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Organic soils can be CO_2 sinks in both drained and undrained hemiboreal peatland forests

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S1. Supplementary text

S1.1. Soil heterotrophic respiration interpretation issues

S1.1.1. Soil heterotrophic respiration measurements

Heterotrophic soil respiration (Rhet) was measured by applying the manual closed dynamic dark chamber method (Denmead, 2008; Hutchinson and Livingston, 1993). For each measurement, a 60 x 90 cm (W x L) trenched (Ngao et al., 2007) locations was prepared at the end of the previous year's growing season to a depth of at least 40 cm, using geotextile on the sides to prevent root ingrowth and by removing alive vegetation and litter layer. In each subplot, measurements were done in 3 replicates, in total, nine measurement locations in each study site. CO_2 flux monitoring was made by EGM5 portable CO_2 gas analyser (PP Systems, Amesbury, MA, USA) and a fan-equipped chamber (area 0.07 m^2, volume 0.017 m^3) placed in the centre of the trenched surface without using a collar. The measurement data was stored at a 1 Hz frequency over a three-minute period in each measurement. Rhet measurements were made in parallel with Rtot measurements. Between the measurement campaigns, Rhet measurement areas were covered with geotextile, which was covered with an equivalent quantity of debris and litter as nearby soil, aiming to simulate natural conditions.

Before flux calculations, the first 15 seconds of the measurement data were discarded to avoid potential error in the results due to the placing of the chamber in the soil. To estimate the slope of the linear regression equation representing CO_2 concentration change in time, the same approach as for Rtot was used (1).

S1.1.2. Identification of Rhet overestimation

We observed an inconsistency between Rhet and Rtot, as direct comparison showed that Rhet (mean 13.0 t CO_2-C ha^{-1} $year^{-1}$) exceeded Rtot by an average of 5.8±3.1 t CO_2-C ha^{-1} $year^{-1}$. The difference is evident in the observed relationship between Rhet or Rtot and temperature, indicating higher Rhet emissions at the same temperatures (Figure S9). Rhet should not be greater than Rtot, as Rtot includes both Rhet and autotrophic respiration of plants.

The main errors in Rhet and Rtot measurements can be introduced during gas sampling and analysis (instrumental method), by site preparation (e.g., collar installation or trenching), or by site-specific factors. To identify the reason for the discrepancy between Rtot and Rhet, we undertook several steps, including investigating the comparability of the instrumental methods and analysing potential sources of error.

In some studies, it has been observed that flux can be underestimated due to nonlinearity in gas concentration increase generally caused by either the small chamber volume or by extended measurement periods (Kutzbach et al., 2007; Nakano et al., 2004; Nomura et al., 2019). Therefore, we assessed method comparability and concentration increase linearity in two steps: 1) by initial quality assurance procedure; 2) by quality control during flux calculation, we checked the linearity of each flux measurement, both visually and using R^2 as an indicator:

1) First, we ensured that the instrumental methods were comparable and investigated whether the discrepancy was due to Rtot underestimation. To compare the methods, we conducted a quality assurance procedure designed to eliminate the influence of site-related factors. Both instrumental methods were therefore compared under controlled conditions. In the laboratory, under constant organic soil temperature (17 ºC) and moisture (50 %) conditions characteristic of natural soil conditions in a warm season, we simultaneously collected gas samples in glass vials from the Rtot measurement chamber for CO_2 concentration analysis with a gas chromatograph, while also measuring changes in CO_2 concentration using a portable gas analyser employed in the Rhet measurements. Repeated measurements (n = 6) revealed that the gas concentration changes in the chamber remained linear throughout the 30-minute measurement period. The relative standard deviation for flux measurements using a gas collection in glass vials and testing with a gas chromatograph was 10%, while with the portable gas analyser, it was 6%. The gas fluxes obtained by the portable

analyser were, on average, 10±7% lower. Consequently, the procedure shows that Rtot measurements could be subject to relative overestimation; however, considering the differences in measurement accuracy and precision, these differences are not significant. Hence, the comparability demonstrated alongside the observed linearity of gas concentration changes in the Rtot chamber, showed that both instrumental methods are comparable and excluded the possibility of Rtot underestimation due to longer measurement times. The nonlinearity can be induced by increasing pressure inside the chamber over time (Silva et al., 2015), consequently, this phenomenon may be more pronounced when using chambers with a small volume. For this reason, it has been advised to use small chambers to emphasize nonlinearity (Kutzbach et al., 2007). Likely, we did not identify nonlinearity as a cause for potential Rtot underestimation in our study due to the relatively large chambers used (area 0.196 m^2, volume 0.0655 m^3). Nevertheless, it has been also advised that linearity itself should not be regarded as an indicator of measurement accuracy (Nakano et al., 2004).

2) During flux calculation, linear regression was applied to establish a relationship between CO_2 concentrations and the elapsed time since chamber closure for each measurement. The data was then screened to identify deviations from the expected trend, with erroneous measurements being removed. We used a regression coefficient of determination (R^2) of 0.9 ($p<0.01$) as a quality threshold, except in cases where the difference between the highest and lowest measured CO_2 concentrations in the chamber was less than the method's uncertainty of 20 ppm. Since an insignificant amount of data was discarded during this process, it reaffirmed that nonlinearity was not a concern, both during the quality assurance procedure and throughout the entire study. However, there is some disagreement regarding the use of R^2 as an indicator for identifying linearity. Recommendations exist against using R^2 as an indicator (Kutzbach et al., 2007), however, these suggestions apply to continuous measurements, where the large volume of field measurement data can indeed lead to false indications of good linearity. In such cases, nonlinear regressions may be appropriate (Kutzbach et al., 2007; Nakano et al., 2004). In cases, such as ours, involving manual chamber usage with a limited number of measurements, nonlinear regression can lead to overfitting an unsuitable trend, making linear regression a safer option. For these reasons nonlinear regression is not recommended for Rtot measurements, as plant responses can be highly variable and unpredictable (Kutzbach et al., 2007). Therefore, we consider our flux estimation approach well suited for this context, as it incorporates rigorous quality control measures to ensure accuracy and reliability in the results.

To summarize, quality assurance demonstrated that nonlinearity was not a concern, while quality control validated the reliability of individual measurements. A comprehensive evaluation of these assessments led to the conclusion that Rhet measurements exceeding Rtot measurements were not because of underestimation of Rtot, but rather due to an overestimation of Rhet.

S1.1.3. Sources of Rhet overestimation and reduced precision

In investigating the causes of errors in Rhet measurements, we identified the main sources of accuracy errors that led to overestimation, as well as factors that led to additional precision errors, further increasing measurement uncertainty. Both types of errors were introduced by the trenching and the approach used to simulate natural conditions between measurements by covering the trenched area with geotextile, topped with a litter layer:

1) To investigate the impact of geotextile cover removal, we compared Rhet measurements taken immediately after removing the geotextile with those taken one hour later. We observed that, on average, the results were lower by a factor of 1.6 ± 1.1 after one hour, with a range of variation between 0.79 and 1.8. This means that the textile reduced the rate of CO_2 diffusion from soil to air, and the textile should have been removed well before the onset of the measurements.

2) Soil trenching was conducted before winter, killing the roots within the trenched area. By spring, when measurements began, the cut roots decomposition was reflected in Rhet measurements. To assess the potential impact of the cut

roots, we collected total belowground biomass samples from the top 40 cm of soil using a soil probe and found that the total root biomass in drained and undrained sites was, on average, 39.3±11.1 and 52.7±18.7 t ha^{-1}, respectively. Considering that around 50% of roots can decompose over two years (Moore et al., 1999; Straková et al., 2012), the study period's underground biomass decomposition could have led to a significant artificial increase in measured Rhet of drained (11.67 t CO_2-C ha^{-1} $year^{-1}$) and undrained (14.37 t CO_2-C ha^{-1} $year^{-1}$) soils. Specifically, the decomposition of resulted killed roots may have raised the Rhet value by 4.90 and 6.59 t CO_2-C ha^{-1} $year^{-1}$, respectively. Although this estimation is rough, it quite well illustrates the potential overestimation generated by root decomposition, especially since the measured Rhet in the study exceeded the Rtot by an average of 5.8±3.1 t CO_2-C ha^{-1} $year^{-1}$.

3) Additional challenges in Rhet interpretation arose due to altered soil conditions caused by trenching, as indicated by the reduced correlation between Rhet and soil temperature. The reduced correlation points towards that further errors in Rhet measurements were introduced by the effects of trenching on soil temperature and, consequently, likely also on moisture levels, in spite of the use of the geotextile cover. Reduced correlation shows that the temperature readings, taken at the centre of the subplot in the untrenched area, did not accurately reflect the temperature within the trenched sections. The correlation (r) between soil temperature and Rhet ranged from a mean of 0.28 ± 0.12 to 0.51 ± 0.12. This was significantly lower than the correlation found with Rtot (r=0.86), thus indicating altered soil conditions in the trenched areas. The correlation between temperature and flux should be comparable for both Rhet and Rtot since both root and microbial respiration are temperature-dependent (Davidson and Janssens, 2006). Furthermore, correlation with Rhet can be expected to be even stronger than with Rtot, as the correlation with Rtot is reduced by the variability in autotrophic respiration (Kutzbach et al., 2007). In our case, the reduced Rhet correlation seems to be generally caused by high emission outliers at elevated soil temperatures. These outliers lead to considerable overestimation of Rhet by flux interpolation models, which are constrained to predict reduced emissions at increased temperatures when soil moisture conditions do not favour microbial activity (Khomik et al., 2009; Yueqian, 2020). Soil respiration is influenced not only by soil temperature but also by water availability (Davidson and Janssens, 2006). Not accounting for moisture regime in the interpolation of flux measurement results can lead to overestimation as Rhet prediction models have to be available to predict lower emissions at even increased temperatures if soil moisture is limiting microbial activity (Jovani-Sancho et al., 2018; Liaw et al., 2021). As the soil temperature and moisture were measured in undisturbed areas of the site, our study design did not account for potential differences in environmental parameters, such as soil temperature and moisture, between trenched and untrenched areas. Therefore, we were unable to address the issue empirically, and the temperature measurements were not applicable to Rhet measurements, preventing both data correction and interpolation. Trenching-altered soil conditions (Ojanen et al., 2012) is a well-known source of Rhet measurement error (Chin et al., 2023; Comstedt et al., 2011; Díaz-Pinés et al., 2010; Epron, 2010; Ngao et al., 2007; Ryhti et al., 2021; Savage et al., 2018; Subke et al., 2006). Due to the challenges in overcoming Rhet measurement errors, root exclusion methods, including trenching, are not entirely satisfactory. As a result, the reliability of using these methods to accurately measure Rhet remains questionable. Given the questionable accuracy and precision in quantifying soil heterotrophic respiration, total soil respiration (Rtot) or soil respiration (Rs) should be considered as an alternative proxy for evaluating soil CO_2 emissions. Rtot and Rs, by causing less soil disturbance, provide more reliable measurement results. Moreover, using these results for relative comparisons, which are necessary for investigating the impact of anthropogenic emissions and management practices on emissions, helps mitigate biases introduced by autotrophic respiration, particularly in cases where biomass is similar across the compared sites.

Considering the significant impacts formed by time from trenching prior to monitoring period and timing of geotextile removal during measurements on the overestimation of Rhet, the primary cause of overestimation could not be definitively identified. The general overestimation likely resulted from the cumulative effects of root decomposition and the CO_2 flux surge following geotextile removal at the start of flux measurements. Attempts to correct these effects would introduce substantial uncertainties. Due to the combined influences of these factors, which cannot be separately isolated, and the observed high variability in overestimation, no robust empirical correction could be applied to obtain instantaneous Rhet values, that could be reliably used for Rhet interpolation. Furthermore, the ability to perform proper interpolation was reduced due to the unavailability of temperature measurements in the trenched areas, further hindering reliable flux annualization and subsequent soil CO_2 balance estimation. Thus, we concluded that a more reliable soil CO_2 balance result was achieved by empirically recalculating Rtot to Rhet. This approach introduced only one additional uncertainty related to the Rtot-to-Rhet conversion, estimated to be approximately 0.32 t CO_2-C ha^{-1} $year^{-1}$, based on the RMSE of the applied conversion model. In comparison, using direct Rhet measurements for soil CO_2 balance estimation would introduce at least seven additional sources of uncertainty. These include root biomass in the trenched area, geotextile removal correction, turnover rates of trenched roots, ground vegetation, tree fine roots, and foliar litter. Further uncertainty would be compounded by the error introduced from using temperature measurements from the untrenched area for Rhet interpolation, as these did not accurately represent the temperature at the trenched site.

S1.1.4. Summary and conclusions

Based on the quality procedures performed, we concluded that the instrumental methods were not responsible for the discrepancy between Rhet and Rtot results. Furthermore, the quality assurance procedure suggested that Rtot was more likely to be potentially slightly overestimated rather than underestimated. We found sufficient evidence of errors, including overestimation, in the Rhet results to support the conclusion that using the Rtot-to-Rhet conversion approach was a more reliable method for annual soil carbon balance estimation. Similar Rhet interpretation issues have been acknowledged by previous studies (Ngao et al., 2007; Epron, 2010; Savage et al., 2018; Chin et al., 2023).

Given the complexity and uncertainty of the Rhet overestimation found, reasonable data corrections were not possible, and thus, using the measured Rhet in CO_2 balance estimation would have resulted in highly unreliable outcomes. The experience emphasizes the necessity of measuring root biomass, stratified by root diameters or branching orders, and conducting a proper root decomposition study to account for the decomposition of killed roots to enable correction of the measured Rhet for CO_2 emissions from trenched root decomposition. It is crucial to perform simultaneous Rtot or Rs measurements in untrenched soil alongside Rhet measurements, as well as soil temperature and moisture measurements at both locations. Since root decomposition is the main concern, the trenching method may be more challenging in regions with increased biomass growth.

S1.2. Country as a CO_2 balance impacting factor

The mean measured Rtot of undrained soil was smaller in both Latvia (mean 57±6 mg CO_2-C m^{-2} h^{-1}) and Lithuania (mean 55±6 mg CO_2-C m^{-2} h^{-1}) compared to Rtot from drained soil in the Baltic states ranging from mean 72±4 to 79±5 mg CO_2-C m^{-2} h^{-1} (Figure S4, g). Estimated annualized Rtot from neither drained sites (overall mean 6.21±0.43 t CO_2-C ha^{-1} $year^{-1}$) nor undrained sites (overall mean 4.38±1.20 t CO_2-C ha^{-1} $year^{-1}$) differed significantly between countries and were generally higher from drained soils (Figure 6, h). Soil CO_2 balance estimates showed higher mean soil CO_2 removals for both drained and undrained sites in Lithuania than those in Estonia and Latvia. This was primarily attributed to greater CO_2 influx from ground vegetation litter (Figure 8). However, the sites in Lithuania also stand out due to greater uncertainty in both CO_2 influx and efflux, resulting in the soil CO_2 balance in drained sites across the countries being equivalent within the margin of error (Figure 9a). The low number of undrained sites in Lithuania (n=2) limited the ability to investigate the patterns behind the observed lower soil CO_2 efflux and higher aGV litter, contributing to significantly higher soil CO_2 removals (+3.70±0.11 t CO_2-C ha^{-1} $year^{-1}$) compared to sites in Latvia (+0.30±0.56 t CO_2-C ha^{-1} $year^{-1}$, n=5).

S2. Supplementary tables

Table S1: Study stands characteristics. Abbreviations: species – dominant tree species; WTL – mean water table level, cm; A – age, years; D – mean tree diameter, cm; H – mean tree height, m; BA – basal area, m^2 ha^{-1}. Site types: Dr - *Dryopterioso–caricosa*; Ox - *Oxalidosa turf. mel.*; My - *Myrtillosa turf.mel.*

Site identifier	Latitude	Longitude	Species	Site type	WTL	Organic layer, cm	A	D	H	BA
Drained sites										
LTC106	54.79312	24.07451	Alder	Ox	−56	50	30	12	13	26
EEC108	58.25010	26.29040		Ox	−23	35	80	21	20	36
LVC108	57.32216	26.06411	Birch	Ox	−30	90	24	14	16	15
LVC115	56.69388	25.68767		Ox	−96	56	33	13	16	21
EEC106	58.43755	26.35558		Ox	−70	70	35	12	13	18
LTC105	54.79010	24.08022		Ox	−94	50	43	22	18	23
EEC109	58.34765	26.47599		Ox	−57	90	45	16	16	22
EEC105	58.42870	26.37470	Pine	My	−82	90	60	22	18	17
LVC110	56.62838	24.11370		My	−76	35	81	12	12	43
LVC107	56.78452	23.86247		Ox	−112	27	101	22	21	48
LVC116	57.26889	25.99285		My	−31	165	141	14	14	34
LVC313	57.26889	25.99285		My	−53	138	141	14	13	39
LVC104	56.99978	24.65896	Spruce	Ox	−80	50	40	22	20	33
LVC105	56.39288	25.65370		Ox	−31	86	55	22	19	22
LVC106	56.39495	25.65134		Ox	−42	95	55	24	21	21
EEC104	58.43861	26.35394		Ox	−66	80	60	20	17	18
LTC104	54.79426	24.08077		My	−63	50	70	20	17	27
LVC308	57.34717	25.92568		Ox	−50	212	141	25	23	36
LVC112	57.33731	26.02635		Ox	−31	68	162	10	10	21
Undrained sites										
LTC109	54.54109	23.61140	Alder	Dr	−10	150	44	16	16	30
LVC109	56.57378	24.82944		Dr	−11	100	74	28	28	36
LTC108	54.54396	23.56578	Birch	Dr	−7	150	44	21	20	22
LVC111	57.29058	25.99874		Dr	−14	230	61	8	9	23
LVC309	57.27915	25.85371	Spruce	Dr	−17	133	81	21	20	34
LVC311	57.27887	25.85441		Dr	−13	205	88	18	17	42
LVC312	57.31164	25.93609		Dr	−17	221	96	17	15	25

Table S2: Relative occurrence and mean projective cover of most common ground vegetation species in the study sites. The species are listed in descending order based on a score calculated as the sum of their cover and occurrence.

Drained			Undrained		
Species	Cover	Occurrence	Species	Cover	Occurrence
Shrub layer					
Picea abies	35	20	Picea abies	19	19
Frangula alnus	21	16	Salix sp.	13	29
Fraxinus excelsior	28	7	Alnus glutinosa	11	24
Betula pendula	14	20	Sorbus aucuparia	11	14
Salix sp.	23	9	Populus tremula	10	10
Sorbus aucuparia	12	18	Betula pendula	5	5
Viburnum opulus	20	9	-	-	-
Prunus padus	18	7	-	-	-
Populus tremula	20	2	-	-	-
Herbaceous layer					
Oxalis acetosella	20	54	Epilobium hirsutum	39	23
Rubus idaeus	17	50	Epilobium parviflorum	18	39
Carex echinata	53	2	Galium palustre	12	44
Vaccinium myrtillus	18	36	Cirsium oleraceum	29	14
Urtica dioica	17	28	Deschampsia cespitosa	21	22
Stellaria nemorum	18	26	Filipendula ulmaria	20	23
Dryopteris carthusiana	8	29	Carex cinerea	24	16
Mycelis muralis	3	30	Rubus idaeus	15	24
Poa angustifolia	28	3	Athyrium filix-femina	16	22
Carex remota	25	5	Carex sp.	12	26
Geranium robertianum	6	22	Oxalis acetosella	3	32
Mercurialis perennis	26	2	Salix sp.	10	23
Vaccinium vitis-idaea	10	15	Chamaenerion angustifolium	30	2
Cirsium oleraceum	20	5	Galium uliginosum	30	1
Carex cespitosa	18	5	Dryopteris carthusiana	5	26
Trientalis europaea	2	21	Chrysosplenium alternifolium	4	26
Calamagrostis arundinacea	17	6	Scirpus sylvaticus	25	4
Galeopsis tetrahit	4	19	Luzula pilosa	9	20
Phragmites australis	19	3	Carex vesicaria	25	1
Betula pendula	9	12	Urtica dioica	7	18
Viburnum opulus	20	1	Stellaria nemorum	8	17
Moss and lichen layer					
Hylocomium splendens	34	45	Hylocomium splendens	14	30
Plagiomnium cuspidatum	16	38	Eurhynchium hians	17	26
Pleurozium schreberi	18	35	Climacium dendroides	10	26
Polytrichum commune	40	1	Rhytidiadelphus triquetrus	10	25
Eurhynchium angustirete	13	24	Plagiomnium cuspidatum	4	23
Plagiomnium affine	5	27	Cirriphyllum piliferum	7	19
Rhytidiadelphus triquetrus	10	16	Plagiomnium affine	3	22
Dicranum polysetum	3	24	Pleurozium schreberi	5	19
Brachythecium rutabulum	20	2	Dicranum scoparium	4	14
Dicranum scoparium	2	20	Polytrichum juniperinum	9	8
Cirriphyllum piliferum	14	7	Eurhynchium striatum	10	4
Ptilium crista-castrensis	20	1	Thuidium tamariscinum	5	9

Table S3: Meteorological conditions during the study period (Estonian Environment Agency. Climate normals, 2024; Latvian Environment, Geology and Meteorology Centre. Climate normals, 2024; Lithuanian Hydrometeorological Service. Climate normals, 2024)

Parameter	Variable	Estonia		Latvia		Lithuania	
		1st year	2nd year	1st year	2nd year	1st year	2nd year
Annual air temperature. °C	Mean	6.4	6.9	7.0	7.3	7.8	8.5
	Range	-22.4...27.2	-14.9, 25.6	−31.0, 33.7	−23.2, 33.7	-12.0, 27.2	-11.3, 25.0
	Climate normal(1)	6.4		6.8		7.4	
Annual precipitation. mm	Sum	597.0	472.9	676.3	685.8	639.8	533.6
	Climate normal(1)	662		686		695	

(1) 30-year averages for climate variables

Table S4: Laboratory standard methods used for sample analysis.

Parameter	Unit	Method principle	Standard method
Analysis of soil and biomass samples			
Bulk density	kg m^{-3}	Gravimetry	LVS ISO 11272:2017
pH	unit	Potentiometry	LVS ISO 10390:2021
Total C	g kg^{-1}	Elementary analysis (dry combustion)	LVS ISO 10694:2006
Total N	g kg^{-1}	Elementary analysis (dry combustion)	LVS ISO 13878:1998
Ash content	g kg^{-1}	Gravimetry	LVS EN ISO 10693:2014
Concentrated HNO_3 extractable potassium (K), calcium (Ca), magnesium (Mg) and phosphorus (P)	g kg^{-1}	ICP-OES	LVS EN ISO 11885:2009
Analysis of water samples			
pH	unit	Potentiometry	LVS EN ISO 10523:2012
DOC	mg L^{-1}	Catalytical combustion with infrared detection	LVS EN 1484:2000
Total N	mg L^{-1}	Catalytical combustion with chemiluminescence detection	LVS EN 1484:2000
NO_3^-, PO_4^{3-}	mg L^{-1}	Ion chromatography	LVS EN ISO 10304 – 1:2009
NH_4^+	mg L^{-1}	Photometry	LVS ISO 7150-1:1984
K, Ca, Mg	mg L^{-1}	Flame atomic absorption spectrometry	LVS EN ISO 7980:2000

Table S5: Biomass (t dm. ha^{-1}) measurement results (mean±SD) stratified by drainage status and country. Abbreviations: aGV and bGV – aboveground and belowground biomass of herbaceous ground vegetation, respectively, S – shrubs, FR- fine roots, FRP – fine root production, M – moss, MP – moss production, fLF – foliar fine litter, cLF – coarse woody litter, RB – total root biomass in depth 0-40 cm. NE – not estimated. *Data used for soil CO_2 balance estimation, ** assuming 100% moss cover.

Category	Drained			Undrained	
	EE	LT	LV	LT	LV
aGV*	0.79±0.33	1.34±2.98	2.38±0.63	4.64±14.53	1.44±0.63
bGV*	NE	4.24±2.01	2.52±0.96	2.3±7.74	2.47±1.26
S	0.36±0.36	2.04±2.42	NE	4.27±24.24	NE
FR	NE	NE	NE	NE	NE
FRP*	NE	2.51±5.35	2.54±1.02	NE	1.08±0.76
M**	4.8±2.49	NE	NE	NE	NE
MP**	0.92±0.48	NE	0.87±0.32	NE	1.01±0.31
fLF*	3.66±0.64	3.7±1.2	2.9±0.69	3.28±13.77	2.23±1.23
cLF	1.39±0.65	0.33±0.62	0.54±0.26	1.35±6.61	0.55±0.68
RB	NE	NE	39.3±11.1	NE	52.7±18.7

Table S6: Characteristics of total soil respiration (Rtot) prediction models used for interpolation of Box-Cox transformed hourly emissions. Abbreviations: R10 - Rtot when soil temperature is 10 °C at 10 cm depth, RMSE – root mean square error of the model prediction. RMSE improvement and R10 increase are relative differences of corresponding model characteristics compared to linear models fitted using log10 transformed data. Model describes: $\frac{Rtot^{lambda-1}}{lambda} = \boldsymbol{a} * \boldsymbol{T} + \boldsymbol{b}$. where:

Rtot – soil instantaneous total respiration (mg CO_2-C m^{-2} h^{-1}), lambda – lambda value used for Rtot data transformation, a – coefficient a of linear model, b – coefficient b of a linear model, T – soil temperature at 10 cm depth (°C).

Site identifier	Coefficient a	Coefficient b	R^2	R10	RMSE	RMSE improvement	R10 increase
LVC104	0.4903	5.6964	0.71	89	35	7%	10%
LVC105	0.74315	4.44323	0.84	116	59	8%	19%
LVC106	0.7318	5.0111	0.85	127	59	14%	20%
LVC107	0.53295	4.32402	0.70	72	36	6%	10%
LVC108	0.70835	3.45753	0.78	88	45	20%	26%
LVC109	0.68144	3.27991	0.80	80	43	34%	24%
LVC110	0.60544	3.41507	0.72	69	31	11%	15%
LVC111	0.70313	2.31005	0.78	67	31	7%	28%
LVC112	0.6929	3.341	0.84	83	24	43%	12%
LVC115	0.61712	4.19065	0.75	85	38	25%	17%
LVC116	0.6038	3.5911	0.77	72	21	31%	12%
LVC308	0.65977	3.86443	0.82	87	23	38%	14%
LVC309	0.5781	2.4058	0.74	50	24	40%	30%
LVC311	0.5456	3.1613	0.63	56	31	6%	29%
LVC312	0.6539	2.1481	0.73	57	33	-11%	35%
LVC313	0.52151	4.277	0.80	69	17	25%	6%
EEC108	0.59162	3.17106	0.82	63	25	27%	19%
EEC106	0.5715	4.2928	0.82	78	37	32%	20%
EEC105	0.44359	4.60199	0.75	62	32	20%	15%
EEC104	0.55427	4.47956	0.72	78	53	14%	20%
EEC109	0.499	5.732	0.63	92	52	6%	26%
LTC104	0.35744	4.25538	0.46	46	38	5%	17%
LTC105	0.4589	5.07975	0.52	72	54	6%	15%
LTC106	0.5431	4.8996	0.54	84	68	7%	22%
LTC108	0.28306	4.04885	0.39	35	26	3%	28%
LTC109	0.36444	4.24811	0.43	46	44	-4%	36%

Table S7: Summary of soil characteristics in 0-30 cm depth in study sites (mean±SD). BD - bulk density, Corg – organic carbon, N – Nitrogen, C:N – C:N ratio, P – phosphorous, K – potassium, Ca – calcium, Mg – magnesium.

Parameter	Unit	Drained			Undrained		
		0-10	0-20	0-30	0-10	0-20	0-30
BD	kg m^{-3}	221±86	270±135	314±214	173±38	174±32	168±32
pH	units	3.9±1.1	4.1±1.1	4.2±1.1	5.3±0.3	5.3±0.3	5.3±0.3
Corg	g kg^{-1}	412±91	416±121	406±153	411±64	432±39	443±39
N	g kg^{-1}	23±6	22±8	20±9	27±4	27±4	27±4
C:N	ratio	19±6	21±6	22±7	15±3	16±3	17±3
P	g kg^{-1}	0.9±0.4	0.8±0.5	0.8±0.6	2±1.7	1.8±1.2	1.6±1.1
K	g kg^{-1}	0.7±0.4	0.5±0.3	0.4±0.3	1.6±1.1	1.3±0.8	1.1±0.6
Ca	g kg^{-1}	15±13	17±14	17±14	28±7	28±7	28±8
Mg	g kg^{-1}	1.2±0.7	1.2±0.8	1.2±0.8	2.6±0.8	2.5±0.8	2.4±0.7

Table S8: Summary of soil water characteristics in the study sites (mean±SD).

Parameter	Unit	Drained			Undrained	
		EE	LT	LV	LT	LV
pH	unit	6.9±0.6	6.5±0.6	6.1±1.2	7±0.5	7±0.5
DOC	mg L^{-1}	69.4±23.1	93.5±64.5	95.4±57.4	103.3±23.7	41.7±30
N	mg L^{-1}	13.2±11.5	12.7±15.4	5.4±4.7	5.5±1.7	2.1±1.4
NH_4^+	mg L^{-1}	0.6±0.9	0.5±0.7	0.4±0.4	0.7±0.9	0.6±0.7
NO_3^-	mg L^{-1}	11.5±12.9	10.7±17.4	2.5±4.3	1.3±1.6	0.5±0.5
PO_4^{3-}	mg L^{-1}	0.1±0.1	0.1±0.2	0.1±0.2	0.1±0.1	0.1±0.1
K	mg L^{-1}	0.4±0.3	2.8±3.5	0.6±0.4	1.9±0.7	0.6±0.3
Ca	mg L^{-1}	63.6±27.8	77.7±51	27.5±16.9	71.1±15.5	29±9.2
Mg	mg L^{-1}	7.5±4.9	14.6±8.2	5.6±4.6	12.9±2.2	6±1.4

Table S9: Characteristics of linear mixed-effects models predicting total forest floor respiration (Rtot) incorporating a random effect for study site. AIC - Akaike information criterion, BIC - Bayesian information criterion, logLik - log-likelihood value, R^2 marginal - variance explained by fixed effects, R^2 conditional - variance explained by fixed and random effects, *p<0.1, **p<0.05, ***p<0.01.

Variable	Coefficient ± standard error				
(Intercept)	3,8±0,12***	3,43±0,16***	3,2±0,36***	3,42±0,34***	3,61±1,25***
T	0,35±0***	0,35±0***	0,35±0***	0,35±0***	0,35±0***
Drainage: undrained	-1,09±0,22***	-1,31±0,24***	-1,35±0,24***	-1,41±0,22***	-1,4±0,19***
K		-0,6±0,21***	-0,58±0,23	-0,4±0,26	-0,48±0,21
Mg		0,38±0,11***	0,43±0,13***	0,36±0,13***	0,12±0,11
P		0,23±0,11	0,26±0,11	0,11±0,11	0,02±0,11
Species: birch			0,08±0,25	-0,08±0,23	-0,64±0,22***
Species: pine			0,26±0,34	-0,25±0,36	-0,34±0,32
Species: spruce			0,14±0,25	-0,19±0,26	-0,67±0,22***
Country: LT				-0,19±0,28	0,23±0,33
Country: LV				0,38±0,2	1,2±0,26***
pH					0,01±0,17
Corg					0±0
N					-0,01±0,02
Ca					0,03±0,01
BA					-0,01±0,01
A					0±0
AIC	10177	10167	10172	10170	10164
BIC	10208	10215	10239	10249	10279
logLik	-5084	-5075	-5075	-5072	-5063
R^2 marginal	0,75	0,77	0,77	0,77	0,78
R^2_conditional	0,79	0,79	0,78	0,78	0,78

Table S10: Mean estimated annual cumulative total respiration (t CO_2-C ha^{-1} $year^{-1}$) and biomass (t dm. ha^{-1}) in the study sites. Abbreviations: Rtot – total respiration, Rhet – heterotrophic respiration, aGV and bGV – aboveground and belowground biomass of herbaceous ground vegetation, respectively, FRP – fine root production, fLF – foliar fine litter, cLF – coarse woody litter; NE – not estimated, NA – biomass not present or in negligible amounts. *Used as soil CO_2 influx values for soil CO_2 balance estimation; ** assuming 100% moss cover.

Study site	Rtot	Rhet	aGV*	bGV*	Shrubs	FRP*	Moss**	Moss production**	fLF*	cLF
EEC104	6.04	7.62	0.93	NE	0.08	NE	7.20	1.24	3.80	1.30
EEC105	4.76	9.48	1.10	NE	0.07	NE	5.63	1.08	3.31	1.72
EEC106	6.07	7.95	0.38	NE	0.43	NE	3.61	1.11	3.63	1.51
EEC108	5.08	12.77	0.83	NE	0.73	NE	NE	0.92	4.44	1.88
EEC109	7.61	10.36	0.70	NE	0.51	NE	2.75	0.26	3.12	0.53
LTC104	3.92	-	NA	5.11	2.72	5.00	5.93	2.08	3.77	0.62
LTC105	6.45	-	2.19	4.10	NA	1.29	NA	NA	3.19	0.13
LTC106	7.59	-	0.50	3.52	1.35	1.25	NA	NA	4.15	0.25
LTC108	2.98	-	3.49	1.69	2.37	NE	0.96	NE	4.37	1.87
LTC109	4.04	-	5.78	2.91	6.18	NE	NA	NA	2.20	0.83
LVC104	6.59	12.45	2.60	0.72	NE	2.10	NE	0.35	4.09	0.03
LVC105	9.01	15.78	2.47	1.43	NE	1.40	NE	0.74	4.03	0.45
LVC106	10.50	18.03	3.23	1.83	NE	2.96	NE	1.68	2.76	0.44
LVC107	5.36	7.57	1.49	3.02	NE	5.57	NE	NA	3.98	1.08
LVC108	7.25	17.25	1.82	2.19	NE	0.94	NE	1.20	2.67	0.35
LVC109	6.89	13.72	1.12	1.36	NE	0.64	NE	NA	3.33	1.52
LVC110	5.43	13.92	1.12	2.43	NE	2.89	NE	0.32	4.00	1.33
LVC111	5.51	17.42	0.82	2.38	NE	1.51	NE	1.18	3.11	0.47
LVC112	6.60	12.50	1.67	3.11	NE	NE	NE	NA	1.52	0.27
LVC115	6.61	10.76	1.44	2.48	NE	1.92	NE	NA	2.57	0.86
LVC116	5.65	11.66	3.22	6.12	NE	NE	NE	1.06	1.42	0.34
LVC308	6.27	7.72	3.15	1.36	NE	NE	NE	0.75	1.85	0.33
LVC309	3.98	12.90	1.61	3.29	NE	NE	NE	NA	2.09	0.33
LVC311	4.57	18.30	1.51	3.69	NE	NE	NE	NA	1.68	0.24
LVC312	5.27	9.49	2.14	1.62	NE	NE	NE	0.83	0.94	0.21
LVC313	4.96	11.11	3.98	3.08	NE	NE	NE	NA	2.96	0.45
Drained	6.21±0.43	11.68±1.72	1.82±0.52	2.89±0.85	0.84±0.45	2.53±0.77	5.02±0.87	0.98±0.25	3.22±0.44	0.73±0.27
Undrained	4.38±1.20	14.37±3.97	2.35±1.61	2.42±0.84	4.27±2.5	1.08±0.57	NE	1.01±0.23	2.53±1.06	0.78±0.62

Table S11: Summary of soil CO_2 balance (mean±CI, t CO_2-C ha^{-1} year^{-1}) estimation results. As soil CO_2 influx only ground vegetation, fine roots of trees and foliar fine litter is considered. Soil CO_2 balance is calculated by subtracting mean Rhet` from mean soil CO_2 influx.

Drainage status	Country	Tree specie	Soil CO_2 input	Rtot	Rhet`	Soil CO_2 balance
Drained	EE	Mean	5.33±3.03	5.91±1.38	3.91±1.08	1.42±3.22
	LT		6.06±3.33	5.99±4.66	3.97±3.63	2.09±4.93
	LV		5.28±0.86	6.75±1.12	4.56±0.87	0.72±1.22
	Mean		5.56±3.35	6.22±4.9	4.15±0.89	1.41±1.70
	Mean	Alder	5.01±2.06	6.34±2.45	4.24±1.91	0.77±2.81
		Birch	4.44±0.9	6.8±0.77	4.60±0.60	-0.16±1.08
		Pine	6.75±1.92	5.23±0.45	3.38±0.35	3.37±1.95
		Spruce	5.41±1.57	6.99±1.98	4.75±1.54	0.66±2.20
		Mean	5.4±0.82	6.34±1.81	4.24±0.98	1.16±2.44
Undrained	LT	Mean	5.73±1.73	3.51±1.04	2.04±0.81	3.69±1.91
	LV		3.69±1.04	5.24±1.37	3.39±1.07	0.30±1.49
	Mean		4.71±0.68	4.38±0.33	2.72±1.32	2.00±3.32
	Mean	Alder	4.57±1.25	5.47±2.80	3.56±2.18	1.01±2.51
		Birch	4.84±2.49	4.25±2.48	2.61±1.93	2.23±3.15
		Spruce	3.7±1.22	4.6±1.60	2.89±0.57	0.81±1.35
		Mean	4.37±1.81	4.77±2.49	3.02±1.21	1.35±1.91

S3. Supplementary figures

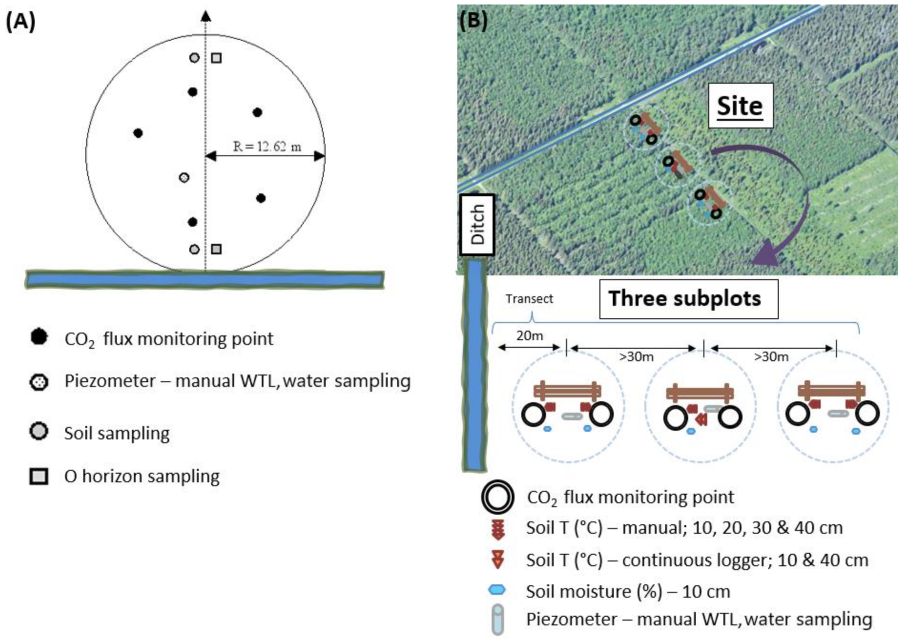

Figure S1: Sampling design.

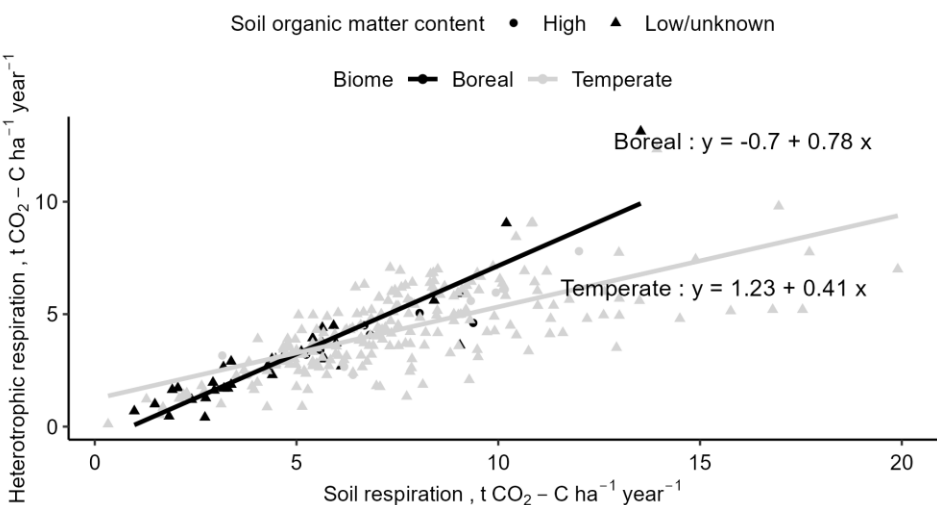

Figure S2: Relationship between total soil respiration and soil heterotrophic respiration in forests according to previous studies (Jian, J. et al., 2021)**.**

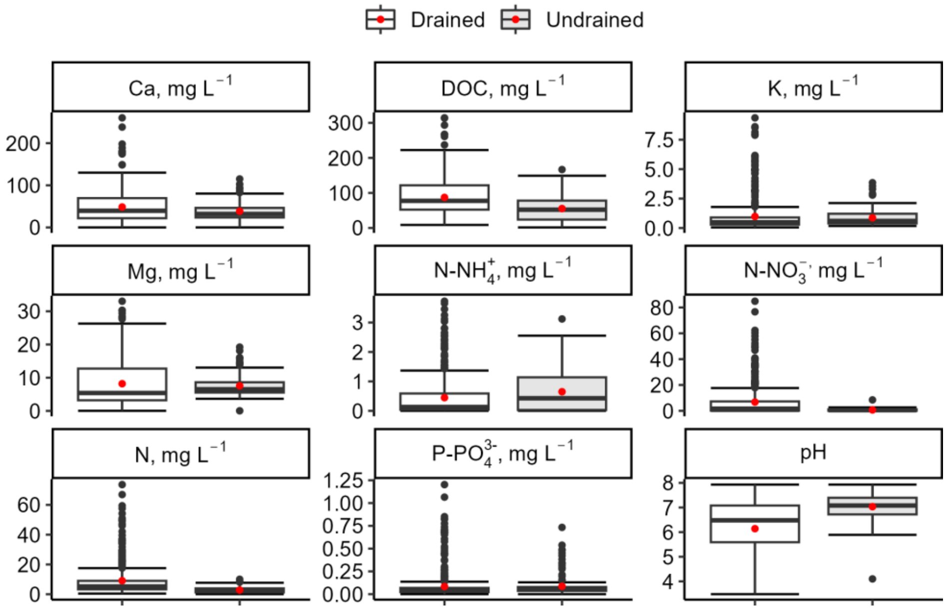

Figure S3: Variation of soil water chemical properties.

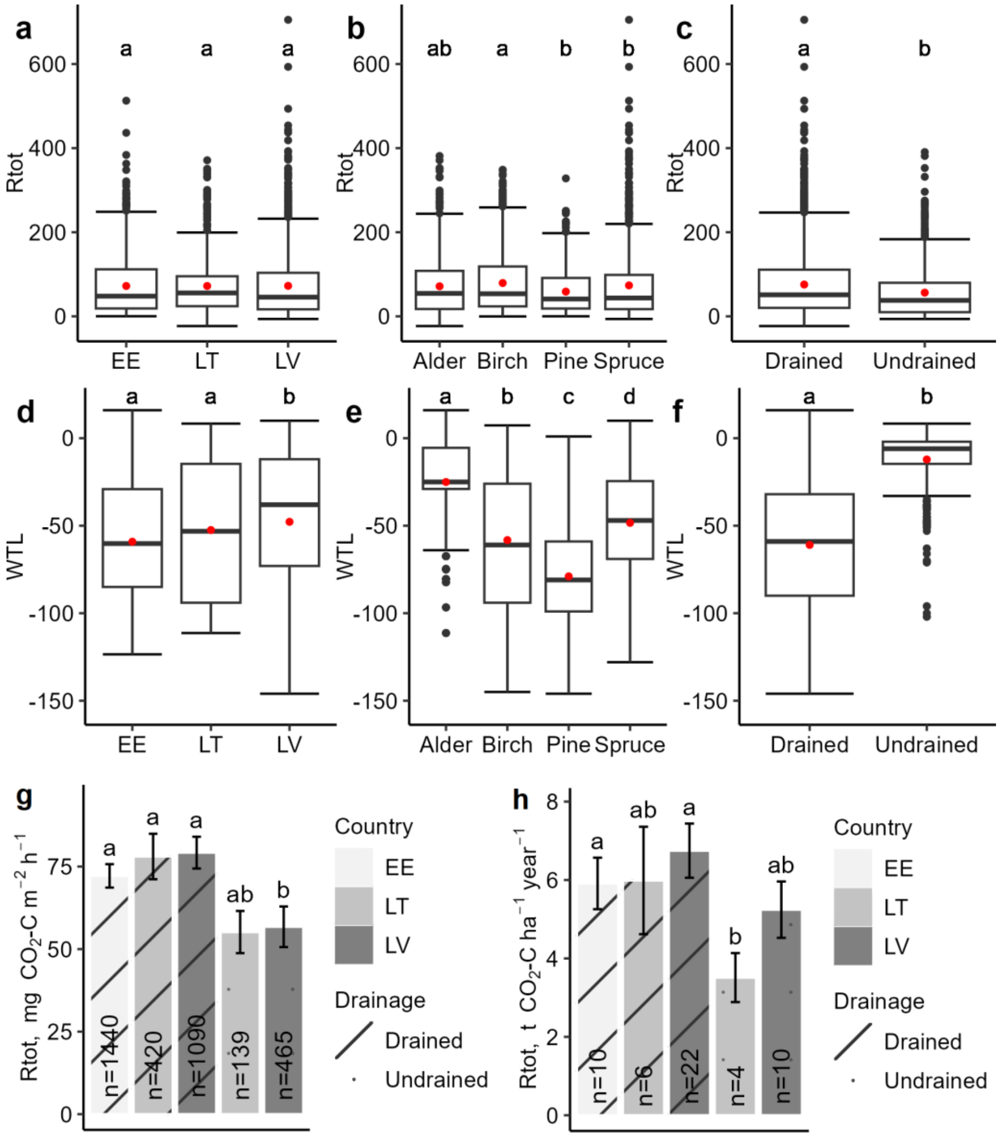

Figure S4: Summary of water table level (WTL, cm) depth and total respiration (Rtot, mg CO_2-C m^{-2} h^{-1}) measurement results by country (a, d), dominant tree species (b, e) or drainage status (c, f), and mean measured (g) or annualized (h) total respiration stratified by both country and drainage status.

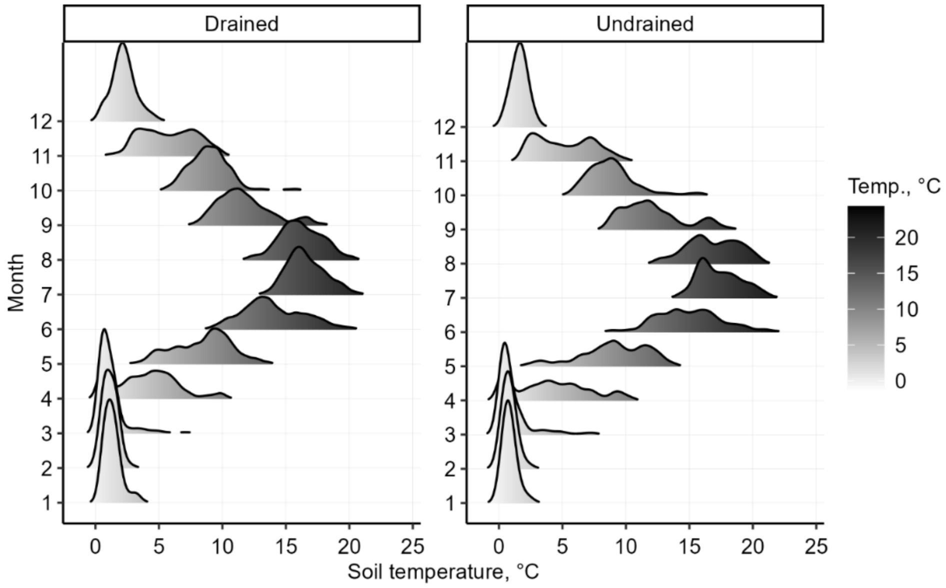

Figure S5: Density plots of soil temperature at 10 cm depth.

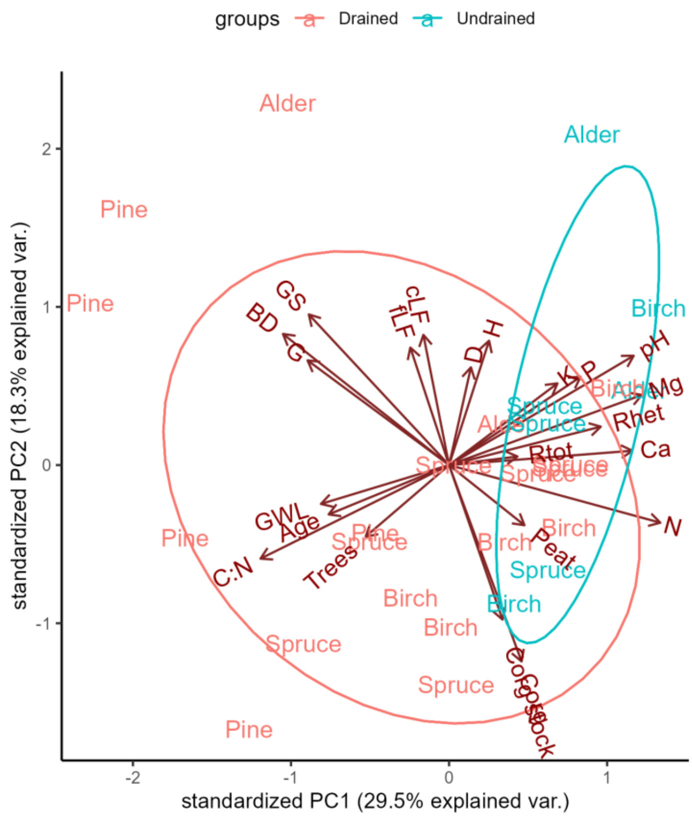

Figure S6: PCA visualizing the covariation of the measured variables. Abbreviations: Age – stand age; BD – bulk density; C:N – ratio between organic carbon and nitrogen in soil; cLF – coarse woody litter; Corg stock – soil organic carbon stock; D – mean tree diameter; fLF – fine foliar litter; G – basal area; GS – growing stock; GWL – water table level; H – mean tree height; pH – soil pH value; Rhet – annual soil heterotrophic respiration; Rtot – annual total forest floor respiration ; Trees – tree density; K, Ca, Mg, P, and Corg represent the content of potassium, calcium, magnesium, phosphorus, and organic carbon in the soil, respectively.

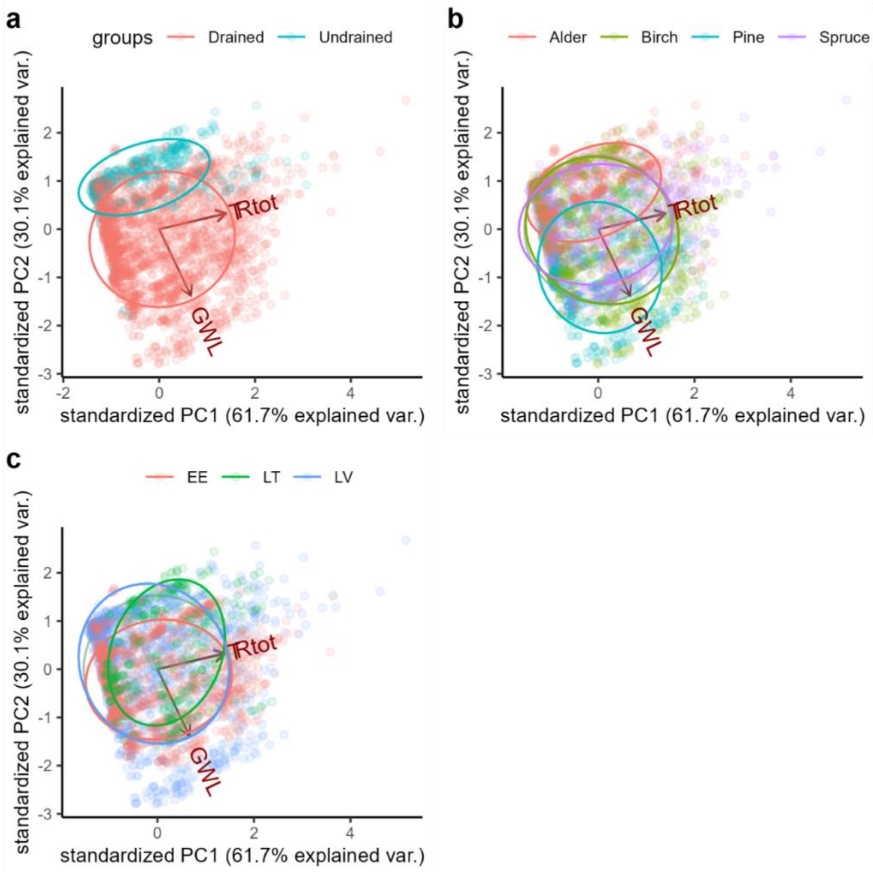

Figure S7: PCA of total forest floor respiration (Rtot), soil temperature and WTL data. In figures a, b, c data are grouped by drainage status, dominant tree species and country, respectively.

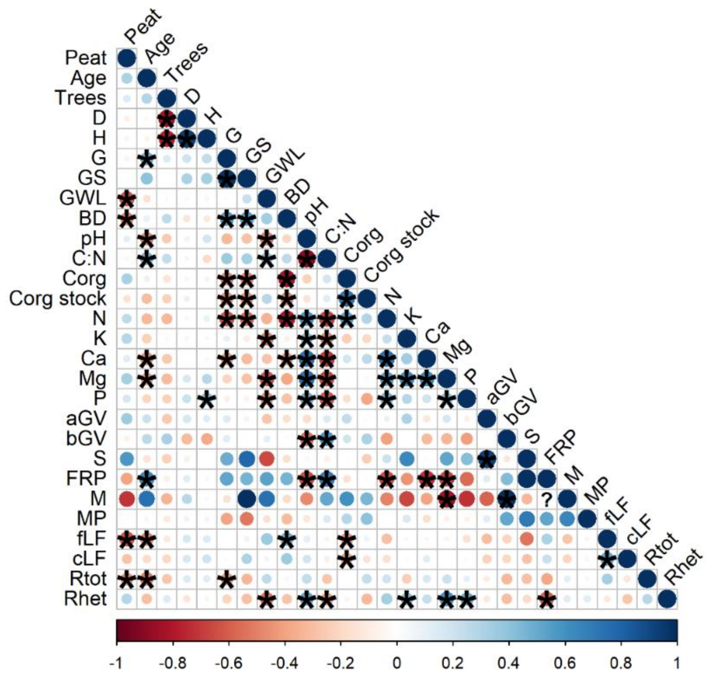

Figure S8: Correlation matrix of annualized data (soil physical and chemical parameters at 0-30 cm depth). Abbreviations: Peat – peat (organic) layer depth; Age – stand age; Trees – tree density; D – mean tree diameter; H – mean tree height; G – basal area; GS – growing stock; GWL – water table level; BD – bulk density; pH – soil pH value; C:N – ratio between organic carbon and nitrogen in soil; Corg stock – soil organic carbon stock; K, Ca, Mg, P, and Corg represent the content of potassium, calcium, magnesium, phosphorus, and organic carbon in the soil, respectively; aGV, bGV, S, FRP, M, MP, fLF, cLF – biomass of aboveground herbaceous vegetation, belowground herbaceous vegetation, shrubs, tree fine root production, moss, moss production, fine foliar litter, coarse woody litter, respectively; Rtot – annual total forest floor respiration ; Rhet – annual soil heterotrophic respiration.

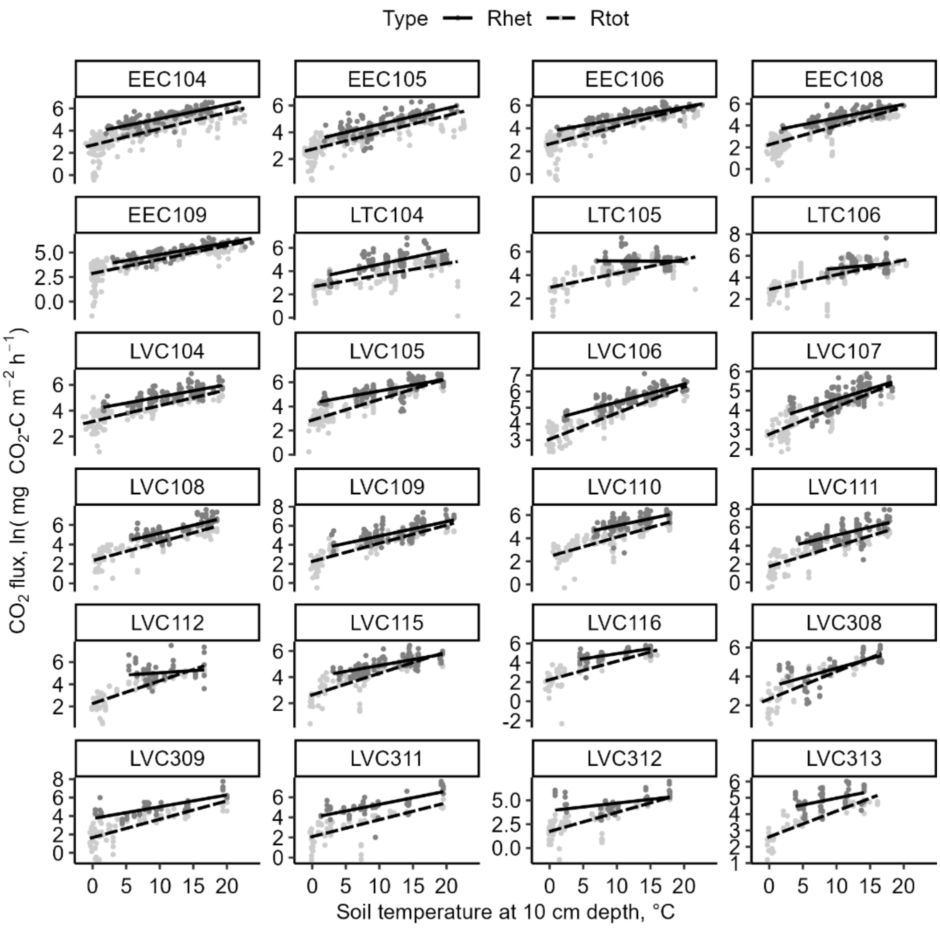

Figure S9: Relationship between soil temperature and log-transformed soil heterotrophic (Rhet) and total (Rtot) respiration.