; infiltration, raised ditch water levels or paludiculture, while orange lines represent control sites (RF; conventional agricultural parcels). In ANK, profiles were collected in each of the alternative crops (*Typha latifolia*, *T. angustifolia*, and *Phragmites*), while in KAL, both baulk (RB) and floating peat raft (KR; water layer between 50 and 100 cm depth) were sampled.

3.4.3 C:N ratios

C:N ratios are somewhat lower in the topsoils and oxic zones in comparison to the deeper saturated peat layers as a combined effect of enhanced microbial decomposition and N enrichment due to fertilisation (Figure 8). Generally, the C:N ratios of the peat profiles in the western peat district (Zegveld, Langeweide, Vlist, Assendelft), which are dominated by wood and sedge peat, stay below 25 over the full 2-meter profile. IJperveld is the only Western location consisting of predominantly Sphagnum peat, which explains why the C:N ratio shows a different pattern with depth. The IJperveld C:N ratio are more similar to those from the more Northern peat areas of Kalenberg and Aldeboarn. These locations contain peat with a more oligotrophic origin, dominated by *Shagnum*, *Ericoids* and *Eriophorum*. The C:N ratios in these locations are also significantly higher, with C:N ratios above 50. Peat profiles in excavated and degraded profiles, such as Ankeveen and Vegelinsoord show only slightly higher C:N ratios between 25 and 50. In Rouveen, a slight overall increase in C:N ratio is visible with depth, with a distinct peak in C:N at 100 cm depth. This coincides with an observed moss layer in this soil profile description. Small peaks in C:N ratios in profiles from Zegveld and Langeweide coincide with the occurrence of large wood fragments.

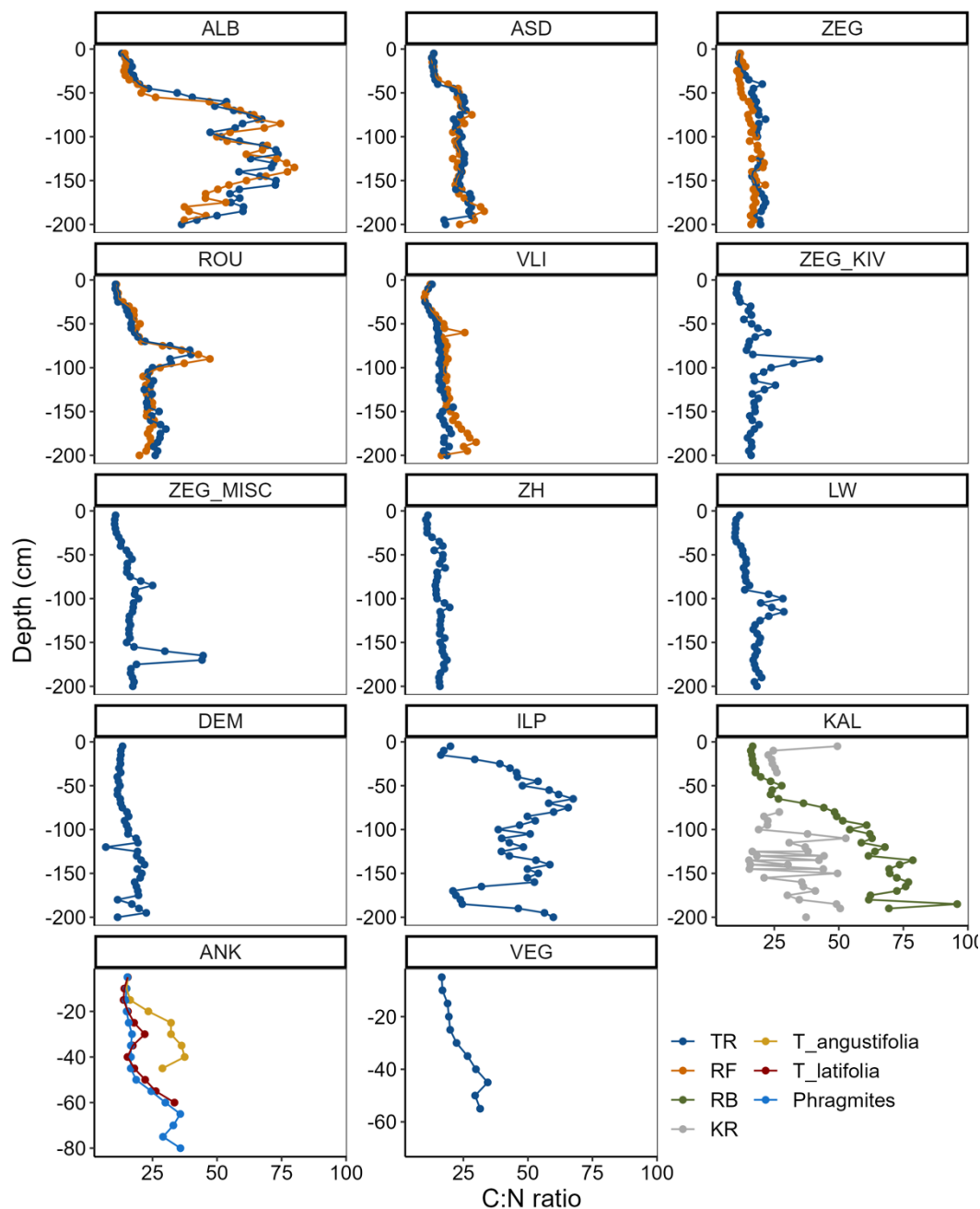


Figure 8. C:N ratios along a depth gradient in all NOBV sites. Blue lines represent sites with a treatment (TR; infiltration, raised ditch water levels or paludiculture, while orange lines represent control sites (RF; conventional agricultural parcels). In ANK, profiles were collected in each of the alternative crops (*Typha latifolia*, *T. angustifolia*, *Phragmites*), while in KAL, both baulk (RB) and floating peat raft (KR; water layer between 50 and 100 cm depth) were sampled.

3.5 Total carbon stocks in relation to groundwater table and depth

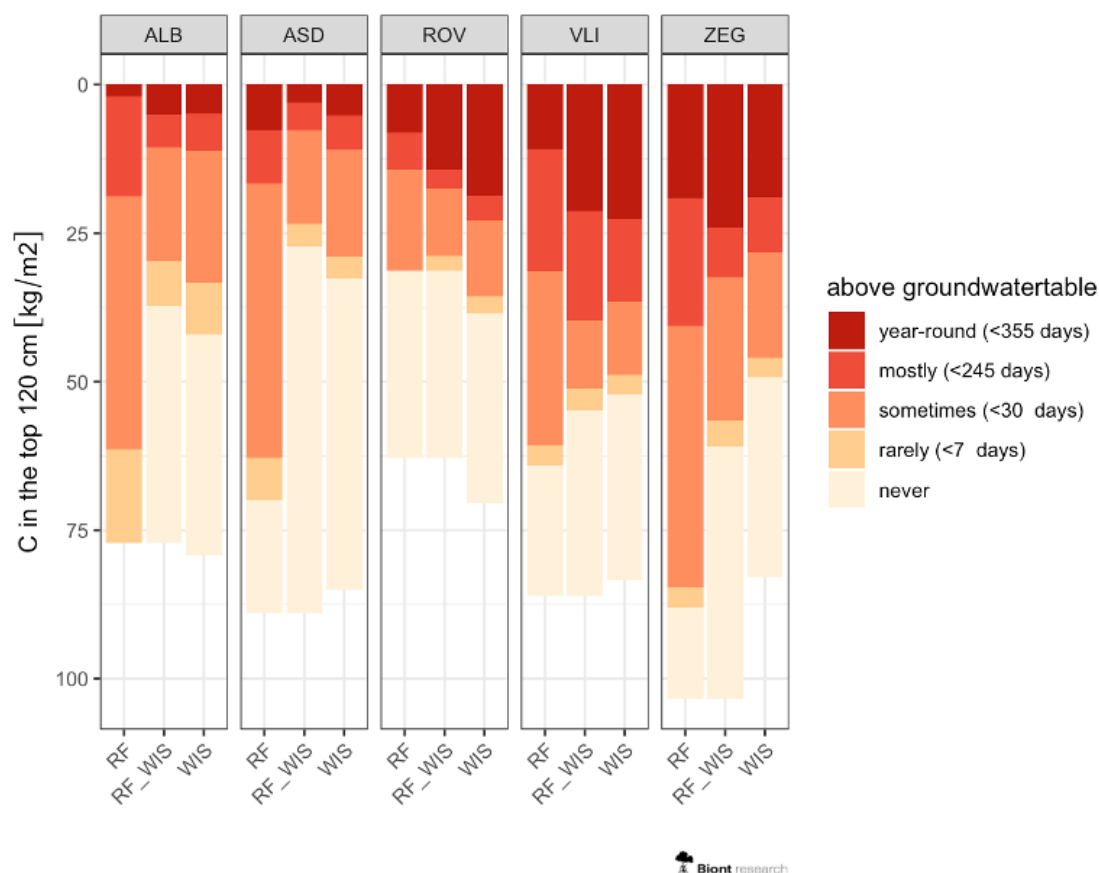


Figure 9. Carbon stocks (up to a depth of 120cm below surface level for comparison with SOMERS) in NOBV sites comparing total carbon stocks in the control (RF) and water infiltration treatment (WIS indicates Water infiltration systems (either pressurized infiltration subsurface infiltration) plots. Colours in the stacked bars indicate number of days that the carbon stock is above the groundwater level as measured in groundwater wells over the year 2022. The RF-WIS column is added to illustrate the effect of water infiltration system on the RF profile excluding any profile differences between plots. <355 indicates the carbon stock that is above the groundwater table for 355-365 days of the year. < 245 days indicates the carbon stock that in above the groundwater table for 355-245 days per year

The total carbon stocks (between 0 and 120 cm depth) vary between the NOBV locations (Figure 9), with the largest C stock found in the wood peat of Zegveld (105 kg per m² over a depth of 120cm) and the lowest C stock in the sedge peat of Rouveen (66 kg per m² over a depth of 120cm). Sites with water infiltration measures (WIS) had a higher fraction of carbon (46%) that was below the groundwater level almost year around (<355) than the reference sites (29%). Sites with WIS also clearly reduced the carbon stock sizes that are exposed to oxygen for a significant number of days in the year (<245 cm) and the carbon that becomes exposed during summer droughts (<30). In contrast, the WIS parcels showed a slightly higher carbon content in the permanently oxidized s zone (<355 days; 18% v 11% in the reference site), most likely due to winter drainage. The RF-WIS column in figure 9 is a theoretical column with the water dynamics of the WIS site of a site projected on the carbon profile from the reference plot of the same site to illustrate the effects of WIS excluding the differences in carbon content between the soil profiles in the RF and WIS sites.

In contrast to figure 9, the carbon stocks in Figures 10 and 11 are presented in depth classes for all NOBV sites and for the full 200cm profiles. We decided to present depth classes instead of days above groundwater table for all sites as detailed measured groundwater dynamics are not analysed yet for the full range of NOBV sites. Generally, we can assume that the carbon stock in the 20-40 cm layer is mostly under unsaturated mostly oxic conditions and hence is at high risk of microbial degradation. Conversely, carbon levels below 80 cm depth are mostly under saturated conditions and hence are at low risk for microbial degradation, with an exception in extremely dry summers, such as the summer of 2022.

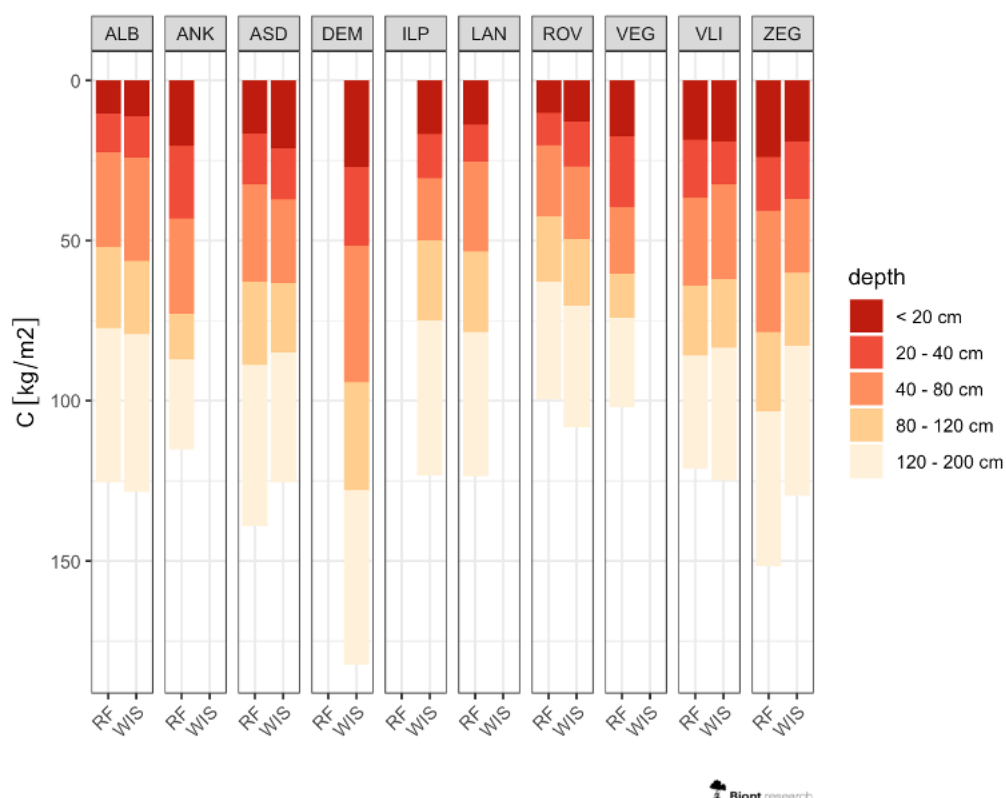


Figure 10. Carbon stocks in stacked bars for the full 0-200 cm profiles in the NOBV sites. The carbon stock is presented in five depth classes 0-20 cm, 20-40 cm, 40-80cm, 80-120cm and 120-200cm. Class 0-20cm represents the average layer above the groundwater table under scenarios of raised groundwater, 20-40cm the current average GWT, 40-80cm is the current layer subjected to fluctuating GWT, 80-120 cm is the layer that is only oxidised under extreme drought and 120-200 the permanently saturated layer. Additionally, 120 cm is the standardized soil depth that is used in pedological maps and carbon models. WIS indicates the plot with water infiltration systems, RF indicate the reference plots.

Generally, total carbon stocks in the top 200 cm were around 120 kg m². To the high end of the range, the total carbon stock of Demmerik was found to hold 180 kg carbon m². Although groundwater levels were generally high in this site, the carbon stock that is above 40 cm depth level is substantial, with 50 kg compared to 20-30 kg in the other sites. Pilot measurements on groundwater level in Demmerik show that groundwater levels can drop below this 40 cm depth. Most likely the thick organic anthropogenic layer (toemaakdek) in this soil profile, originating from household waste from the city of Amsterdam, contributes to a dense carbon stock in the top layer. Remarkably, the total carbon content in the peaty soil of Vegelinsoord is comparable to the carbon content in Rouveen over a depth of 2 meter, while the thickness and degradation state of the peat layers vary widely. In Vegelinsoord the profile contains an unsaturated strongly degraded and

layered (“schalterveen”) peat layer of only 10-25 cm thick and the soil profile in Rouveen consisted of a 30 to 40 cm thick clay layer on top of a moderate to weakly amorphous layer of carex peat of >160 cm. Note also that the carbon stocks for Ankeveen (paludiculture site) are presented in the same depth (and risk) classes. However, with the current year-round saturated or flooded conditions, the depth layers in this specific profile have no direct relation with the oxygen status or the risk of decomposition.

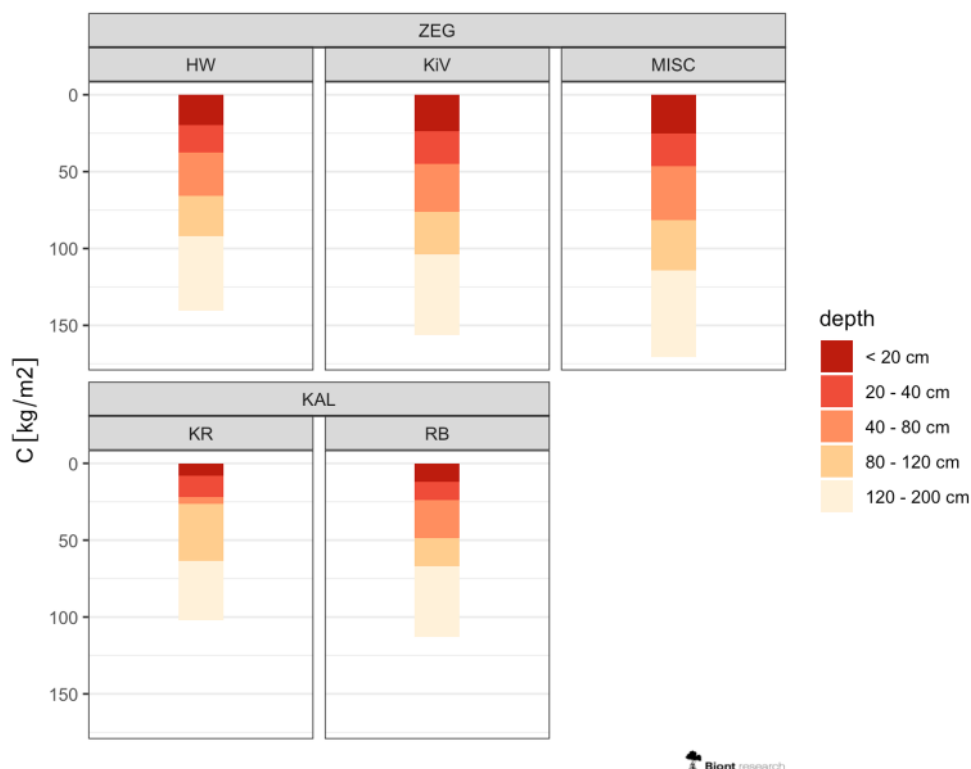


Figure 11. Carbon stocks for the full 0-200 cm profiles for the additional locations in ZEG=Zegveld, and KAL=Kalenberg, Abbreviations for the mitigation measures are as follows: HW=High water, KIV=Clay addition to peat, MISC=Miscanthus field, , KR= Nature area: floating peat raft (Kragge), RB= Nature area: Baulk (Rib). Carbon stocks are separated into depth classes: 0-20 cm: corresponding to the unsaturated rooting zone, 20-40 cm: unsaturated peat layer, 40-80cm: layer with fluctuating groundwater levels above average lowest groundwater level (GLG), 80-120cm: layer between GLG and usual soil profile depth, 120-200 cm permanently water saturated zone.

Note that total stocks over a range of locations i.e. Zegveld MP (WIS), Vlist MS (WIS) (Ilperveld, Assendelft MP (WIS) and Aldeboarn MS(WIS) figure 10 and 11 are almost identical, whereas carbon profiles within Zegveld show a large variety of stocks between 130 and 170 kg/m². This can partly be explained by differences in historical land management. It is important to measure differences in carbon profiles between treatment plots as these differences can feed through into emissions and can incorrectly be interpreted as effects of the measure.

4 Discussion

4.1.1 Total carbon stocks

We investigated the total carbon stocks in the different NOBV locations to be able to compare net carbon emissions to carbon availability and to assign a risk category to this available carbon, based on its position relative to the groundwater level. Carbon contents based on a soil depth of 120 cm in the NOBV site ranged from 62 (Rouveen) to 128 kg/m² (Demmerik), with an average of 86 kg/m².

Kuikman et al (2003) reported C stocks of 60 to >70 kg C/m² for the Western peat district. Our measured carbon stocks are at the high end of this range, despite the fact that Kuikman et al., (2003) used a higher SOC/SOM conversion (0.5) than we obtained in our measured dataset (0.46). Kuikman et al., (2003) present an overview of measured and modelled CO₂ emissions from the surface of Dutch peatlands ranging from 1.7 to 7 ton C/ha/jr. Such an annual flux comprises 0.2-1% of the total estimated carbon stock up to 120cm. However only the peat layer exposed to unsaturated conditions (or the depth to which the peat is drained) contributes dominantly to the measured CO₂ emissions. This layer is often shallower than the measured 120cm. Data from our study can now be combined with NOBV flux measurements and the SOMERS 2.0 model and will provide an important nuance and improvement of these estimates which will allow us to express the annual fluxes as percentage of a dynamic active carbon pool.

4.1.2 SOC/SOM ratios

No significant shifts in SOC/SOM ratios were observed when comparing different botanical peat profiles. Therefore, the suggestion from Klingenfuss et al., (2014) to differentiate between peat types with 0.58 for peat from vascular plants and 0,5 for Sphagnum based peat cannot be supported based on data from this study. In general, we found lower SOC/SOM ratios of 0.49 for peat soils under agricultural use and even lower ratios for the whole dataset combined 0.47 (all samples including the clastic layers). Clear differences were found when ratios were calculated for different soil types. Humic sands showed higher ratios, while humic clays showed substantially lower SOC/SOM ratios than peat. This again contradicts Klingenfuss et al., (2014), who reported lower ratios (0.41) for amorphous peat and humic sands, although they mention that the latter category shows large variability. As the carbon content of organic matter is a crucial parameter in SOMERS and other national GHG registration models, we may need to differentiate between types of clastic layers and amorphous and intact peat soils.

We observed that clastic layers and peaty soils can contain significant amounts of organic material with high carbon contents that can override the amount of carbon in organic material from "pristine" peat layers. The bulk density of the studied peat soils generally decreased with depth from 0.5 to 0.1 kg DW/l, while the organic matter content increased with depth. Peat in the oxic layers generally contained higher fractions of mineral material and was in some cases even classified as clay. Accumulation of mineral material from decomposed peat deposits, anthropogenic additions (toemaakdek) and natural clastic deposits are common phenomena in Dutch peat systems and peat soils without mineral enrichment in the top layers are rare.

Conversely, deeper saturated peat layers generally have bulk densities below 0.2 kg DW/l with the lowest density measured in sedge peat from Rouveen with a value of 0.08 kg DW/l. Organic matter in these layers experience low effective stress. The weight of overlying soil layers is mostly

carried by the water. These peat deposits did, however, experience some minor compaction as densities are still slightly higher than the density of pristine peat, which is considered to be between 0.08 and 0.11 kg DW/l for fen peats with a LOI of 90% (Van Asselen, 2011) and densities of pristine peat samples are generally in the same range for different botanical peat types. Erkens et al 2016 calculated that the average organic matter density of peat in the Netherlands, after transformation through compaction and decomposition, was 103 kg/m³ (0.103 kg DW/l). With an average C content of 0.487 (as reported in this chapter for agricultural peat soils), the carbon stocks would be (0.487*103*1.2) 60 kg/m² comparable to our lowest measured carbon stock of 62 kg/m² carbon in 120 cm peat soil.

4.1.3 Peat degradation proxies

The lower C:N ratios in the unsaturated zone show indications of fertilisation and microbial decomposition. However, the botanical origin and nutrient status of the peat substrate seems to overrule the effect of fertilisation and microbial decomposition on the general C:N patterns. The presence of oligotrophic peat dominated by *Sphagnum*, *Eriophorum* and *Ericoid* species results in substantially higher C:N ratios compared to the minerotrophic and mesotrophic peat types dominated by wood, reed and sedges. Incidentally high C:N ratios are also found in wood peat profiles from Langeweide and Zegveld when the dominant matrix is wood (high content of lignin). The sedge peat of Rouveen is exemplary for this overruling effect as a small interval with moss at ~100 cm depth coincides exactly with a peak in C:N ratio. Theoretically a shift in stable isotopes ratios indicates microbial incorporation of N and microbial metabolic processing. Organisms prefer the lighter ¹⁴N over the heavier ¹⁵N, therefore ¹⁵N remains in the bulk soil whereas ¹⁴N can be lost by outgassing (via denitrification), uptake or leaching of nitrate (nitrification). The observed stable isotope $\delta^{15}\text{N}$ enrichment generally observed at a depth of 20-50 cm indicates *in situ* microbial metabolic processing of organic matter coinciding with the unsaturated zone. However, values in the top/ rootzone 0-20 cm are undoubtedly also influenced by the ¹⁵N: ¹⁴N signature of organic fertiliser application (manure and compost), as organic fertilizers typically have ¹⁵N enrichment of +10‰ ± 4 while mineral fertilisers have ¹⁵N enrichment of roughly 0 ‰ (Shearer, 1974).

Soxhlet data showed a clear pattern from dominantly acid soluble (AS) to dominantly acid insoluble (AIS) fractions for unsaturated and saturated soil layers. This pattern is partly in accordance to findings of Laiho et al., 2006 and Tomassen et al 2004, who observed that oxic layers show lower lignin contents. The change in AS/AIS ratio over depth was largely similar between different botanical peat types. This contradicts the hypothesis that wood peat might have a higher total AIS fraction due to its high lignin content and Sphagnum moss peat typically has higher hemicellulose and cellulose contents. Still, wood fragments did increase the acid insoluble carbon at certain depth in the profiles of Zegveld. The fact that we see the same pattern with an increasing AIS fraction in sphagnum, sedge and wood dominated peat can be caused by other insoluble phenolic compounds in Sphagnum peat (Naumova et al, 2013). Another noticeable difference is the higher water-soluble carbon fraction in the permanent reduced layers of Assendelft. This can be an indication of anaerobic decomposition with alternative electron acceptor (possibly SO₄²⁻, given the high S content in Assendelft). During this anaerobic decomposition intermediate degradation products can accumulate. This is in agreement with the relatively high respiration rates of samples from the reduced zone in Assendelft under oxic conditions (Weidner et al in prep). New insights in peat organo-chemical characterization reveals that zooming in to the loss of specific hemicellulose structures is a more reliable proxy for organic matter degradation in peat soils than ratios between (hemi)cellulose and lignin compounds as determined by this method (Serk et al., 2023)

4.1.4 Carbon stocks in relation to the groundwater level

In this study the carbon stocks are presented in times that they are above the groundwater table. These classes can be interpreted as microbial oxidation risk classes. The carbon situated in the stock that is above the groundwater level for most days of the year are considered to be at the highest risk to oxic microbial decomposition. Based on the total carbon stock in 120 cm soil profile we observed that generally less than 30% of the carbon falls into these high-risk zones. Water infiltration systems tend to increase the fraction of the carbon stock that is exposed over the whole year, probably due to drainage of the top soil in the wet season (winter). However, the carbon stocks of mostly exposed and sometimes exposed are significantly reduced by the measure. Summer droughts (largely contributing to the carbon in the “sometimes exposed” stock) are clearly smaller with WIS. Considering the strong effects of temperature on the microbial oxidation of peat the efficacy of WIS during the warmer summer months is significantly higher when compared to the strongly oxidized reference.

In this chapter we assumed that carbon stocks that are only incidentally (> 1 week) above the groundwater table during dry summers are still at risk of oxic microbial decomposition. It is, however, questionable if incidental groundwater drawdown in dry summer month is threatening these wet peat reserves as capillary rise and high oxygen consumption rates in overlying peat layers could prevent a significant oxygen diffusion in these peat layers. Furthermore, we have to acknowledge that the groundwater level data used for this calculation are based on groundwater dynamics measured in the extremely dry year 2022. Still, with increasing climate change summer droughts will occur frequently and exposure of these layers will become highly likely. Another reservation that we have to face with these data is the fact that at every location we could only sample one representative core at high resolution. We have to be aware that peat soils are intrinsically heterogeneous soils and observed differences cannot always directly be assigned to differences in location or treatments.

5 Conclusions

In this study we presented a first descriptive exploration of the carbon profile data. The objective was to determine the size of the total carbon stocks for each of the research sites to be able to relate the measured fluxes to measured pool sizes and to compare the potential carbon reservoir between locations. Another aim was to determine the significance of organic rich mineral deposits (i.e. humic clay and sand layers) in the total carbon stock of peat soils and to get insights in the quality and degree of decomposition of the peat along a depth profile. We decided to combine the carbon stock data with site specific daily groundwater data to determine which part of the carbon stock was likely at risk of microbial oxidation. Additionally, specific model parameters can be extracted from this detailed dataset, which can be useful for national emission registration models. We hypothesize that peaty soils and excavated soils like the paludiculture site In Ankeveen had significant lower total carbon stocks in the depth profile compared to more pristine and deep peat profiles. We also expected to find specific SOC/SOM factors for peat substrates of a diverse botanical composition. Finally, peat degradation proxies (C:N, Stable isotopes, C fractionation) were expected to show lower peat degradation levels in peat that is permanently saturated compared to the unsaturated layer despite the increase in age of deeper peat deposits. Based on this descriptive analysis we conclude that carbon stocks in the Dutch peat soils are larger than previously assumed. Carbon stocks differ between the research locations of the NOBV but differences were smaller than hypothesized at the start. Average carbon stocks were 87 kg/m² based on a standard soil profile depth of 120cm and stock between location ranged from 66-128 kg/m². Strikingly, shallow organic matter layers in peaty soils contain C stocks in the same order of magnitude as one profile with relatively undisturbed peat soils due to the higher density of organic matter. Carbon stocks in plots with water infiltration measures were generally in the same order of magnitude as stocks in the reference counterpart plots, apart from Zegveld, where the water infiltration plot had a substantially lower carbon stock than the reference plot. Overall, water infiltration measures resulted in lower amounts of carbon exposed to aerobic conditions for most days of the year (>245 days) and lower amounts exposed during dry summer months (<30 days) but slightly higher permanently oxidized carbon stocks in the topsoil, due to drainage in wet winter months. Carbon contents of organic matter in our dataset was lower with a fraction of 0.47-0.49 than the commonly used SOC/SOM ratio of 0.50-0.58 (Pribyl 2010). The high-resolution depth profiles provide a unique dataset that needs further in-depth analyses. Future analysis should include a thorough statistical analysis and dive deeper in the differences in chemical peat composition and nutrient contents in relation to oxidation vulnerability, the risks of eutrophication and anoxic microbial degradation (Van Diggelen et al., 2020). Another important next step will be the addition of temperature profiles and oxygen demands of specific peat layers to connect insights in peat carbon profiles, peat exposure and peat degradation stage to inform and improve national emission registration models.

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Appendix

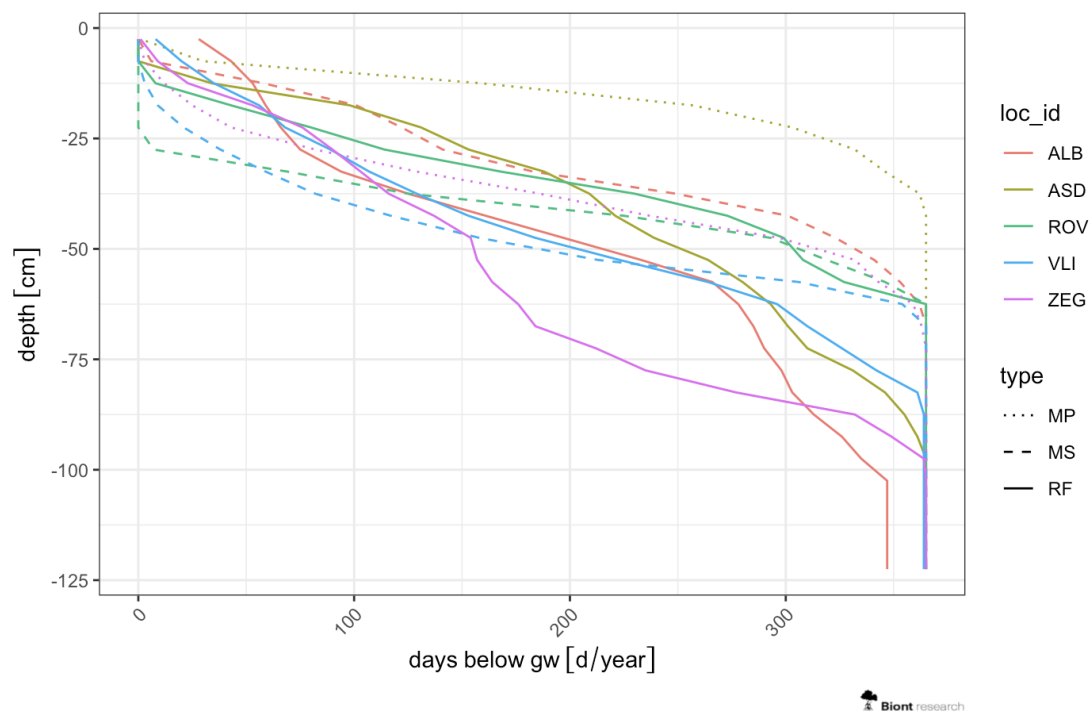


Figure A1 Cumulative daily groundwater data with depth.

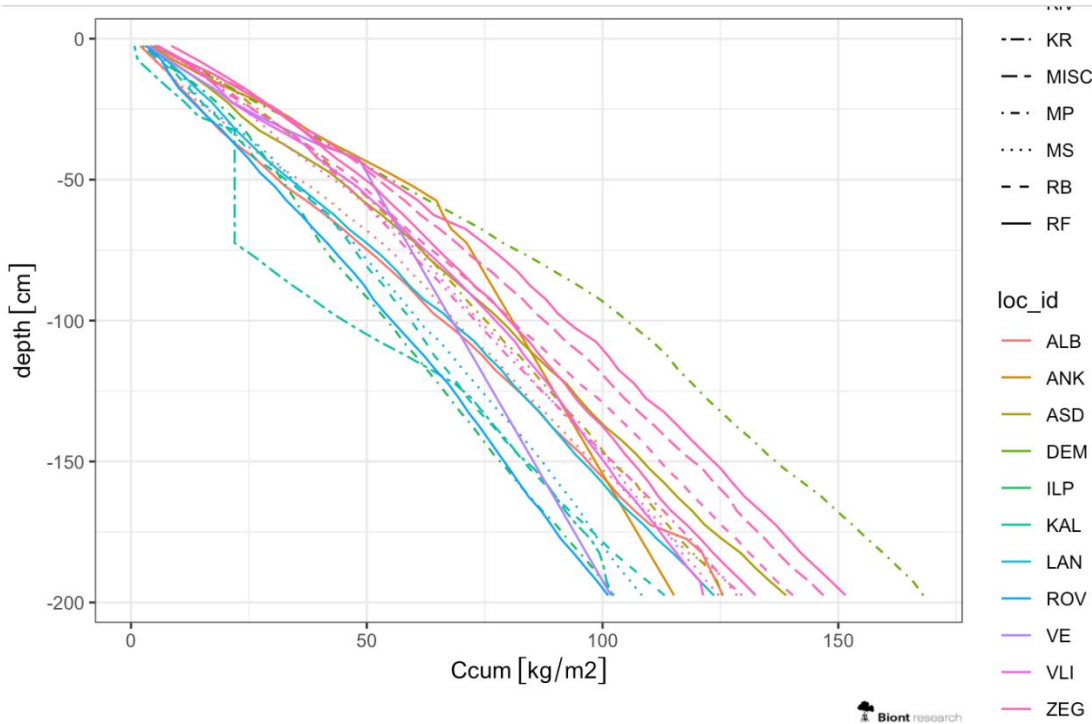


Figure A2 Cumulative carbon content for all NOBV research locations with depth

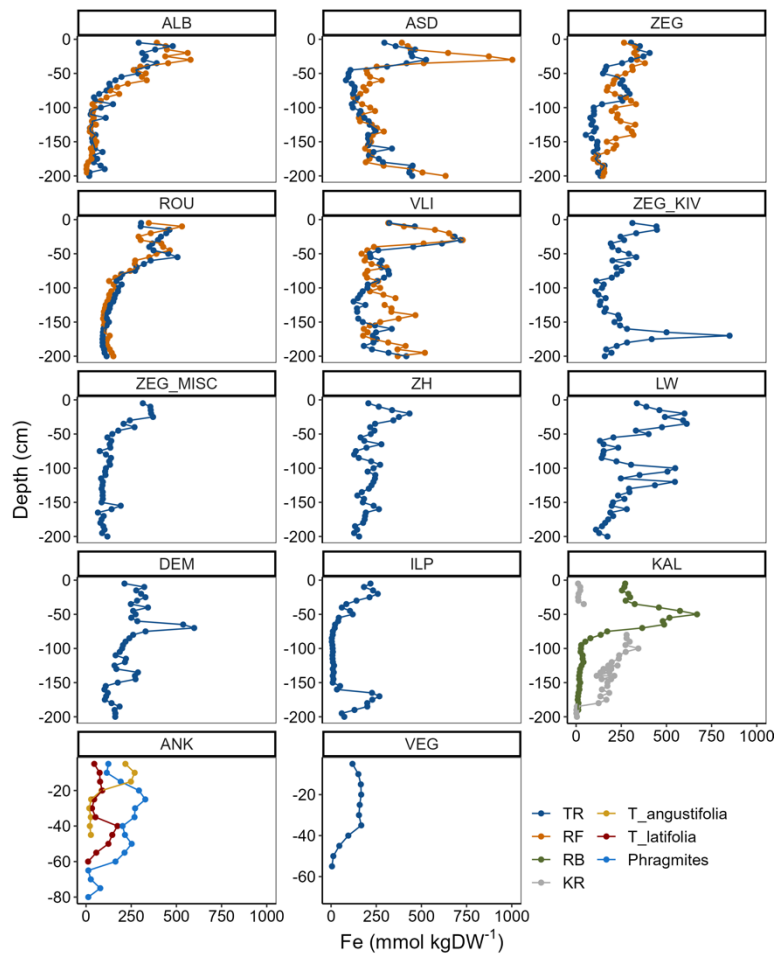


Figure A3. Iron (Fe) content (mmol kgDW⁻¹) along a depth gradient in all NOBV sites. Blue lines represent sites with a mitigation measure as treatment (TR; infiltration, raised ditch water levels or paludiculture, while orange lines represent control sites (RF; conventional agricultural parcels). In ANK, profiles were collected in each of the alternative crops (*Typha latifolia*, *T. angustifolia*, and *Phragmites*), while in KAL, both baulk (RB) and floating peat raft (KR; water layer between 50 and 100 cm depth) were sampled.

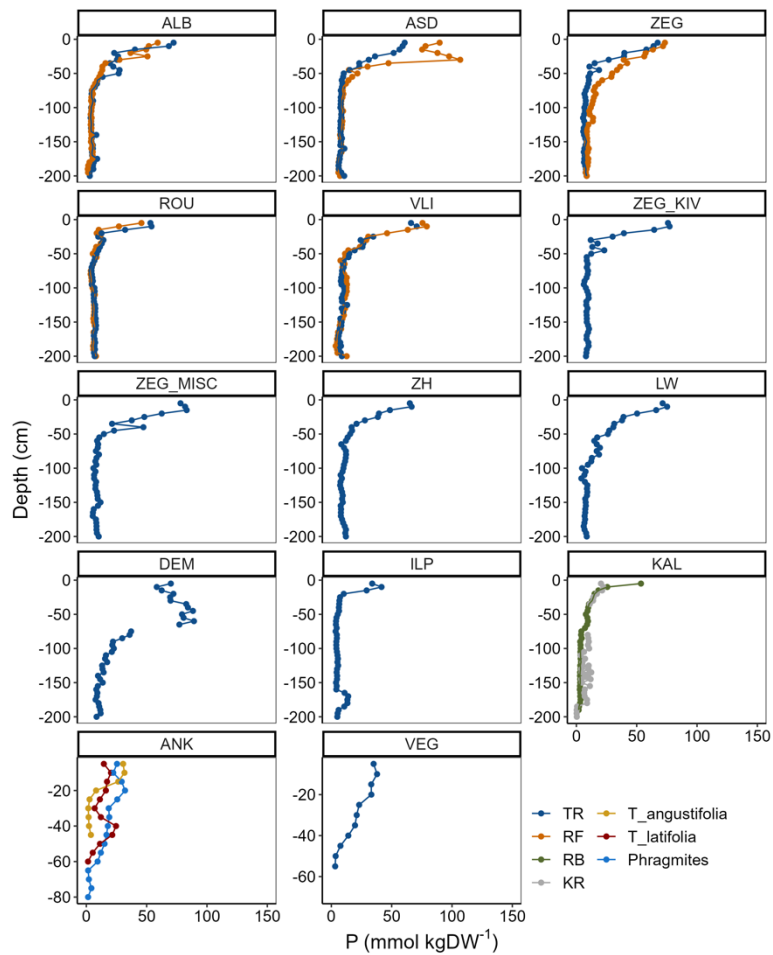


Figure A4; Phosphorus (P) content (mmol kgDW⁻¹) along a depth gradient in all NOBV sites. Blue lines represent sites with a mitigation measure as treatment (TR; infiltration, raised ditch water levels or paludiculture, while orange lines represent control sites (RF; conventional agricultural parcels). In ANK, profiles were collected in each of the alternative crops (*Typha latifolia*, *T. angustifolia*, and *Phragmites*), while in KAL, both baulk (RB) and floating peat raft (KR; water layer between 50 and 100 cm depth) were sampled.

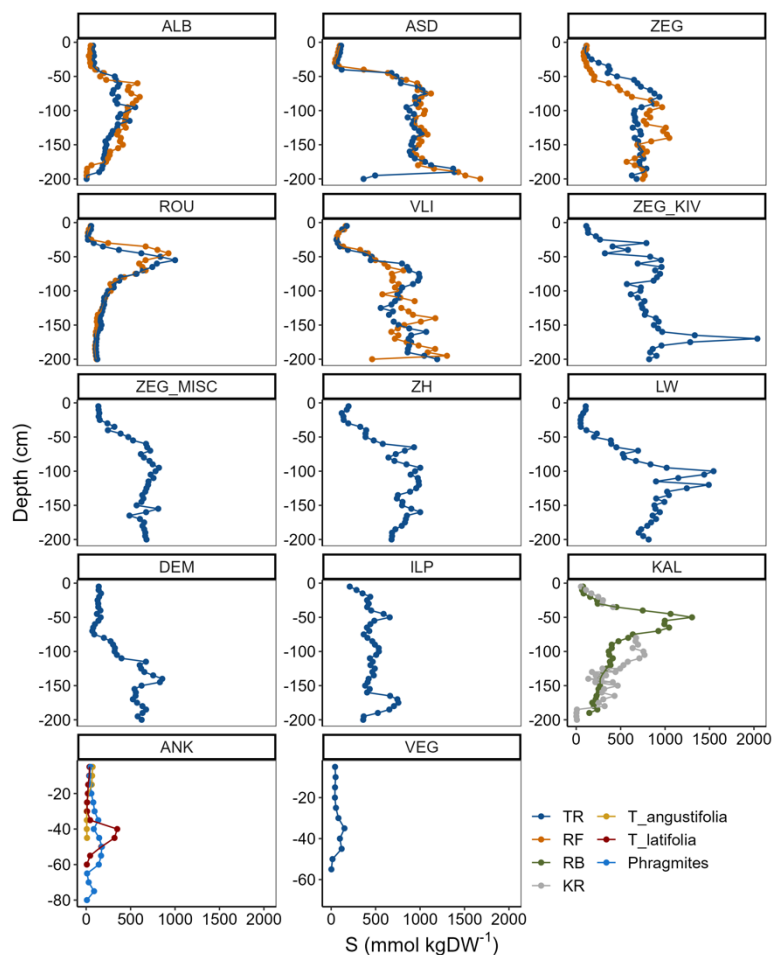


Figure A5. Sulphur (S) content (mmol kgDW⁻¹) along a depth gradient in all NOBV sites. Blue lines represent sites with a mitigation measure as treatment (TR; infiltration, raised ditch water levels or paludiculture, while orange lines represent control sites (RF; conventional agricultural parcels). In ANK, profiles were collected in each of the alternative crops (*Typha latifolia*, *T. angustifolia*, *Phragmites*), while in KAL, both baulk (RB) and floating peat raft (KR; water layer between 50 and 100 cm depth) were sampled.

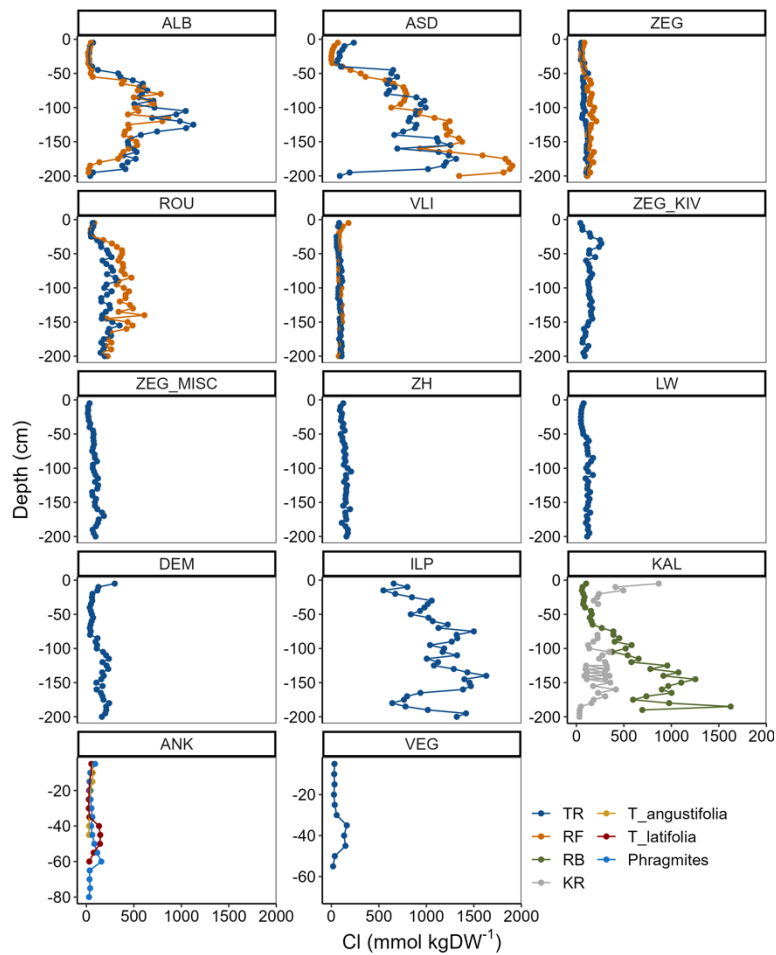


Figure A6. Chloride (Cl) content (mmol kgDW⁻¹) along a depth gradient in all NOBV sites. Blue lines represent sites with a mitigation measure as treatment (TR; infiltration, raised ditch water levels or paludiculture, while orange lines represent control sites (RF; conventional agricultural parcels). In ANK, profiles were collected in each of the alternative crops (*Typha latifolia*, *T. angustifolia*, and *Phragmites*), while in KAL, both baulk (RB) and floating peat raft (KR; water layer between 50 and 100 cm depth) were sampled.

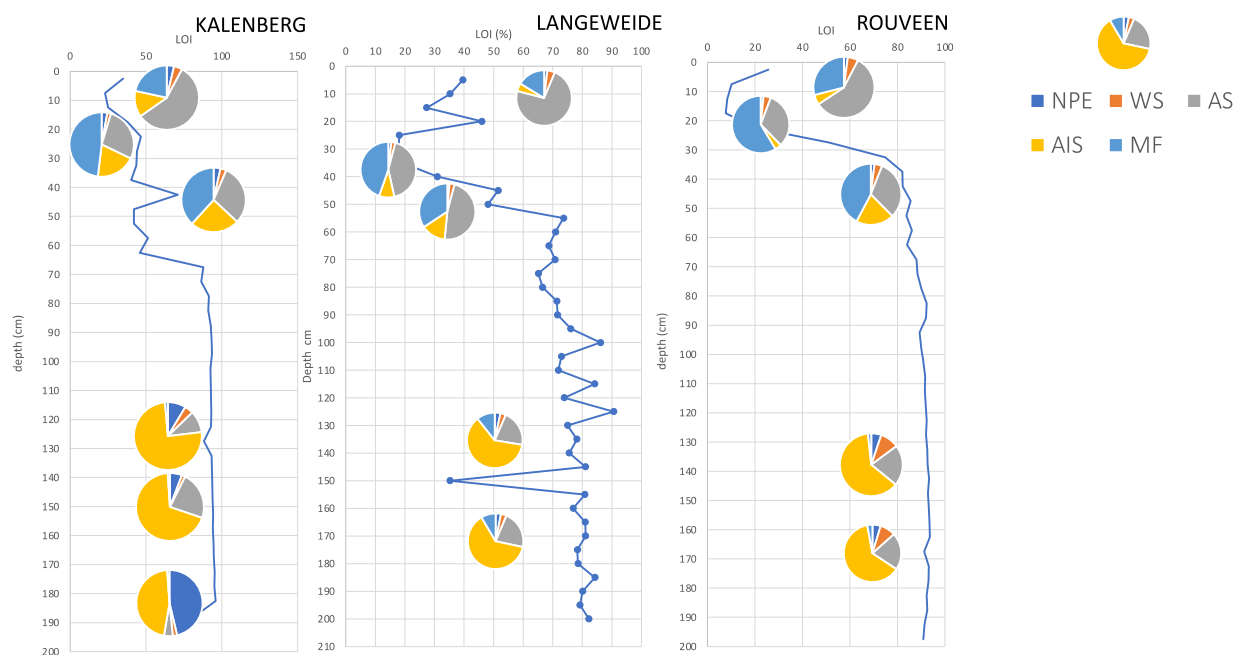


Figure A7. Soxhlet data and carbon profiles for NOBV locations with distinctly different botanical peat composition (Kalenberg: Moss peat; Langeweide: wood peat; Rouveen: Sedge peat). Legend abbreviations are: NPE= non polar extractives; WS= water soluble extractive; AS= acid soluble extractives; AIS =acid insoluble fraction; MF= mineral fraction.

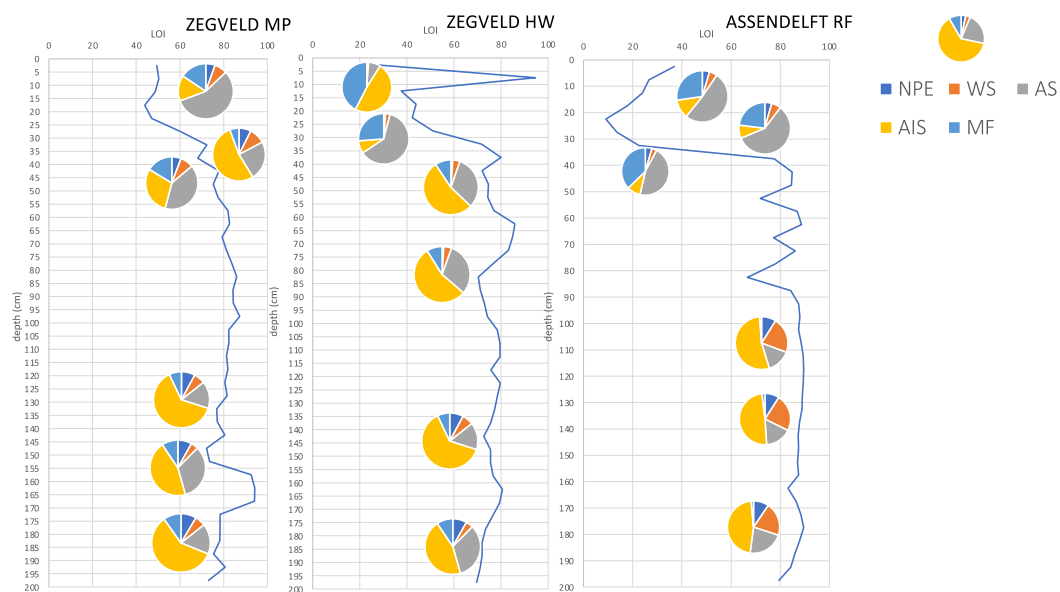


Figure A8. Soxhlet data and carbon profiles for NOBV locations (Zegveld Wood peat, Assendelft Sedge/ Reed peat) Legend abbreviations are: NPE= non polar extractives; WS= water soluble extractive; AS= acid soluble extractives ;AIS =acid insoluble fraction; MF= mineral fraction.