# Modeling soil organic carbon dynamics in temperate forests using Yasso07

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# Supporting Material I: Supplementary tables and figures

**Table S1 Information on forest inventories for stand biomass estimation**

| Site | Dominant Species | Soil | Forest inventory for stand biomass | | | | Storm event (yr) | No. of thinnings |
|---|---|---|---|---|---|---|---|---|
| | | | Beginning(yr) | End (yr) | Span (yrs) | No. of inventories | | |
| QR_10 | *Quercus robur* | Calcisol | 1991 | 2009 | 18 | 7 | | 1 |
| QR_18 | *Quercus robur* | Planosol | 1991 | 2009 | 18 | 7 | | 3 |
| QR_40 | *Quercus robur* | Cambisol | 1992 | 2011 | 19 | 9 | 2009 | 2 |
| QR_49 | *Quercus robur* | Planosol | 1991 | 2010 | 19 | 6 | 2009 | 3 |
| QR_55 | *Quercus robur* | Calcisol | 1992 | 2009 | 17 | 6 | | 2 |
| QR_59 | *Quercus robur* | Luvisol | 1991 | 2010 | 19 | 8 | | 2 |
| QR_65 | *Quercus robur* | Cambisol | 1992 | 2012 | 20 | 6 | | 3 |
| QR_70 | *Quercus robur* | Luvisol | 1992 | 2011 | 19 | 7 | | 3 |
| QR_71 | *Quercus robur* | Luvisol | 1991 | 2009 | 18 | 6 | | 2 |
| QP_1 | *Quercus petraea* | Cambisol | 1991 | 2011 | 20 | 7 | | 2 |
| QP_3 | *Quercus petraea* | Cambisol | 1991 | 2009 | 18 | 7 | | 3 |
| QP_10 | *Quercus petraea* | Luvisol | 1991 | 2010 | 19 | 9 | | 3 |
| QP_18 | *Quercus petraea* | Luvisol | 1991 | 2009 | 18 | 7 | | 3 |
| QP_21 | *Quercus petraea* | Luvisol | 1991 | 2012 | 21 | 7 | | 2 |
| QP_27 | *Quercus petraea* | Luvisol | 1992 | 2009 | 17 | 9 | 1999 | 2 |
| QP_35 | *Quercus petraea* | Luvisol | 1991 | 2011 | 20 | 6 | | 2 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| QP_41 | *Quercus petraea* | Luvisol | 1991 | 2010 | 19 | 7 | | 1 |
| QP_51 | *Quercus petraea* | Cambisol | 1992 | 2004 | 12 | 5 | 1999 | 0 |
| QP_57a | *Quercus petraea* | Planosol | 1992 | 2009 | 17 | 8 | 1999 | 1 |
| QP_57b | *Quercus petraea* | Podzol | 1992 | 2009 | 17 | 5 | | 2 |
| QP_58 | *Quercus petraea* | Luvisol | 1991 | 2009 | 18 | 6 | | 3 |
| QP_60 | *Quercus petraea* | Planosol | 1992 | 2009 | 17 | 7 | | 2 |
| QP_61 | *Quercus petraea* | Luvisol | 1991 | 2009 | 18 | 7 | 1999 | 2 |
| QP_68 | *Quercus petraea* | Calcisol | 1992 | 2009 | 17 | 7 | 1999 | 2 |
| QP_72 | *Quercus petraea* | Luvisol | 1991 | 2009 | 18 | 8 | | 3 |
| QP_81 | *Quercus petraea* | Luvisol | 1992 | 2009 | 17 | 6 | | 1 |
| QP_86 | *Quercus petraea* | Luvisol | 1991 | 2009 | 18 | 6 | 1999 | 4 |
| QP_88 | *Quercus petraea* | Cambisol | 1992 | 2011 | 19 | 8 | | 3 |
| QP&QR_67 | *Quercus petraea & Q. robur* | Cambisol | 1992 | 2004 | 12 | 5 | 1999 | 3 |
| QP&QR_77 | *Quercus petraea & Q. robur* | Podzol | 1991 | 2009 | 18 | 6 | 1999 | 2 |
| PM_23 | *Pseudotsuga menziesii* | Cambisol | 1991 | 2008 | 17 | 7 | 1999 | 1 |
| PM_34 | *Pseudotsuga menziesii* | Cambisol | 1991 | 2010 | 19 | 7 | | 4 |
| PM_61 | *Pseudotsuga menziesii* | Luvisol | 1991 | 2011 | 20 | 7 | | 3 |
| PM_65 | *Pseudotsuga menziesii* | Cambisol | 1992 | 2004 | 12 | 5 | | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| PM_69 | *Pseudotsuga menziesii* | Cambisol | 1991 | 2004 | 13 | 7 | 1999 | 1 |
| PM_71 | *Pseudotsuga menziesii* | Podzol | 1993 | 2013 | 20 | 11 | | 5 |
| PA_8 | *Picea abies* | Podzol | 1992 | 2009 | 17 | 5 | | 1 |
| PA_34 | *Picea abies* | Podzol | 1991 | 2009 | 18 | 7 | 2009 | 3 |
| PA_39a | *Picea abies* | Luvisol | 1991 | 2004 | 13 | 5 | | 1 |
| PA_63 | *Picea abies* | Andosol | 1991 | 2009 | 18 | 7 | | 3 |
| PA_71 | *Picea abies* | Podzol | 1991 | 2004 | 13 | 5 | | 1 |
| PA_73 | *Picea abies* | Cambisol | 1992 | 2007 | 15 | 5 | | 2 |
| PA_74 | *Picea abies* | Luvisol | 1991 | 2009 | 18 | 8 | | 3 |
| PA_81 | *Picea abies* | Podzol | 1992 | 2004 | 12 | 5 | | 1 |
| PA_87 | *Picea abies* | Podzol | 1991 | 2009 | 18 | 7 | 1999 | 2 |
| PA_88 | *Picea abies* | Cambisol | 1992 | 1999 | 7 | 3 | 1999 | 0 |
| FS_2 | *Fagus sylvatica* | Luvisol | 1992 | 2009 | 17 | 6 | | 2 |
| FS_3 | *Fagus sylvatica* | Cambisol | 1991 | 2009 | 18 | 8 | | 3 |
| FS_4 | *Fagus sylvatica* | Cambisol | 1992 | 2009 | 17 | 5 | | 0 |
| FS_9 | *Fagus sylvatica* | Podzol | 1992 | 2009 | 17 | 6 | | 1 |
| FS_14 | *Fagus sylvatica* | Cambisol | 1991 | 2013 | 22 | 8 | | 3 |
| FS_21 | *Fagus sylvatica* | Leptosol | 1991 | 2009 | 18 | 6 | 1999 | 1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| FS_25 | *Fagus sylvatica* | Cambisol | 1991 | 2009 | 18 | 7 | | 3 |
| FS_26 | *Fagus sylvatica* | Leptosol | 1991 | 2009 | 18 | 6 | | 1 |
| FS_29 | *Fagus sylvatica* | Luvisol | 1991 | 2009 | 18 | 6 | | 3 |
| FS_30 | *Fagus sylvatica* | Podzol | 1991 | 2012 | 21 | 7 | | 2 |
| FS_52 | *Fagus sylvatica* | Leptosol | 1991 | 2005 | 14 | 6 | 1999 | 2 |
| FS_54a | *Fagus sylvatica* | Planosol | 1992 | 1999 | 7 | 3 | 1999 | 1 |
| FS_54b | *Fagus sylvatica* | Leptosol | 1992 | 1999 | 7 | 4 | 1999 | 0 |
| FS_55 | *Fagus sylvatica* | Podzol | 1992 | 2011 | 19 | 8 | 1999 | 2 |
| FS_60 | *Fagus sylvatica* | Luvisol | 1992 | 2009 | 17 | 7 | 1999 | 1 |
| FS_64 | *Fagus sylvatica* | Cambisol | 1992 | 2011 | 19 | 8 | | 3 |
| FS_65 | *Fagus sylvatica* | Cambisol | 1992 | 2009 | 17 | 7 | | 2 |
| FS_76 | *Fagus sylvatica* | Luvisol | 1991 | 2009 | 18 | 9 | | 2 |
| FS_81 | *Fagus sylvatica* | Podzol | 1992 | 2009 | 17 | 6 | | 1 |
| FS_88 | *Fagus sylvatica* | Cambisol | 1992 | 2009 | 17 | 8 | | 2 |
| LD_5 | *Larix deciduas* | Regosol | 1991 | 2014 | 23 | 6 | | 2 |
| PN_20 | *Pinus nigra* | Cambisol | 1991 | 2009 | 18 | 7 | | 2 |
| PN_41 | *Pinus nigra* | Podzol | 1991 | 2004 | 13 | 6 | 1999 | 2 |
| PP_17 | *Pinus pinaster* | Arenosol | 1991 | 2009 | 18 | 7 | 1999 | 1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| PP_20 | *Pinus pinaster* | Cambisol | 1991 | 2004 | 13 | 5 | | 2 |
| PP_40a | *Pinus pinaster* | Podzol | 1992 | 2004 | 12 | 8 | | 2 |
| PP_40b | *Pinus pinaster* | Podzol | 1992 | 2009 | 17 | 7 | 2009 | 2 |
| PP_40c | *Pinus pinaster* | Podzol | 1992 | 2009 | 17 | 8 | 2009 | 3 |
| PP_72 | *Pinus pinaster* | Podzol | 1991 | 2010 | 19 | 7 | | 4 |
| PP_85 | *Pinus pinaster* | Arenosol | 1991 | 2011 | 20 | 6 | | 3 |
| PS_4 | *Pinus sylvestris* | Leptosol | 1991 | 2004 | 13 | 4 | | 0 |
| PS_15 | *Pinus sylvestris* | Cambisol | 1991 | 2011 | 20 | 7 | 1999 | 2 |
| PS_35 | *Pinus sylvestris* | Luvisol | 1991 | 2013 | 22 | 7 | | 3 |
| PS_41 | *Pinus sylvestris* | Podzol | 1991 | 2004 | 13 | 6 | 1999 | 2 |
| PS_44 | *Pinus sylvestris* | Luvisol | 1991 | 2010 | 19 | 7 | | 3 |
| PS_45 | *Pinus sylvestris* | Planosol | 1991 | 2005 | 14 | 7 | | 2 |
| PS_61 | *Pinus sylvestris* | Luvisol | 1991 | 1999 | 8 | 3 | 1999 | 0 |
| PS_63 | *Pinus sylvestris* | Cambisol | 1991 | 2009 | 18 | 7 | 1999 | 0 |
| PS_67a | *Pinus sylvestris* | Podzol | 1992 | 2009 | 17 | 7 | 1999 | 1 |
| PS_67b | *Pinus sylvestris* | Podzol | 1992 | 2013 | 21 | 9 | 1999 | 3 |
| PS_76 | *Pinus sylvestris* | Podzol | 1991 | 2009 | 18 | 7 | 1999 | 1 |
| PS_78 | *Pinus sylvestris* | Podzol | 1992 | 2007 | 15 | 6 | 1999 | 1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| PS_88 | *Pinus sylvestris* | Podzol | 1992 | 2007 | 15 | 6 | 1999 | 1 |
| PS_89 | *Pinus sylvestris* | Podzol | 1991 | 1999 | 8 | 4 | 1999 | 1 |
| AA_5 | *Abies alba* | Cambisol | 1991 | 2009 | 18 | 5 | | 1 |
| AA_7 | *Abies alba* | Podzol | 1991 | 2010 | 19 | 6 | | 1 |
| AA_9 | *Abies alba* | Podzol | 1992 | 2008 | 16 | 7 | 2009 | 2 |
| AA_11 | *Abies alba* | Luvisol | 1992 | 2009 | 17 | 8 | | 2 |
| AA_25 | *Abies alba* | Cambisol | 1991 | 2012 | 21 | 8 | | 3 |
| AA_26 | *Abies alba* | Cambisol | 1991 | 2014 | 23 | 6 | | 2 |
| AA_38 | *Abies alba* | Cambisol | 1992 | 2009 | 17 | 6 | | 1 |
| AA_39 | *Abies alba* | Cambisol | 1991 | 2009 | 18 | 6 | | 2 |
| AA_57 | *Abies alba* | Cambisol | 1992 | 2009 | 17 | 9 | 1999 | 2 |
| AA_63 | *Abies alba* | Cambisol | 1992 | 2004 | 12 | 6 | | 1 |
| AA_68 | *Abies alba* | Cambisol | 1992 | 2012 | 20 | 7 | | 3 |

| | **Beginning (yr)** | **End (yr)** | **Mean span (yrs)** | **Mean no. of inventories** | **Frequency (storms/100 yrs)** | **Frequency (thinnings/10 yrs)** |
|---|---|---|---|---|---|---|
| All sites: | 1991 | 2014 | 17.0 | 6.6 | 2.1 | 1.1 |

**Table S2 Linear regressions for explaining the variability of annual carbon change residuals using soil physical and chemical properties**

| | Sites dominated by broadleaves | | | | Sites dominated by conifers | | | |
|---|---|---|---|---|---|---|---|---|
| **Variable** | **$R^2$** | **Slope** | **Intercept** | ***P*-value** | **$R^2$** | **Slope** | **Intercept** | ***P*-value** |
| Total nitrogen (in tN/ha) | 0.4822 | -0.3276 | 2.149 | <0.001*** | 0.1531 | -0.1721 | 0.1788 | <0.01** |
| Proportion of clay (in %) | 0.2026 | -0.0253 | 1.3078 | <0.01** | 0.0087 | -0.0093 | -0.3893 | >0.05 |
| Proportion of sand (in %) | 0.1863 | 0.0121 | 0.3821 | <0.01** | 0.0126 | 0.0041 | -0.7549 | >0.05 |
| Exchangeable Mg (in kmol/ha) | 0.1513 | -0.0127 | 0.9537 | <0.01** | 0.0000 | -0.0005 | -0.5294 | >0.05 |
| Exchangeable Ca (in kmol/ha) | 0.1000 | -0.0011 | 0.8938 | <0.05* | 0.0000 | 0.0000 | -0.5355 | >0.05 |
| Exchangeable K (in kmol/ha) | 0.0904 | -0.0709 | 1.0475 | <0.05* | 0.0002 | 0.0100 | -0.5563 | >0.05 |
| Proportion of silt (in %) | 0.0746 | -0.0100 | 1.2309 | >0.05 | 0.0125 | -0.0059 | -0.3551 | >0.05 |
| Exchangeable Al (in kmol/ha) | 0.0279 | -0.0026 | 0.9486 | >0.05 | 0.0765 | -0.0074 | -0.135 | <0.05* |
| pH | 0.0268 | -0.1147 | 1.2595 | >0.05 | 0.0258 | 0.1615 | -1.2397 | >0.05 |
| Total phosphorus (in tN/ha) | 0.0094 | -0.0053 | 0.8676 | >0.05 | 0.0207 | 0.0013 | -0.6048 | >0.05 |
| Carbon:nitrogen ratio | 0.0072 | 0.0138 | 0.516 | >0.05 | 0.0027 | 0.0039 | -0.6381 | >0.05 |

Note: the grey zone indicates the variables chosen for plotting the Figure 5 in the manuscript. $R^2$ = coefficient of determination;

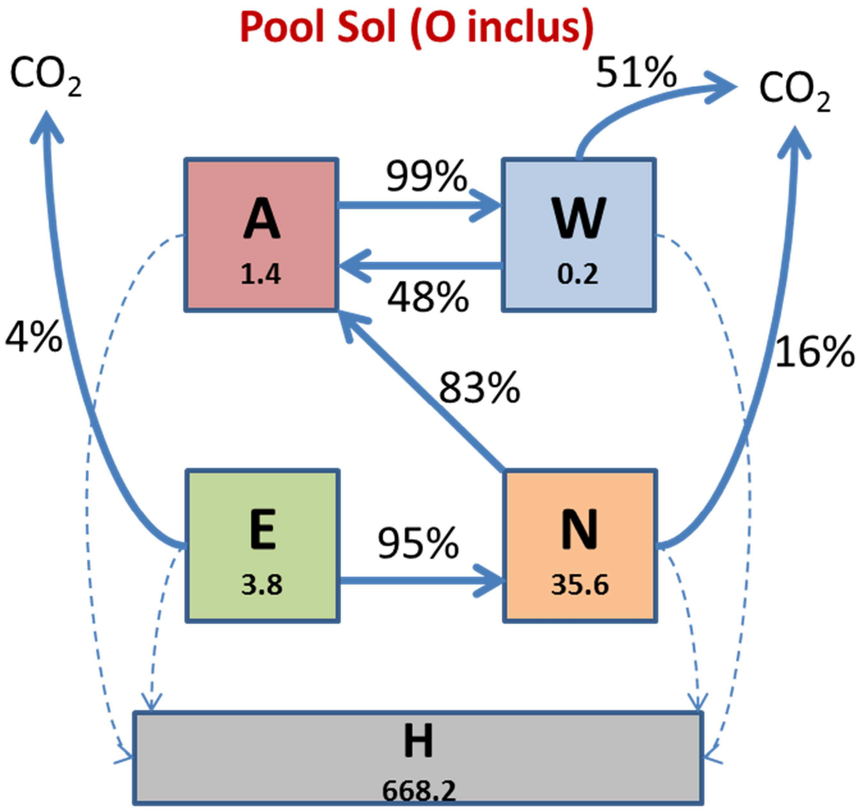


Figure S1 Partitioning of soil carbon pools in Yasso07 (after Tuomi et al., (2011b)) Letters: A: hydrolysable in Acid; W: soluble in Water; E: soluble Ethanol; N: Non-soluble; H: recalcitrant Humus. Solid arrows represented the carbon flows that are statistically significant from zero. Dashed arrows refer to the carbon flows toward H. Values in each pool is an example inverse of mean residence time (*1/k*, in year) estimated using Yasso07 parameters.

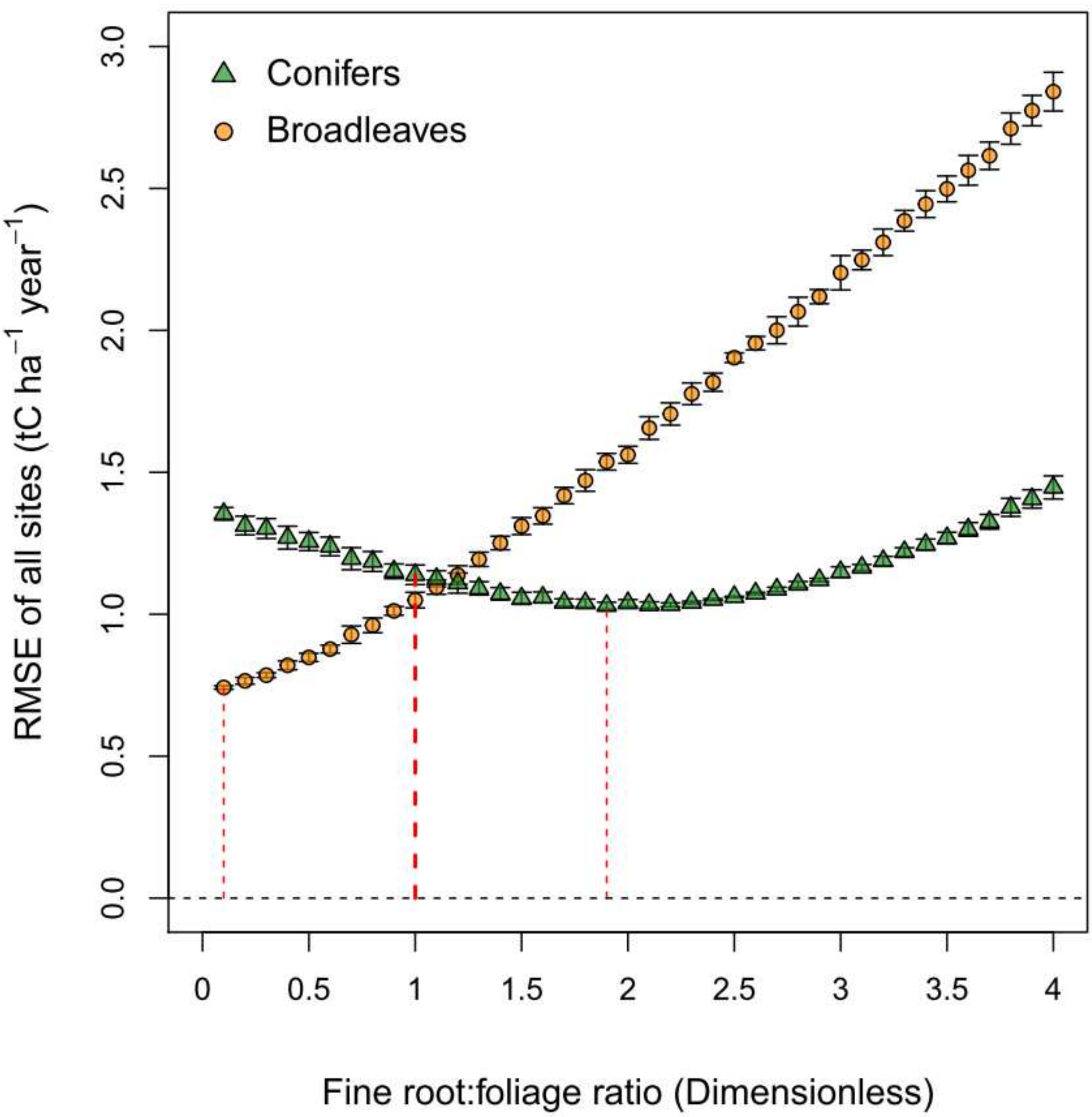


Figure S2 Influence of the choice of fine root:foliage ratio of litter input on the performance of Yasso07 toward the French RENECOFOR data. RMSE – root mean square error; Error bars are standard deviations of 10 simulations differing in parameters which were randomly chosen. Red dash lines perpendicular to *x*-axis: the two thin ones showing the values of fine root:foliage ratio for the minima of RMSE for broadleaves (0.1) and conifers (1.9), respectively; the thick red dash line at 1.0 (i.e., the ratio used for result presentation) showing that the RMSE of broadleaves and conifers are slightly higher than the minima, but still acceptable.

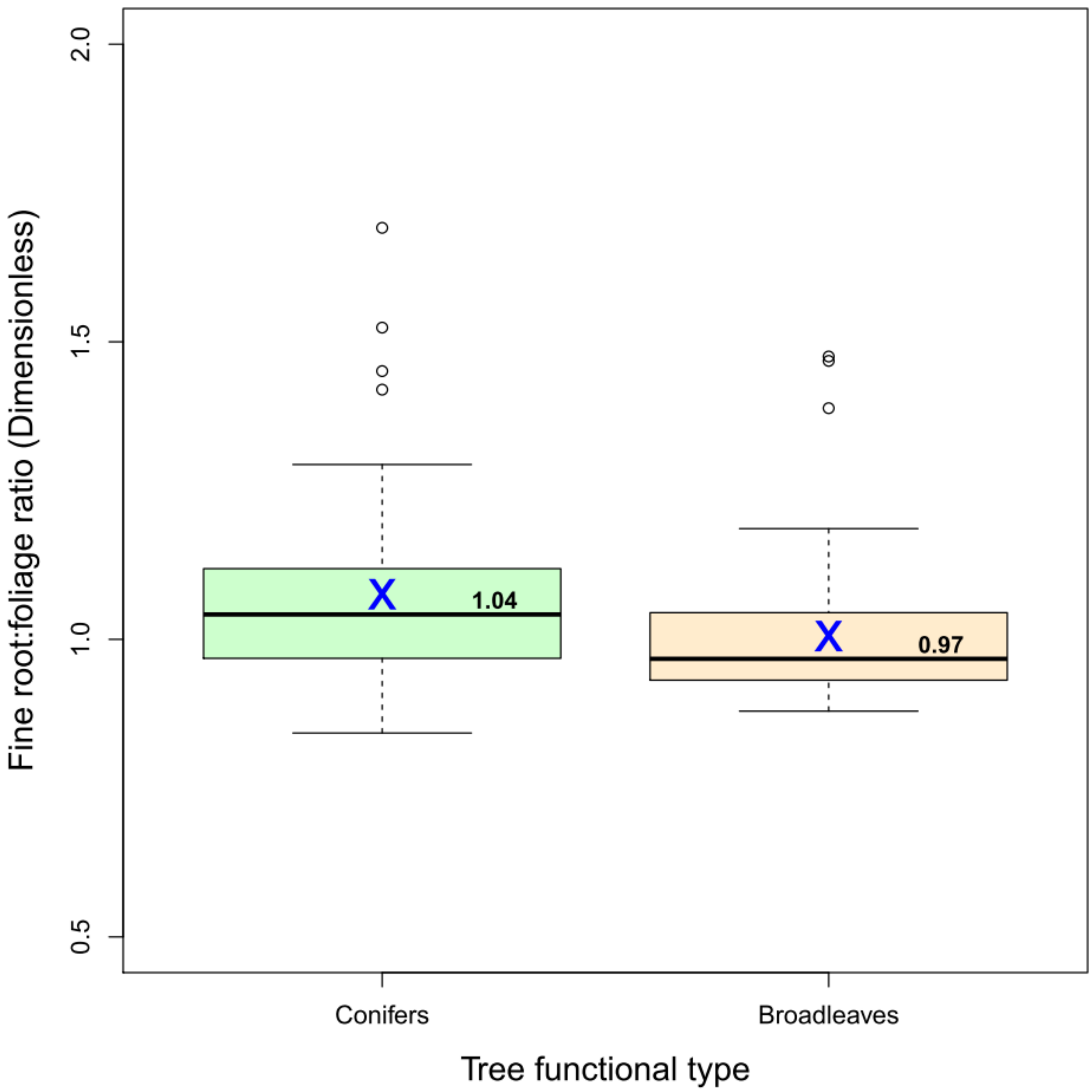


Figure S3 Distributions of fine root:foliage ratio of litter input in different tree functional types calculated using the equation of Raich and Nadelhoffer (1989), see Jonard et al., (2017). For each boxplot, the lower and top edge of the box corresponds to the 25$^{th}$ and 75$^{th}$ percentile data points; lower and top bars the line within the box represents the median and the hollow points indicate outliers. Median values are shown beside median lines. “X” indicates mean values: 1.08 ± 0.02 (mean ± standard error) for sites dominated by conifers and 1.01 ± 0.02 for sites dominated by broadleaves.

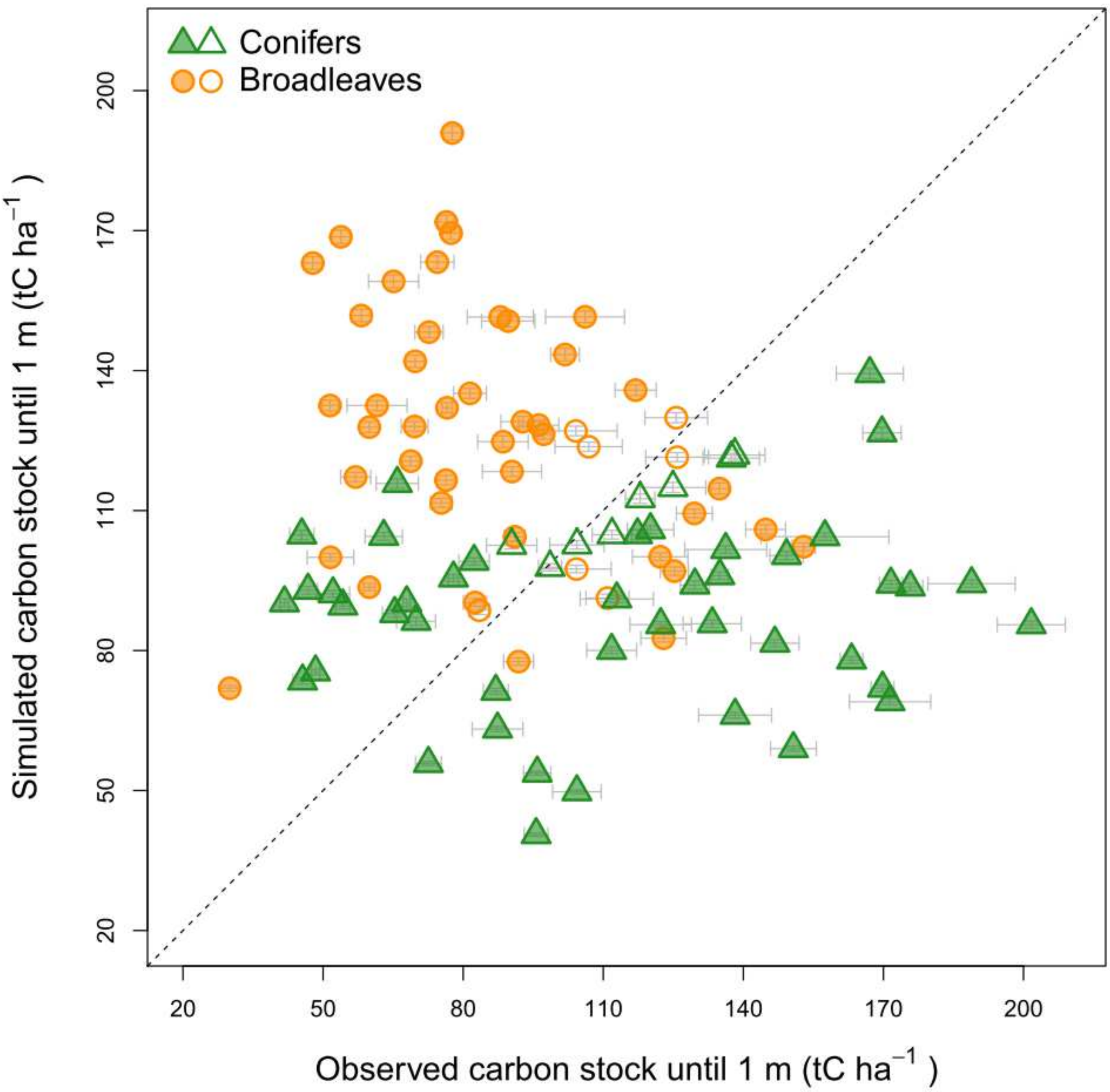


Figure S4 Comparison between simulated and observed annual carbon stock until 1 m (CS, in tC ha$^{-1}$). Round and triangle symbols represent sites dominated by broadleaves and conifers, respectively. The chosen fine root:foliage ratio for broadleaves and conifers is 1.0. Error bars represent standard errors; hollow and filled points represent non-significant and significant differences between simulated and observed ACC according to t-test (at 95% confidence level).

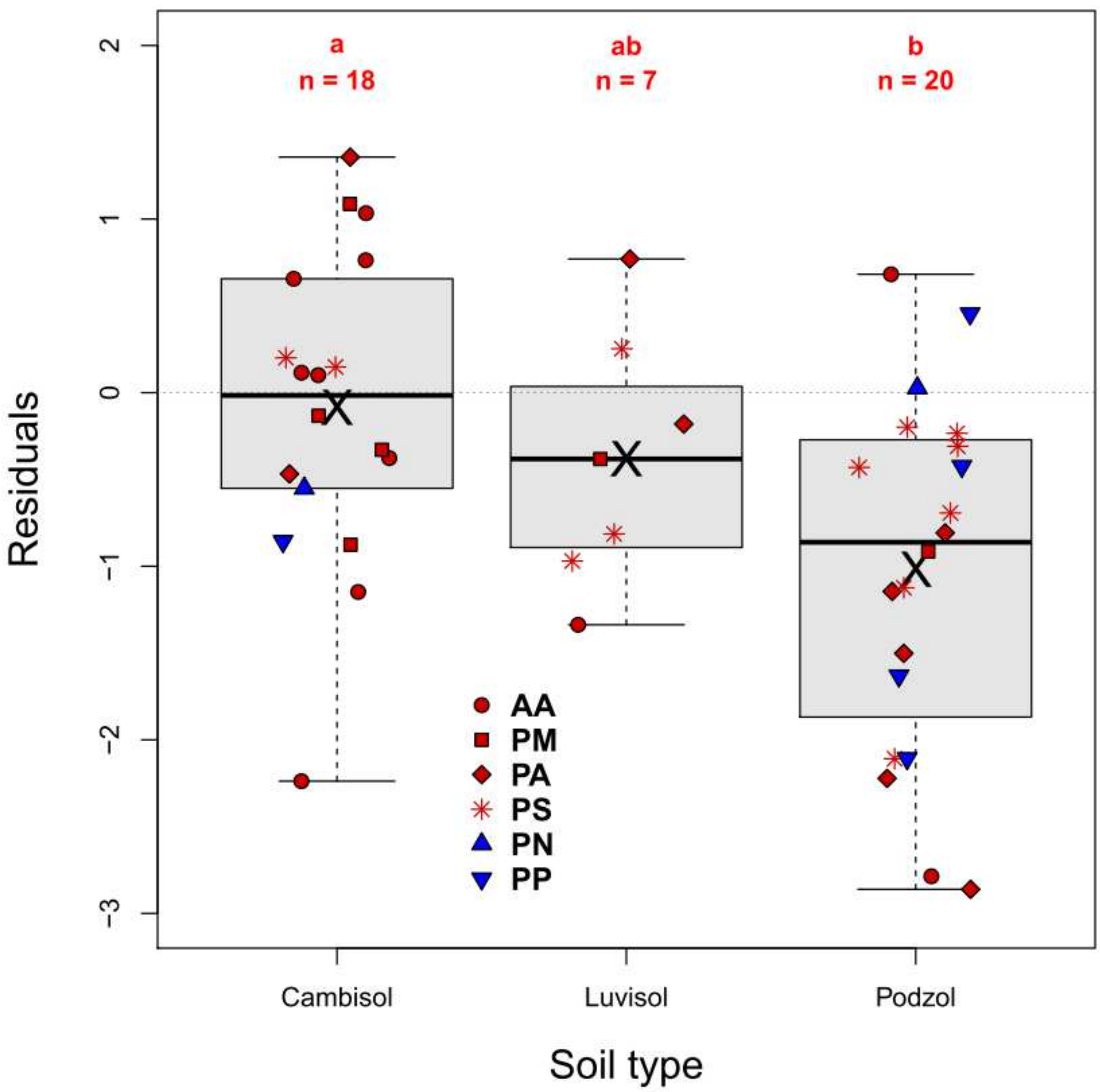


Figure S5 Distributions of the residuals (simulated minus observed annual carbon stock changes) of Yasso07's fit for sites dominated by conifers. For each boxplot, the lower and top edge of the box corresponds to the 25th and 75th percentile data points; lower and top bars the line within the box represents the median; no outilier points in this case. "X" indicates mean values: -0.08 ± 0.21 (mean ± standard error) for cambisol,-0.38 ± 0.28 for luvisol and -1.02 ± 0.23 for podzol. Species accronyms: AA – *Abies alba*; PM – *Pseudotzuga menziesii*; PA – *Picea abies*; PS – *Pinus sylvestris*; PN – *Pinus nigra*; PP – *Pinus pinaster*. Colors for different species: deep red for species that can be found for all the three types of soil; blue for species that can only found for cambisol and podzol, but not for luvisol.

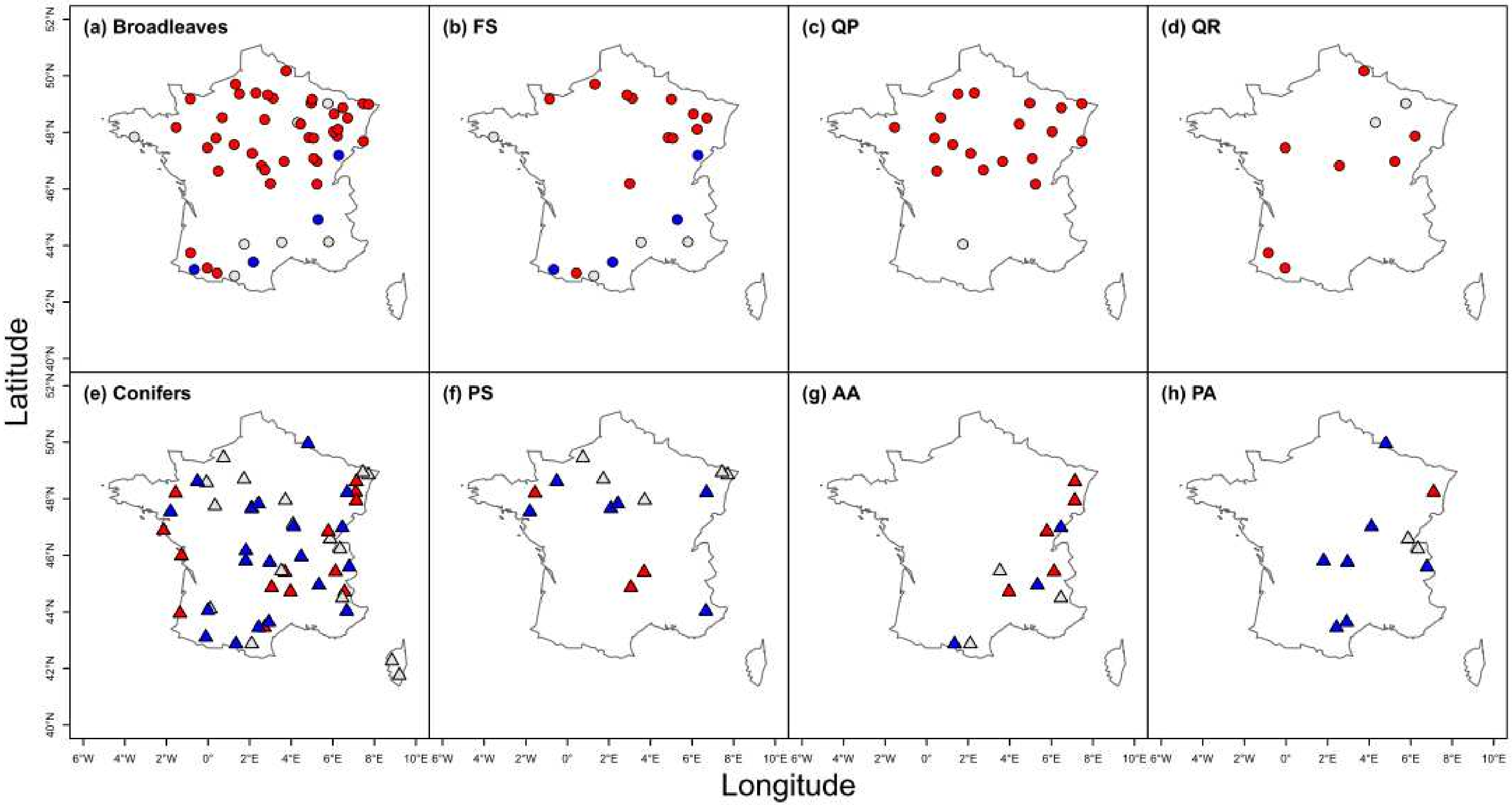


Figure S6 Spatial visualization of residuals (i.e. the difference between simulated and observed annual carbon changes) for sites dominated by broadleaves (a) and conifers (b). Colors: red – overestimation with residuals being significantly > 0; blue – underestimation with residual being significantly < 0; grey – residuals that are not significantly different from 0. Species abbreviations: FS – *Fagus sylvatica*; QP– *Quercus petraea*; QR - *Quercus robur* (*including* two mixed *Quercus* sites); PS - *Pinus sylvestris*; AA- *Abies alba*; PA - *Picea abies*.

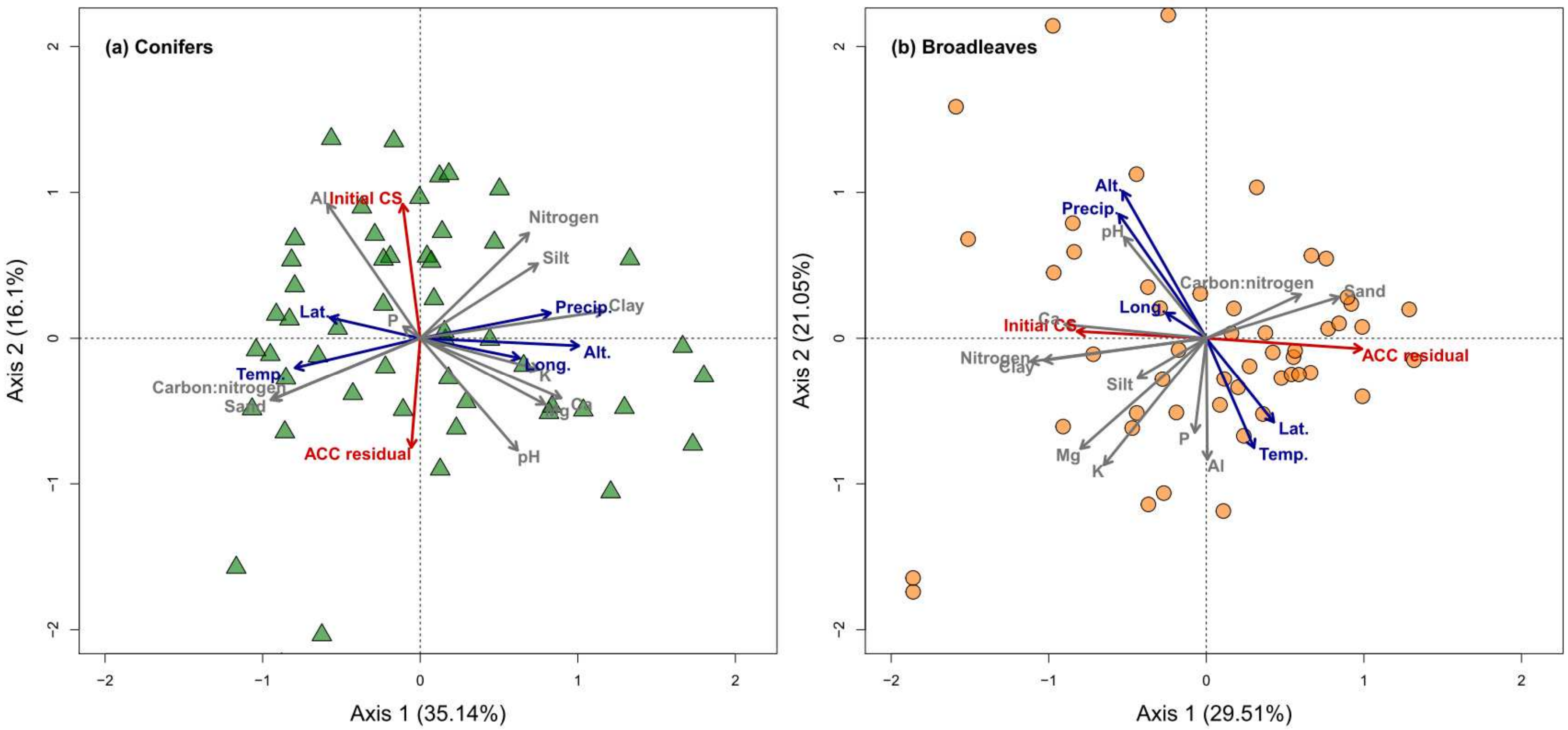


Figure S7 Relationships among indicators of site features and model predicts using principal component analysis for sites dominated by conifers (a) and broadleaves (b). Colours of arrows: red – residuals of annual carbon change and observed initial carbon stock; grey – soil physical and chemical properties; blue –site geographical and climatic variables. Each point corresponds to one RENECOFOR site. See Table S2 for full names of soil properties.

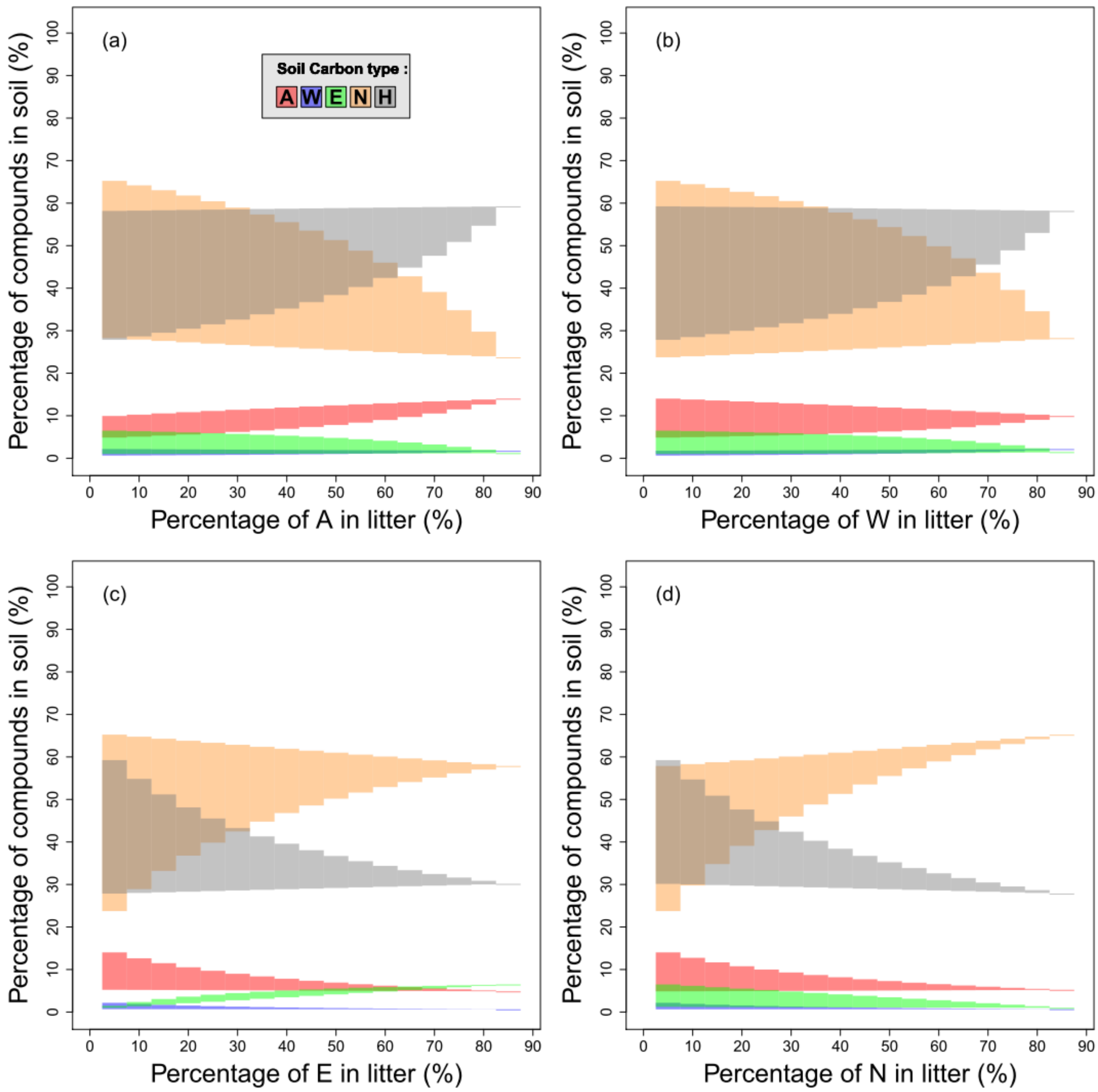


Figure S8 Variation of soil carbon quality at steady-state (y-axis) in response to fully theoretical permutation of carbon pool composition in litter. From (a) to (d) – permutations of proportion of litter A, W, E and N carbon pools, respectively. Outcomes were calculated using the matrix method. For each permutation, litter input quantity was fixed to a constant.

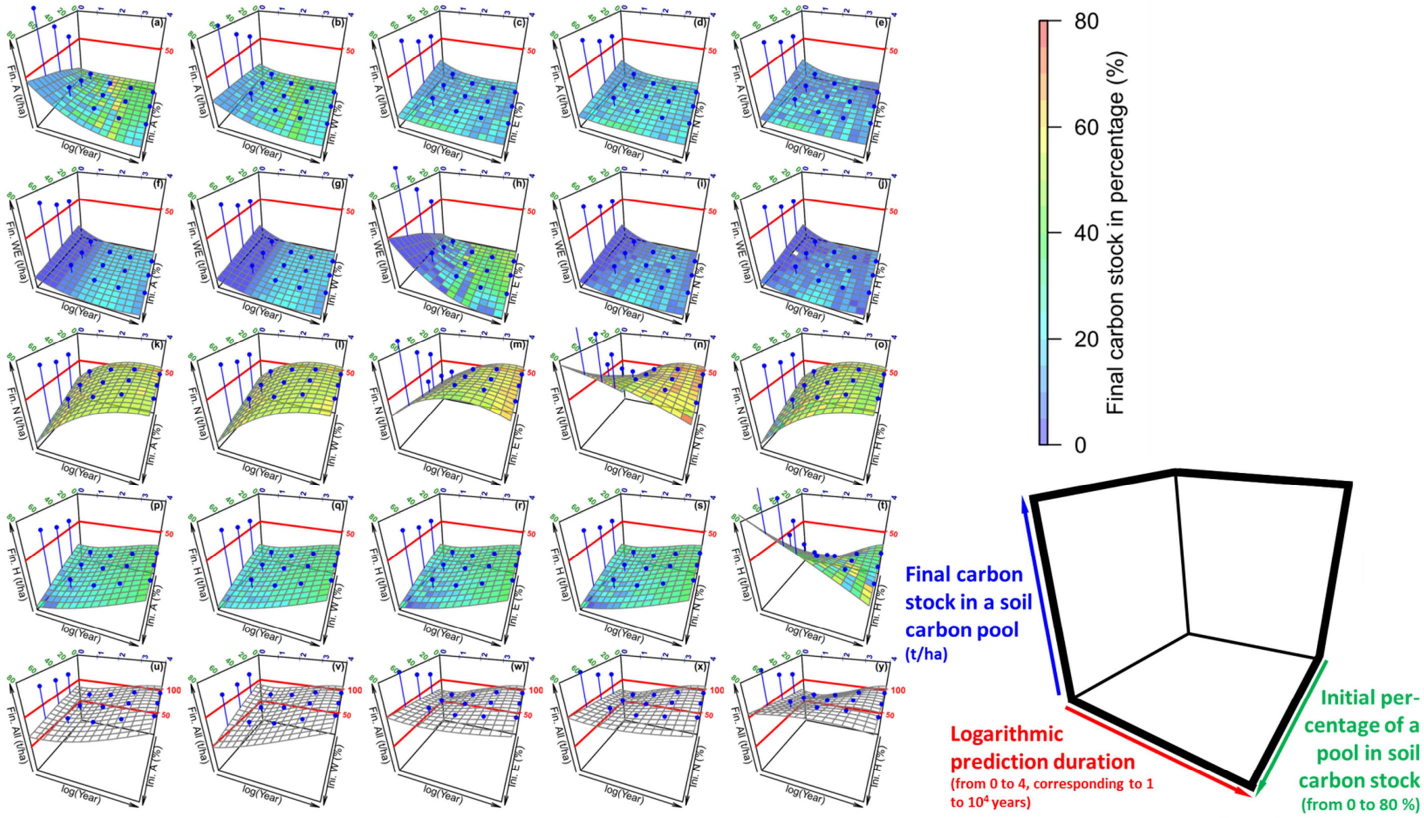


Figure S9 Sensitivity analysis of the impact of carbon pool composition of initial soil C stock (*x*-axis (↙), in %) and simulation length (*y*-axis (→), in logarithmic years) on final soil carbon stock (*z*-axis (↑), in tC ha$^{-1}$). Here, the results are generated using the mean broadleaved litter input quantity and quality of the RENECOFOR sites. Initial soil carbon stock was fixed to 100 tC ha$^{-1}$. Subplots in each row show the final stock evolution of one type of soil carbon pools (i.e. A, W, E, N and H). Particularly, in the 2$^{nd}$ row W and E were combined due to their weak quantities in most of cases. Subplots in each column show the effect of one type of soil chemical groups on the final stocks of the five soil carbon pools (each of them for the first four and the last one is the total stock). In each subplot, a membrane (with grids for three-dimensional effect) represents the loess fit (polynomial equation) to *z* (in tC ha$^{-1}$) as a function of *x* and *y*; the color of the membrane represent the relative value of *z* (in %), i.e. the proportion of one soil carbon pool within the total soil carbon stock. No color is assigned to the membranes in the last row, because the relative value is 100 %. Blue lollipops denote the standard deviations of the simulated mean z (on the membrane surface) given each (x, y) locations, which follow a systematic distribution.