Supplementary figures and tables

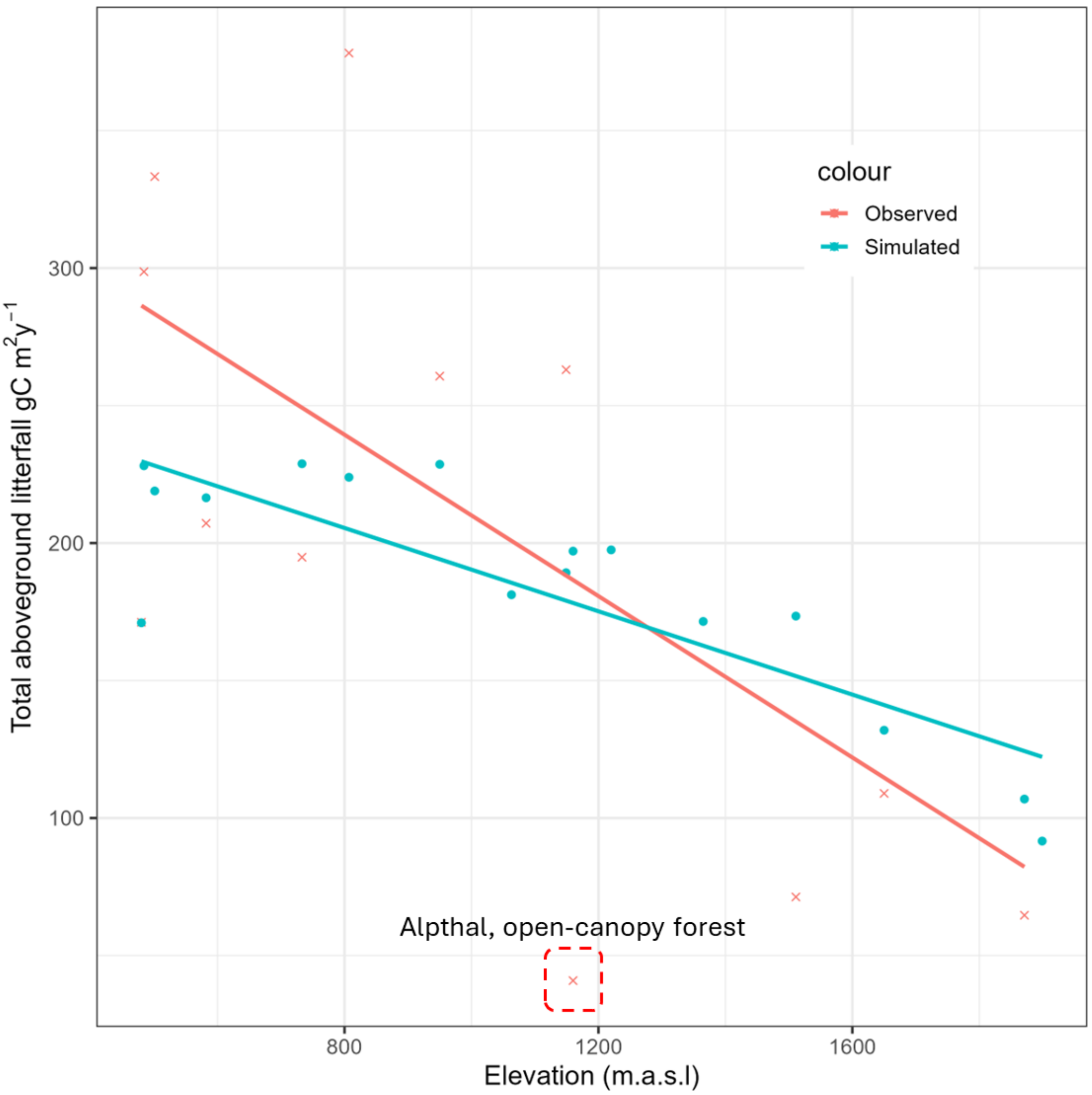

Figure S1. Comparison of ForClim simulated aboveground litter input to measured annual litterfall (measured by litter trap at 1 meter height from 1996-2020) at Swiss ICP-II forest sites. Linear regression lines were estimated excluding the open-canopy forest Alpthal where most litter was not captured by litter traps. The Pearson R of simulated vs. observed aboveground litterfall is 0.79 and R2 is 0.62.

Aboveground litterfall was slightly over-estimated in cold, high-elevation forests and underestimated in warm, low-elevation forests by ForClim. However, cold, high-altitude sites have proportionally more litter coming from smaller trees and non-tree species i.e., herbs and understory litter (Bonito et al., 2003; Leppälammi-Kujansuu et al., 2014), which measurements (litter trap at 1m height) could not effectively capture. The underestimated litter in low-elevation forests may be a result of ForClim's litter parameters not capturing litter types other than foliage and twig (e.g., reproductive litter, fruit). Nonetheless, the measured litterfall elevational trend here is also steeper than the litter elevational trend reported in Gosheva (2017) (see figure S2 below) and the Swiss study by Caprez et al. (2012). ForClim produced a milder elevational trend which is in closer agreement to these two studies.

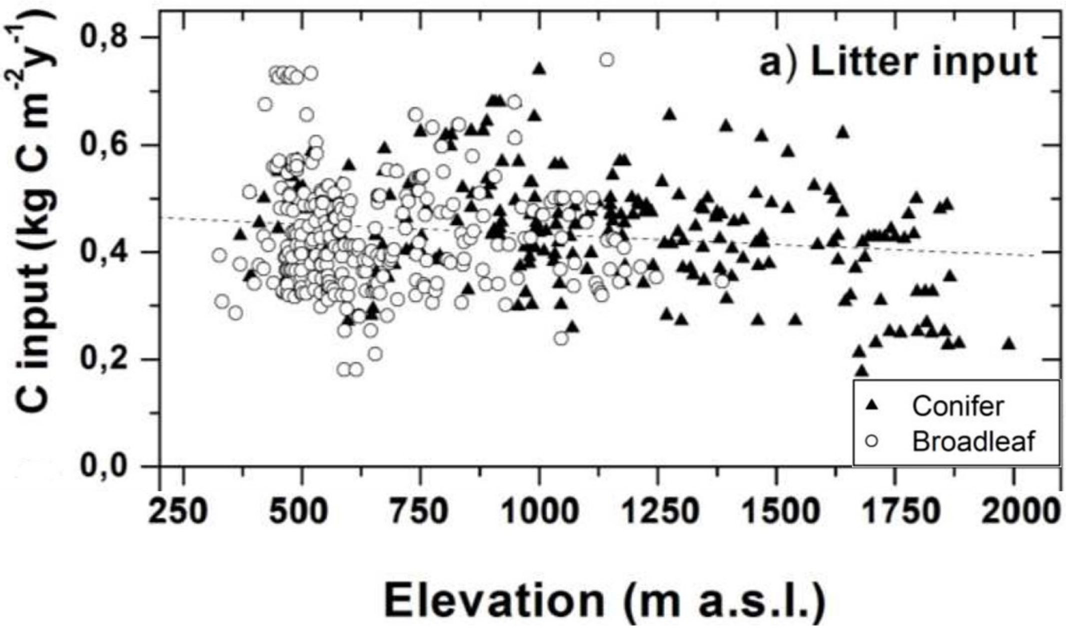

Figure S2. Adapted from the doctoral dissertation Figure 3a of Gosheva (2017).

The range of total (not only aboveground) litter input is ≈ 500gC/m^2/y in Gosheva (2017), which was simulated by MASSIMO forced with Swiss forest inventory data. This range is similar to ForClim's simulated total litter. If the assumption of soil C equilibrium holds, heterotrophic respiration was also estimated at around 500 gC/m^2/y in Swiss forests (Caprez et al., 2012; Etzold et al., 2011) and thus litter inputs should be at a similar rate.

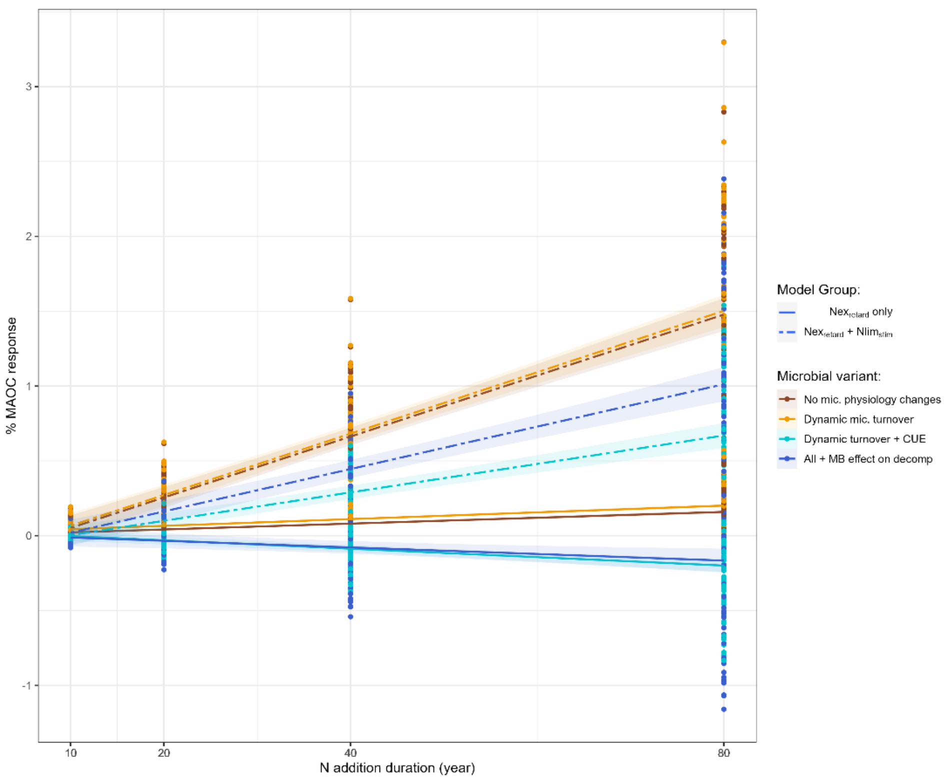

Figure S3. The trends of simulated MAOC response averaged from year 5 – 15, 10-30, 30-50, 70-90, under N addition level of 100 kg/ha/y. Shaded areas are 95% confidence intervals of inter-site variances.

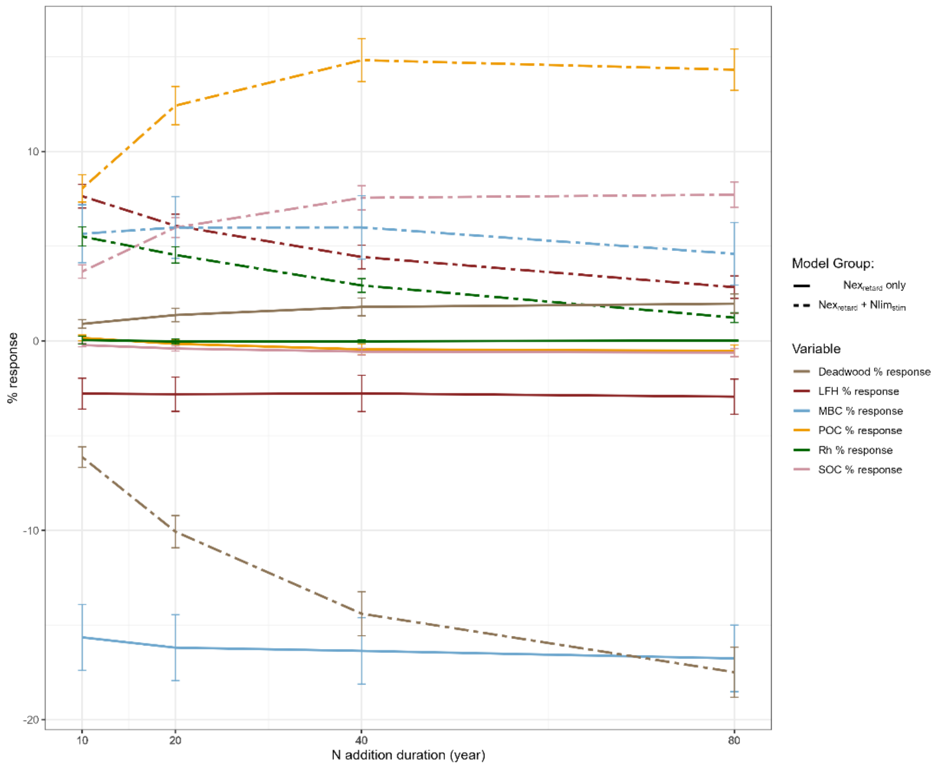

Figure S4. Selected simulated % responses of C pools and fluxes averaged from year 5 – 15, 10-30, 30-50, 70-90, under N addition level of 100 kg/ha/y. Model variants are aggregated by groups: Nex$_{retard}$ only and Nex$_{retard}$ + Nlim$_{stim}$, in order to reduce the number of lines. Error bars are 95% confidence intervals.

Table S3. Adjusted litter inputs of the converted, low-elevation spruce stands by a scaling factor of 1.5 for all litters. The scaling factor is derived from the ratio of observed vs. simulated aboveground litter inputs in Vordemwald. The value in parentheses are original values in unconverted, all-species equilibrium simulations shown for reference. Units are in gC m^{-2} y^{-1}. Spruce litter belongs to the low-quality litter category. Further information about the litter quality classes is available in Appendix 1.

Site	High-quality Leaf*	Mid-quality Leaf*	Low-quality Leaf*	Fine twig*	**Aboveground non-woody total**	Fine root†	Exudates†	**Belowground non-woody total**	High-quality coarse wood‡	Mid-quality coarse wood‡	Low-quality coarse wood‡
Belp (827 m.a.s.l)	0 (2.4)	0 (103)	106 (24.7)	111 (91)	**217 (221)**	95.5 (104)	9.6 (10.4)	**106 (115)**	0 (4.4)	0 (343)	316 (82.2)
Eschenbach (500 m.a.s.l)	0 (2.5)	0 (123)	91.4 (13.7)	87.8 (88)	**179 (227)**	82.3 (111)	8.2 (11.3)	**90.5 (122)**	0 (4.4)	0 (368)	245 (35.9)
Kaisten (310 m.a.s.l)	0 (3.1)	0 (141)	68.0 (1.4)	46.8 (82.6)	**115 (228)**	61.2 (116)	6.1 (11.6)	**67.3 (128)**	0 (5.9)	0 (358)	117 (2.8)
Le flon (882 m.a.s.l)	0 (2.1)	0 (96)	106 (29)	105 (89)	**210 (215)**	95.2 (101)	9.5 (10.1)	**105 (111)**	0 (4.1)	0 (323)	274 (122)
Rapperswill (480 m.a.s.l)	0 (3.4)	0 (127)	94.3 (9.4)	101 (89)	**195 (229)**	84.8 (112)	8.5 (11.2)	**93.3 (123)**	0 (8.4)	0 (431)	243 (46.8)
Siviriez (857 m.a.s.l)	0 (2.3)	0 (95.0)	105 (29.0)	109 (90)	**214 (216)**	94.9 (101)	9.5 (10.1)	**104 (111)**	0 (3.6)	0 (343)	325 (103)
Soubey (720 m.a.s.l)	0 (1.7)	0 (111)	102 (20.2)	93.0 (84)	**205 (218)**	92.2 (106)	9.2 (10.6)	**101 (117)**	0 (2.6)	0 (293)	209 (52.7)
Vordemwald (470 m.a.s.l)	0 (2.1)	0 (126)	90.0 (9.9)	81.1 (86)	**171 (224)**	81.0 (111)	8.1 (11.1)	**88.1 (122)**	0 (4.0)	0 (345)	188 (54.1)

* Leaf and twig litters constitute the total aboveground litterfall.
† The estimated belowground fine root litters and exudates are up to 20cm soil depth.

‡ Coarse wood includes both above- (branches and trunks) and below-ground (coarse roots).

Table S2. Summary of N addition meta-analysis response data used in this study.

	Number of observations after filtering*	N addition rate range	N addition duration range	Site MAT mean (lower, upper quartiles)	Site MAP mean (lower, upper quartiles)	Mean response (lower, upper quartiles)	Source references
Swiss forest data	N = 54	100 (simulation setup)	5-15 (simulation setup)	7.7 (6.5, 9.4)	1129 (927, 1286)	NA	González-Domínguez et al., 2019
LFH	N = 20	40-150	Not reported	Not reported (mostly temperate forests)	Not reported (mostly temperate forests)	27.6 (8.3, 32)	Liu & Greaver, 2010
SOC	N = 55	40-150	4-16	12.9 (4.6, 21)	1273 (678, 1748)	10.4 (-2.6, 19.6)	Tang et al., 2023; Wu et al., 2023
POC	N = 51	40-150	4-16	12.1 (4.3, 17.9)	1236 (662, 1749)	18.7 (-6.7, 40.7)	Tang et al., 2023; Wu et al., 2023
MAOC	N = 43	40-150	4-16	10.7 (4.3, 17.9)	1121 (580, 1600)	8.9 (-3.1, 17.9)	Tang et al., 2023; Wu et al., 2023
MBC	N = 82	40-150	4-25	10.4 (5.5, 18.9)	1161 (723, 1620)	-8.9 (-25.0, 2.5)	Jia et al., 2020; Zhang et al., 2018
MBC:MBN	N = 37	50-150	4-25	12.6 (4.6, 15.5)	1342 (676, 1620)	-0.77 (-14.8, 11.9)	Jia et al., 2020; Zhang et al., 2018
R_h	N = 29	50-150	4-13	6.6 (1.0, 11.9)	699 (450, 740)	3.7 (-17.5, 14.0)	Liu, Men, et al., 2023

* Filters include ecosystems = forest or any other wooded ecosystems (e.g., savanna), but excluding wetland; N addition rate between 40-150 kgN/ha/y; and N addition duration at least 4 years.

Table S3. Multiple regression of organic matter proportions against organic matter CN ratios and other site factors. The evaluated null hypothesis is that all model variants and observation are the same concerning the relationship between organic matter proportions and organic matter CN ratios (alpha = 0.05), which is handled by a "C:N ratio × Variant" interaction ("Variant" is a categorical variable that includes both model variants and observation, and the latter is set as the reference level). Non-significant site factors (MAT, MAP, Ndep, pH, CEC, %Clay) and the main effect of "Variant" (i.e., intercept effects) are not shown.

Predictors	Standardized beta	P-values	Generalized VIF
1. MAOC: Total SOC ~ MAOC:N × Variant + MAT + MAP + Ndep + pH + CEC + %Clay + B:C litterfall† + error			
MAOC:N	-0.69	<0.001***	5.9
MAT	-0.1	<0.001***	3.3
MAP	0.17	<0.001***	1.3
CEC	-0.08	<0.001***	2.0
Clay	0.32	<0.001***	2.2
MAOC:N × Variant0*	-0.16	0.051.	5.9
MAOC:N × Variant1*	-0.24	0.003**	5.9
MAOC:N × Variant2*	-0.23	0.005**	5.9
MAOC:N × Variant3*	-0.17	0.044*	5.9
MAOC:N × Variant4*	-0.17	0.037*	5.9
MAOC:N × Variant5*	-0.15	0.050.	5.9
MAOC:N × Variant6*	-0.15	0.049*	5.9
MAOC:N × Variant7*	-0.08	0.33	5.9
MAOC:N × Variant8*	-0.1	0.204	5.9
2. MAOC: Annual Litter ~ MAOC:N × Variant + MAT + MAP + Ndep + pH + CEC + %Clay + B:C litterfall† + error			
MAOC:N	0.08	0.424	5.7
MAT	-0.58	<0.001***	3.3
MAP	0.1	<0.001***	1.4
pH	-0.23	<0.001***	4.5
Clay	0.61	<0.001***	2.2
MAOC:N × Variant0*	-0.29	0.019*	5.7
MAOC:N × Variant1*	-0.54	<0.001***	5.7
MAOC:N × Variant2*	-0.55	<0.001***	5.7
MAOC:N × Variant3*	-0.24	0.066.	5.7
MAOC:N × Variant4*	-0.21	0.087.	5.7
MAOC:N × Variant5*	-0.36	0.003**	5.7
MAOC:N × Variant6*	-0.36	0.003**	5.7
MAOC:N × Variant7*	-0.16	0.208	5.7
MAOC:N × Variant8*	-0.14	0.232	5.7
3. Light fraction C: Annual Litter ~ Light fraction C:N × Variant + MAT + MAP + Ndep + pH + CEC + %Clay + B:C litterfall† + error			
Light fraction C:N	0	0.939	2.0
MAT	-0.37	<0.001***	3.3
MAP	-0.16	<0.001***	1.5
pH	-0.54	<0.001***	1.6
Clay	-0.15	0.003**	2.2
Light fraction C:N × Variant0*	-0.12	0.774	2.0
Light fraction C:N × Variant1*	-0.19	0.671	2.0
Light fraction C:N × Variant2*	-0.21	0.646	2.0
Light fraction C:N × Variant3*	-0.07	0.903	2.0
Light fraction C:N × Variant4*	-0.32	0.546	2.0
Light fraction C:N × Variant5*	-0.19	0.643	2.0

Light fraction C:N × Variant6*	-0.2	0.627	2.0
Light fraction C:N × Variant7*	-0.17	0.724	2.0
Light fraction C:N × Variant8*	-0.39	0.41	2.0

* Variant0 = base model, Variant1 = base model + Nex_{retard} , Variant2 = Variant1 + dynamic microbial turnover, Variant3 = Variant2 + dynamic carbon use efficiency, Variant4 = Variant3 + microbial biomass control on decomposition, Variant5 = Nex_{retard} + $Nlim_{stim}$ model, Variant6 = Variant5 + dynamic microbial turnover, Variant7 = Variant6 + dynamic carbon use efficiency, Variant8 = Variant7 + microbial biomass control on decomposition (For details, see Table 1 in the main text).

† B:C litterfall is broadleaved: conifer litterfall ratio.

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