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Supplement of

The influence of soil properties and nutrients on conifer forest growth in Sweden, and the first steps in developing a nutrient availability metric

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1 The productivity vs climate regression model

We disentangled the influence of climatological variables (TSUM and precipitation) on productivities of spruce and pine forests using ANCOVA (Analysis of Covariance). All possible combinations of single continuous variables and their interactions with species were alternatively included in data-driven regression models to finally select the one with the lowest mean square of prediction error according to 10-fold cross-validation (package DAAG - Maindonald and Braun, 2015). In addition, potential non-linearities were detected with a generalized additive model from the mgcv package (Wood, 2006) and histograms of the variables. Assumptions of linearity, normality of residuals, homoscedasticity, outliers and non-collinearity were tested with the methods mentioned in the main text.

$$MAI\ [m^3\ ha^{-1}\ yr^{-1}] = a \times TSUM^2\ [°C\ days] + b \times TSUM\ [°C\ days] + c \times MAP\ [mm] + d\ , \quad (S1)$$

Table S1. Overall mean squared error (ms) after 10-fold cross-validation for the most relevant (i.e. TSUM and spp clearly had to be included) candidate model structures that explain variation in productivity (mean annual increment - MAI - $m^3\ ha^{-1}\ yr^{-1}$) by climate (TSUM and MAP) and species across Swedish spruce and pine forests. The selected model is marked in gray. Abbreviations: TSUM = growing season temperature sum [°C days]; MAP = mean annual precipitation [mm]; spp = species.

Variables in model	Overall ms	Variables in model	Overall ms
$TSUM^2$:spp, TSUM:spp, $TSUM^2$, TSUM, MAP, spp	*1.48*	TSUM:spp, MAP, TSUM, spp	1.63
$TSUM^2$:spp, TSUM:spp, MAP:spp, $TSUM^2$, TSUM, MAP, spp	1.48	TSUM:spp, TSUM, spp	1.64
$TSUM^2$:spp, TSUM:spp, TSUM, spp	1.49	$TSUM^2$, TSUM, MAP, spp	2.23
$TSUM^2$, TSUM:spp, MAP:spp, TSUM, MAP, spp	1.58	$TSUM^2$, TSUM, spp	2.24
TSUM:spp, $TSUM^2$, TSUM, MAP, spp	1.59	MAP:spp, TSUM, MAP, spp	2.24
TSUM:spp, $TSUM^2$, TSUM, spp	1.60	TSUM, MAP, spp	2.27
TSUM:spp, MAP:spp, TSUM, MAP, spp	1.61	TSUM, spp	2.28

Table S2. Species specific estimates, statistics (*t* and partial R^2) and significance (*P* values) for the parameters in Eq. (S1) and *F* statistics and significance for species differences in these estimates. (Partial) R^2 values were approximated based on comparing fitted values with actual productivities.

Parameter	Species difference	Spruce			Pine		
		Estimate	Statistics		Estimate	Statistics	
a	$F_{1,2475} = 175.3$ $P < 0.01$	$(9.0 \pm 0.6) \times 10^{-6}$	$t_{1071} = 14.15$ $P < 0.01$	$R^2 \approx 0.854$	$(-3.0 \pm 0.6) \times 10^{-6}$	$t_{1403} = -4.64$ $P < 0.01$	$R^2 \approx 0.480$
b	$F_{1,2475} = 1112.2$ $P < 0.01$	-0.008 ± 0.001	$t_{1071} = -5.76$ $P < 0.01$		0.011 ± 0.001	$t_{1403} = 7.80$ $P < 0.01$	
c	N/A[a]	$(0.3 \pm 0.3) \times 10^{-3}$	$t_{1071} = 0.97$ $P = 0.33$	$R^2 \approx 0.001$	$(0.3 \pm 0.3) \times 10^{-3}$	$t_{1403} = 0.97$ $P = 0.33$	$R^2 \approx 0$
d	$F_{1,2475} = 1731.1$ $P < 0.01$	3.5 ± 0.8	$t_{1071} = 4.59$ $P < 0.01$		-4.1 ± 0.7	$t_{1403} = -5.24$ $P < 0.01$	
Total				$R^2 \approx 0.856$			$R^2 \approx 0.480$
					$R^2 = 0.805$		

[a]A regression model without MAP * species interaction was selected by the cross-validation procedure (Table S1).

Table S3. Association between (log) N deposition and normalized productivity, stratified by soil moisture class (dry to moist). Significance (*P*-values) of N deposition on residual productivity (mean annual increment - MAI [$m^3\ ha^{-1}\ yr^{-1}$]) and actual/attainable MAI (for spruce only) across Sweden are given. For (near) significant variables (i.e. $P < 0.10$), parameter estimates ± s.e.m. and the proportion of variation explained (R^2) are shown as well. Abbreviations: N = north; M = middle; S = south.

Normalized productivity response	**Region**	**ln N deposition [kg N $ha^{-1}\ yr^{-1}$]**			
		Dry	**Fresh**	**Fresh-moist**	**Moist**
Residual MAI (method 1)	N	slope = 0.7 ± 0.3 *P* = 0.04 intercept = -1.0 ± 0.2 *P* < 0.01 R^2 = 0.100 *n* = 32	*P* = 0.51 *n* = 399	*P* = 0.37 *n* = 132	*P* = 0.26 *n* = 5
	M	*P* = 0.63 *n* = 50	slope = 0.6 ± 0.2 *P* < 0.01 intercept = -0.2 ± 0.1 *P* < 0.01 R^2 = 0.022 *n* = 549	*P* = 0.99 *n* = 237	*P* = 0.29 *n* = 7
	S	*P* = 0.79 *n* = 62	*P* = 0.39 *n* = 742	*P* = 0.42 *n* = 233	slope = -3 ± 1 *P* = 0.04 intercept = 3 ± 2 *P* = 0.23 R^2 = 0.201 *n* = 17
Actual/attainable MAI (method 2)	entire Sweden	slope = 19 ± 5 *P* < 0.01 intercept = 8 ± 9 *P* = 0.36 R^2 = 0.373 *n* = 22	slope = 14.6 ± 0.5 *P* < 0.01 intercept = 22.7 ± 0.8 *P* < 0.01 R^2 = 0.565 *n* = 702	slope = 12.7 ± 0.8 *P* < 0.01 intercept = 20 ± 1 *P* < 0.01 R^2 = 0.415 *n* = 318	slope = 12 ± 4 *P* = 0.02 intercept = 21 ± 4 *P* < 0.01 R^2 = 0.384 *n* = 11

Table S4. Association between (log) N deposition and normalized productivity, stratified by soil type. Significance (*P*-values) of N deposition on residual productivity (mean annual increment - MAI [m^3 ha^{-1} yr^{-1}]) and actual/attainable MAI (for spruce only) across Sweden are given. For (near) significant variables (i.e. $P < 0.10$), parameter estimates ± s.e.m. and the proportion of variation explained (R^2) are shown as well. Abbreviations: N = north; M = middle; S = south.

Normalized productivity response	**Region**	**ln N deposition [kg N ha^{-1} yr^{-1}]**				
		Histosol	**Gleysol**	**Regosol**	**Leptosol**	**Podzol**
Residual MAI (method 1)	N	$P = 0.13$ $n = 13$	$P = 0.23$ $n = 30$	$P = 0.86$ $n = 217$	$P = 0.87$ $n = 23$	$P = 0.57$ $n = 268$
	M	slope = 0.8 ± 0.4 $P = 0.09$ intercept = -2.0 ± 0.5 $P < 0.01$ $R^2 = 0.031$ $n = 60$	$P = 0.66$ $n = 28$	$P = 0.60$ $n = 277$	$P = 0.25$ $n = 41$	slope = 1.0 ± 0.2 $P < 0.01$ intercept = -0.8 ± 0.2 $P < 0.01$ $R^2 = 0.064$ $n = 400$
	S	$P = 0.77$ $n = 101$	$P = 0.51$ $n = 37$	$P = 0.44$ $n = 372$	$P = 0.64$ $n = 116$	$P = 0.70$ $n = 324$
Actual/attainable MAI (method 2)	entire Sweden	slope = 19 ± 2 $P < 0.01$ intercept = 10 ± 3 $P < 0.01$ $R^2 = 0.541$ $n = 64$	slope = 10 ± 2 $P < 0.01$ intercept = 26 ± 2 $P < 0.01$ $R^2 = 0.404$ $n = 63$	slope = 15.5 ± 0.7 $P < 0.01$ intercept = 21 ± 1 $P < 0.01$ $R^2 = 0.578$ $n = 377$	slope = 12 ± 2 $P < 0.01$ intercept = 22 ± 4 $P < 0.01$ $R^2 = 0.270$ $n = 70$	slope = 14.3 ± 0.6 $P < 0.01$ intercept = 21.2 ± 0.9 $P < 0.01$ $R^2 = 0.581$ $n = 399$

Table S5. Associations between single soil variables and normalized productivity of Table 2, stratified by soil moisture class (dry to moist). Significance (*P*-values) of single soil variable effects on residual productivity (mean annual increment - MAI [m^3 ha^{-1} yr^{-1}]) and actual/attainable MAI (for spruce only) across Sweden are given. For (near) significant variables (i.e. $P < 0.10$), parameter estimates ± s.e.m. and the proportion of variation explained (R^2) are shown as well. Abbreviations: N = north; M = middle; S = south; SOC = soil organic carbon concentration; Soil C:N = soil carbon to nitrogen ratio; TEB = total exchangeable bases; quad = parameter estimate for quadratic term; lin = parameter estimate for linear term of a quadratic function.

Normalized productivity response	**Region**	**ln SOC $_{0\text{-}20cm}$ [%]**			
		Dry	**Fresh**	**Fresh-moist**	**Moist**
Residual MAI (method 1)	N	$P = 0.32$ $n = 32$	quad = -0.13 ± 0.02 $P < 0.01$ lin = 0.39 ± 0.10 $P < 0.01$ intercept = -0.05 ± 0.10 $R^2_{tot} = 0.052$ $n_{tot} = 1569$	quad = -0.22 ± 0.06 $P < 0.01$ lin = 0.9 ± 0.3 $P < 0.01$ intercept = -0.8 ± 0.3 $P = 0.01$ $R^2_{tot} = 0.106$ $n_{tot} = 830$	quad = -3 ± 1 $P = 0.03$ lin = 15 ± 7 $P = 0.03$ intercept = -23 ± 10 $P = 0.03$ $R^2_{tot} = 0.314$ $n_{tot} = 4$
	M	$P = 0.75$ $n = 47$	quad = -0.13 ± 0.02 $P < 0.01$ lin = 0.33 ± 0.09 $P < 0.01$ intercept = 0.17 ± 0.09 $P = 0.06$ $R^2_{tot} = 0.052$ $n_{tot} = 1569$	quad = -0.22 ± 0.06 $P < 0.01$ lin = 0.8 ± 0.1 $P < 0.01$ intercept = -0.9 ± 0.3 $P < 0.01$ $R^2_{tot} = 0.106$ $n_{tot} = 830$	quad = -3 ± 1 $P = 0.03$ lin = 13 ± 5 $P = 0.03$ intercept = -14 ± 6 $P = 0.02$ $R^2_{tot} = 0.314$ $n_{tot} = 7$
	S	$P = 0.10$ $n = 44$	quad = -0.13 ± 0.02 $P < 0.01$ slope = 0.2 ± 0.1 $P = 0.09$ intercept = 0.5 ± 0.1 $P < 0.01$ $R^2_{tot} = 0.052$ $n_{tot} = 1569$	quad = -0.22 ± 0.06 $P < 0.01$ lin = 0.7 ± 0.3 $P = 0.03$ intercept = -0.6 ± 0.4 $P = 0.19$ $R^2_{tot} = 0.106$ $n_{tot} = 830$	quad = -3 ± 1 $P < 0.01$ lin = 13 ± 6 $P = 0.05$ intercept = -16 ± 9 $P = 0.07$ $R^2_{tot} = 0.314$ $n_{tot} = 17$
Actual/attainable MAI (method 2)	entire Sweden	$P = 0.66$ $n = 19$	quad = -1.6 ± 0.5 $P < 0.01$ lin = 9 ± 2 $P < 0.01$ intercept = 34 ± 2 $P < 0.01$ $R^2 = 0.043$ $n = 641$	quad = -3.4 ± 0.8 $P < 0.01$ lin = 16 ± 4 $P < 0.01$ intercept = 19 ± 4 $P < 0.01$ $R^2 = 0.056$ $n = 285$	$P = 0.53$ $n = 10$

Table S5 (continued)**.**

Normalized productivity response	**Region**	**ln N stock $_{0\text{-}20cm}$ [g m^{-2}]**			
		Dry	**Fresh**	**Fresh-moist**	**Moist**
Residual MAI (method 1)	N	P = 0.56 n_{tot} = 123	slope = 0.22 ± 0.06 P < 0.01 intercept = -1.0 ± 0.3 P < 0.01 R^2_{tot} = 0.007 n_{tot} = 1569	slope = 0.26 ± 0.08 P < 0.01 intercept = -1.5 ± 0.4 P < 0.01 R^2_{tot} = 0.012 n_{tot} = 830	P = 0.78 n_{tot} = 28
	M	P = 0.56 n_{tot} = 123	slope = 0.22 ± 0.06 P < 0.01 intercept = -1.0 ± 0.3 P < 0.01 R^2_{tot} = 0.007 n_{tot} = 1569	slope = 0.26 ± 0.08 P < 0.01 intercept = -1.5 ± 0.4 P < 0.01 R^2_{tot} = 0.012 n_{tot} = 830	P = 0.78 n_{tot} = 28
	S	P = 0.56 n_{tot} = 123	slope = 0.22 ± 0.06 P < 0.01 intercept = -1.0 ± 0.3 P < 0.01 R^2_{tot} = 0.007 n_{tot} = 1569	slope = 0.26 ± 0.08 P < 0.01 intercept = -1.5 ± 0.4 P < 0.01 R^2_{tot} = 0.012 n_{tot} = 830	P = 0.78 n_{tot} = 28
Actual/attainable MAI (method 2)	entire Sweden	P = 0.10 n = 19	slope = 11 ± 1 P < 0.01 intercept = -19 ± 6 P < 0.01 R^2 = 0.149 n = 641	slope = 10 ± 1 P < 0.01 intercept = -2 ± 7 P < 0.01 R^2 = 0.212 n = 285	P = 0.12 n = 10

Table S5 (continued)**.**

Normalized productivity response	**Region**	**Soil C:N** $_{\text{0-20cm}}$			
		Dry	**Fresh**	**Fresh-moist**	**Moist**
Residual MAI (method 1)	N	$P = 0.20$ $n = 32$	slope = -0.007 ± 0.004 $P = 0.09$ intercept = 0.3 ± 0.1 $P < 0.01$ $R^2 = 0.005$ $n = 385$	slope = -0.040 ± 0.008 $P < 0.01$ intercept = 0.8 ± 0.2 $P < 0.01$ $R^2 = 0.184$ $n = 121$	$P = 0.13$ $n = 4$
	M	$P = 0.22$ $n = 47$	slope = -0.015 ± 0.006 $P = 0.02$ intercept = 0.7 ± 0.2 $P < 0.01$ $R^2 = 0.008$ $n = 515$	slope = -0.039 ± 0.010 $P < 0.01$ intercept = 0.5 ± 0.3 $P = 0.09$ $R^2 = 0.067$ $n = 208$	$P = 0.39$ $n = 7$
	S	$P = 0.28$ $n = 44$	slope = -0.048 ± 0.009 $P < 0.01$ intercept = 1.5 ± 0.2 $P < 0.01$ $R^2 = 0.041$ $n = 669$	slope = -0.09 ± 0.01 $P < 0.01$ intercept = 1.8 ± 0.4 $P < 0.01$ $R^2 = 0.170$ $n = 216$	$P = 0.14$ $n = 17$
Actual/attainable MAI (method 2)	entire Sweden	N/A	N/A	N/A	N/A

125 **Table S5** (continued)**.**

Normalized productivity response	**Region**	**ln soil C:N** **0-10 cm**			
		Dry	**Fresh**	**Fresh-moist**	**Moist**
Residual MAI (method 1)	N M S	N/A N/A N/A	N/A N/A N/A	N/A N/A N/A	N/A N/A N/A
Actual/attainable MAI (method 2)	entire Sweden	slope = -33 ± 15 P = 0.04 intercept = 143 ± 47 P < 0.01 R^2 = 0.174 n = 19	slope = -17 ± 2 P < 0.01 intercept = 96 ± 6 P < 0.01 R^2 = 0.112 n = 641	slope = -19 ± 3 P < 0.01 intercept = 95 ± 8 P < 0.01 R^2 = 0.149 n = 285	P = 0.35 n = 10

Table S5 (continued)**.**

Normalized productivity response	Region	Mineral soil sand [%]			
		Dry	**Fresh**	**Fresh-moist**	**Moist**
Residual MAI (method 1)	N	slope = 0.021 ± 0.009 P = 0.02 intercept = -1.3 ± 0.8 P = 0.10 R^2_{tot} = 0.101 n_{tot} = 123	slope = 0.004 ± 0.001 P < 0.01 intercept = -0.2 ± 0.1 P = 0.04 R^2_{tot} = 0.006 n_{tot} = 1569	slope = 0.006 ± 0.002 P < 0.01 intercept = -0.4 ± 0.1 P < 0.01 R^2_{tot} = 0.015 n_{tot} = 830	P = 0.64 n_{tot} = 28
	M	slope = 0.021 ± 0.009 P = 0.02 intercept = -1.0 ± 0.6 P = 0.09 R^2_{tot} = 0.101 n_{tot} = 123	slope = 0.004 ± 0.001 P < 0.01 intercept = -0.15 ± 0.09 P = 0.10 R^2_{tot} = 0.006 n_{tot} = 1569	slope = 0.006 ± 0.002 P < 0.01 intercept = -0.6 ± 0.1 P < 0.01 R^2_{tot} = 0.015 n_{tot} = 830	P = 0.64 n_{tot} = 28
	S	slope = 0.021 ± 0.009 P = 0.02 intercept = -1.6 ± 0.5 P < 0.01 R^2_{tot} = 0.101 n_{tot} = 123	slope = 0.004 ± 0.001 P < 0.01 intercept = -0.01 ± 0.08 P = 0.86 R^2_{tot} = 0.006 n_{tot} = 1569	slope = 0.006 ± 0.002 P < 0.01 intercept = -0.5 ± 0.1 P < 0.01 R^2_{tot} = 0.015 n_{tot} = 830	P = 0.64 n_{tot} = 28

Table S5 (continued)**.**

Normalized productivity response	**Region**	**Mineral soil clay [%]**			
		Dry	**Fresh**	**Fresh-moist**	**Moist**
Residual MAI (method 1)	N	slope = 0.10 ± 0.05 P = 0.03 intercept = -0.8 ± 0.3 P = 0.02 R^2_{tot} = 0.072 n_{tot} = 123	slope = 0.011 ± 0.005 P = 0.02 intercept = 0.06 ± 0.04 P = 0.14 R^2_{tot} = 0.003 n_{tot} = 1569	P = 0.97 n_{tot} = 545	slope = 0.05 ± 0.02 P = 0.03 intercept = -0.6 ± 0.2 P = 0.03 R^2_{tot} = 0.124 n_{tot} = 28
	M	slope = 0.10 ± 0.05 P = 0.03 intercept = -0.8 ± 0.3 P = 0.02 R^2_{tot} = 0.072 n_{tot} = 123	slope = 0.011 ± 0.005 P = 0.02 intercept = 0.06 ± 0.04 P = 0.14 R^2_{tot} = 0.003 n_{tot} = 1569	P = 0.97 n_{tot} = 545	slope = 0.05 ± 0.02 P = 0.03 intercept = -0.6 ± 0.2 P = 0.03 R^2_{tot} = 0.124 n_{tot} = 28
	S	slope = 0.10 ± 0.05 P = 0.03 intercept = -0.8 ± 0.3 P = 0.02 R^2_{tot} = 0.072 n_{tot} = 123	slope = 0.011 ± 0.005 P = 0.02 intercept = 0.06 ± 0.04 P = 0.14 R^2_{tot} = 0.003 n_{tot} = 1569	P = 0.97 n_{tot} = 545	slope = 0.05 ± 0.02 P = 0.03 intercept = -0.6 ± 0.2 P = 0.03 R^2_{tot} = 0.124 n_{tot} = 28
Actual/attainable MAI (method 2)	entire Sweden	P = 0.80 n = 19	slope = 0.21 ± 0.07 P < 0.01 intercept = 41.8 ± 0.7 P < 0.01 R^2 = 0.011 n = 641	P = 0.30 n = 285	P = 0.84 n = 10

Table S5 (continued)**.**

Normalized productivity response	**Region**	**ln TEB stock $_{0\text{-}20cm}$ [cmol$_+$ m^{-2}]**			
		Dry	**Fresh**	**Fresh-moist**	**Moist**
Residual MAI (method 1)	N	slope = 0.4 ± 0.1 *P* < 0.01 intercept = -1.7 ± 0.3 *P* < 0.01 R^2 = 0.274 *n* = 32	slope = 0.22 ± 0.05 *P* < 0.01 intercept = -0.6 ± 0.2 *P* < 0.01 R^2 = 0.039 *n* = 385	slope = 0.31 ± 0.08 *P* < 0.01 intercept = -1.5 ± 0.3 *P* < 0.01 R^2 = 0.111 *n* = 121	slope = 0.5 ± 0.1 *P* = 0.02 intercept = -3.0 ± 0.5 *P* = 0.01 R^2 = 0.808 *n* = 4
	M	*P* = 0.23 *n* = 47	slope = 0.20 ± 0.07 *P* < 0.01 intercept = -0.4 ± 0.2 *P* = 0.09 R^2 = 0.015 *n* = 515	slope = 0.18 ± 0.09 *P* = 0.04 intercept = -1.3 ± 0.4 *P* < 0.01 R^2 = 0.016 *n* = 208	*P* = 0.97 *n* = 7
	S	*P* = 0.41 *n* = 44	slope = -0.20 ± 0.06 *P* < 0.01 intercept = 1.3 ± 0.3 *P* < 0.01 R^2 = 0.014 *n* = 669	slope = 0.4 ± 0.1 *P* < 0.01 intercept = -2.4 ± 0.5 *P* < 0.01 R^2 = 0.050 *n* = 216	*P* = 0.16 *n* = 17
Actual/attainable MAI (method 2)	entire Sweden	*P* = 0.51 *n* = 19	slope = 2.7 ± 0.7 *P* < 0.01 intercept = 32 ± 3 *P* < 0.01 R^2 = 0.025 *n* = 641	slope = 3.6 ± 0.8 *P* < 0.01 intercept = 20 ± 4 *P* < 0.01 R^2 = 0.060 *n* = 285	*P* = 0.68 *n* = 10

Table S5 (continued)**.**

Normalized productivity response	**Region**	**pH_{KCl} 0-20cm**			
		Dry	**Fresh**	**Fresh-moist**	**Moist**
Residual MAI (method 1)	N	P = 0.80 n_{tot} = 123	quad = -0.54 ± 0.07 P < 0.01 lin = 3.9 ± 0.5 P < 0.01 intercept = -7 ± 1 P < 0.01 R^2_{tot} = 0.043 n_{tot} = 1569	quad = -0.4 ± 0.1 P < 0.01 lin = 3.4 ± 0.8 P < 0.01 intercept = -7 ± 2 P < 0.01 R^2_{tot} = 0.121 n_{tot} = 545	quad = -1.8 ± 0.8 P = 0.03 lin = 12 ± 5 P = 0.03 intercept = -22 ± 9 P = 0.02 R^2_{tot} = 0.415 n_{tot} = 28
	M	P = 0.80 n_{tot} = 123	quad = -0.54 ± 0.07 P < 0.01 lin = 4.2 ± 0.5 P < 0.01 intercept = -8 ± 1 P < 0.01 R^2_{tot} = 0.043 n_{tot} = 1569	quad = -0.4 ± 0.1 P < 0.01 lin = 3.5 ± 0.8 P < 0.01 intercept = -8 ± 1 P < 0.01 R^2_{tot} = 0.121 n_{tot} = 545	quad = -1.8 ± 0.8 P = 0.03 lin = 12 ± 5 P = 0.03 intercept = -23 ± 9 P = 0.02 R^2_{tot} = 0.415 n_{tot} = 28
	S	P = 0.80 n_{tot} = 123	quad = -0.54 ± 0.07 P < 0.01 lin = 4.2 ± 0.5 P < 0.01 intercept = -8 ± 1 P < 0.01 R^2_{tot} = 0.043 n_{tot} = 1569	quad = -0.4 ± 0.1 P < 0.01 lin = 3.8 ± 0.8 P < 0.01 intercept = -8 ± 1 P < 0.01 R^2_{tot} = 0.121 n_{tot} = 545	quad = -1.8 ± 0.8 P = 0.03 lin = 12 ± 5 P = 0.03 intercept = -21 ± 9 P = 0.03 R^2_{tot} = 0.415 n_{tot} = 28
Actual/attainable MAI (method 2)	entire Sweden	P = 0.13 n = 19	P = 0.21 n = 641	slope = 4 ± 2 P = 0.02 intercept = 23 ± 5 P < 0.01 R^2 = 0.016 n = 285	P = 0.45 n = 10

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Table S6. Associations between single soil variables and normalized productivity of Table 2, stratified by soil type. Significance (*P*-values) of single soil variable effects on residual productivity (mean annual increment - MAI [$m^3\ ha^{-1}\ yr^{-1}$]) and actual/attainable MAI (for spruce only) across Sweden are given. For (near) significant variables (i.e. $P < 0.10$), parameter estimates ± s.e.m. and the proportion of variation explained (R^2) are shown as well. Abbreviations: N = north; M = middle; S = south; SOC = soil organic carbon concentration; Soil C:N = soil carbon to nitrogen ratio; TEB = total exchangeable bases; quad = parameter estimate for quadratic term; lin = parameter estimate for linear term of a quadratic function.

Normalized productivity response	**Region**	**ln SOC $_{0\text{-}20cm}$ [%]**				
		Histosol	**Gleysol**	**Regosol**	**Leptosol**	**Podzol**
Residual MAI (method 1)	N	quad = -1.9 ± 0.9 *P* = 0.04 lin = 11 ± 7 *P* = 0.15 intercept = -14 ± 17 *P* = 0.42 R^2_{tot} = 0.063 n_{tot} = 156	*P* = 0.66 *n* = 30	quad = -0.12 ± 0.03 *P* < 0.01 lin = 0.3 ± 0.1 *P* = 0.02 intercept = -0.1 ± 0.1 *P* = 0.64 R^2_{tot} = 0.064 n_{tot} = 823	*P* = 0.46 n_{tot} = 71	quad = -0.12 ± 0.03 *P* < 0.01 lin = 0.4 ± 0.1 *P* < 0.01 intercept = -0.1 ± 0.1 *P* = 0.26 R^2_{tot} = 0.043 n_{tot} = 979
	M	quad = -1.9 ± 0.9 *P* = 0.04 lin = 12 ± 7 *P* = 0.07 intercept = -20 ± 13 *P* = 0.11 R^2_{tot} = 0.063 n_{tot} = 156	*P* = 0.56 *n* = 28	quad = -0.12 ± 0.03 *P* < 0.01 lin = 0.2 ± 0.1 *P* = 0.07 intercept = 0.1 ± 0.1 *P* = 0.39 R^2_{tot} = 0.064 n_{tot} = 823	*P* = 0.46 n_{tot} = 71	quad = -0.12 ± 0.03 *P* < 0.01 lin = 0.3 ± 0.1 *P* = 0.03 intercept = 0.0 ± 0.1 *P* = 0.68 R^2_{tot} = 0.043 n_{tot} = 979
	S	quad = -1.9 ± 0.9 *P* = 0.04 lin = 10 ± 5 *P* = 0.07 intercept = -12 ± 8 *P* = 0.14 R^2_{tot} = 0.063 n_{tot} = 156	slope = -0.6 ± 0.2 *P* < 0.01 intercept = 0.9 ± 0.6 *P* = 0.11 R^2 = 0.183 *n* = 34	quad = -0.12 ± 0.03 *P* = 0.27 lin = 0.2 ± 0.1 *P* = 0.23 intercept = 0.5 ± 0.2 *P* < 0.01 R^2_{tot} = 0.064 n_{tot} = 823	*P* = 0.46 n_{tot} = 71	quad = -0.12 ± 0.03 *P* < 0.01 lin = 0.2 ± 0.1 *P* = 0.19 intercept = 0.4 ± 0.2 *P* = 0.01 R^2_{tot} = 0.043 n_{tot} = 979
Actual/attainable MAI (method 2)	entire Sweden	slope = -11 ± 5 *P* = 0.05 intercept = 75 ± 20 *P* < 0.01 R^2 = 0.051 *n* = 56	*P* = 0.55 *n* = 59	quad = -1.9 ± 0.7 *P* < 0.01 lin = 8 ± 3 *P* < 0.01 intercept = 35 ± 3 *P* < 0.01 R^2 = 0.016 *n* = 350	quad = -3 ± 1 *P* = 0.01 lin = 16 ± 5 *P* < 0.01 intercept = 20 ± 6 *P* < 0.01 R^2 = 0.199 *n* = 27	quad = -2.3 ± 0.6 *P* < 0.01 lin = 10 ± 2 *P* < 0.01 intercept = 31 ± 2 *P* < 0.01 R^2 = 0.041 *n* = 390

Table S6 (continued)**.**

Normalized productivity response	**Region**	**ln N stock $_{0\text{-}20cm}$ [g m^{-2}]**				
		Histosol	**Gleysol**	**Regosol**	**Leptosol**	**Podzol**
Residual MAI (method 1)	N	slope = 0.9 ± 0.2 P < 0.01 intercept = -6.3 ± 0.9 P < 0.01 R^2_{tot} = 0.140 n_{tot} = 158	P = 0.62 n_{tot} = 91	slope = 0.23 ± 0.08 P < 0.01 intercept = -1.0 ± 0.4 P = 0.02 R^2_{tot} = 0.008 n_{tot} = 825	P = 0.95 n_{tot} = 73	slope = 0.28 ± 0.08 P < 0.01 intercept = -1.2 ± 0.4 P < 0.01 R^2_{tot} = 0.012 n_{tot} = 981
	M	slope = 0.9 ± 0.2 P < 0.01 intercept = -6.3 ± 0.9 P < 0.01 R^2_{tot} = 0.140 n_{tot} = 158	P = 0.62 n_{tot} = 91	slope = 0.23 ± 0.08 P < 0.01 intercept = -1.0 ± 0.4 P = 0.02 R^2_{tot} = 0.008 n_{tot} = 825	P = 0.95 n_{tot} = 73	slope = 0.28 ± 0.08 P < 0.01 intercept = -1.2 ± 0.4 P < 0.01 R^2_{tot} = 0.012 n_{tot} = 981
	S	slope = 0.9 ± 0.2 P < 0.01 intercept = -6.3 ± 0.9 P < 0.01 R^2_{tot} = 0.140 n_{tot} = 158	P = 0.62 n_{tot} = 91	slope = 0.23 ± 0.08 P < 0.01 intercept = -1.0 ± 0.4 P = 0.02 R^2_{tot} = 0.008 n_{tot} = 825	P = 0.95 n_{tot} = 73	slope = 0.28 ± 0.08 P < 0.01 intercept = -1.2 ± 0.4 P < 0.01 R^2_{tot} = 0.012 n_{tot} = 981
Actual/attainable MAI (method 2)	entire Sweden	slope = 10 ± 3 P < 0.01 intercept = -26 ± 15 P = 0.10 R^2 = 0.213 n = 56	slope = 8 ± 3 P < 0.01 intercept = -9 ± 14 P = 0.54 R^2 = 0.131 n = 59	slope = 12 ± 1 P < 0.01 intercept = -25 ± 8 P < 0.01 R^2 = 0.178 n = 350	slope = 18 ± 3 P < 0.01 intercept = -64 ± 21 P < 0.01 R^2 = 0.442 n = 27	slope = 12 ± 2 P < 0.01 intercept = -24 ± 9 P < 0.01 R^2 = 0.115 n = 390

Table S6 (continued)**.**

Normalized productivity response	**Region**	**Soil C:N** 0-20cm				
		Histosol	**Gleysol**	**Regosol**	**Leptosol**	**Podzol**
Residual MAI (method 1)	N	slope = -0.06 ± 0.02 *P* = 0.04 intercept = 0.6 ± 0.7 *P* = 0.40 R^2 = 0.255 *n* = 13	slope = -0.03 ± 0.01 *P* = 0.03 intercept = 0.6 ± 0.3 *P* = 0.10 R^2 = 0.121 *n* = 30	*P* = 0.13 *n* = 203	*P* = 0.45 n_{tot} = 71	slope = -0.013 ± 0.006 *P* = 0.03 intercept = 0.4 ± 0.2 *P* = 0.01 R^2 = 0.015 *n* = 267
	M	slope = -0.05 ± 0.02 *P* = 0.03 intercept = 0.0 ± 0.6 *P* = 0.99 R^2 = 0.079 *n* = 50	*P* = 0.11 *n* = 25	slope = -0.016 ± 0.009 *P* = 0.07 intercept = 0.5 ± 0.2 *P* = 0.04 R^2 = 0.008 *n* = 262	*P* = 0.45 n_{tot} = 71	slope = -0.026 ± 0.008 *P* < 0.01 intercept = 0.8 ± 0.2 *P* < 0.01 R^2 = 0.027 *n* = 390
	S	slope = -0.10 ± 0.02 *P* < 0.01 intercept = 1.3 ± 0.7 *P* = 0.06 R^2 = 0.154 *n* = 93	*P* = 0.40 *n* = 34	slope = -0.07 ± 0.01 *P* < 0.01 intercept = 1.8 ± 0.3 *P* < 0.01 R^2 = 0.067 *n* = 358	*P* = 0.45 n_{tot} = 71	slope = -0.04 ± 0.01 *P* < 0.01 intercept = 1.3 ± 0.3 *P* < 0.01 R^2 = 0.027 *n* = 322
Actual/attainable MAI (method 2)	entire Sweden	N/A	N/A	N/A	N/A	N/A

Table S6 (continued)**.**

Normalized productivity response	**Region**	**ln soil C:N** **0-10cm**				
		Histosol	**Gleysol**	**Regosol**	**Leptosol**	**Podzol**
Residual MAI (method 1)	N	N/A	N/A	N/A	N/A	N/A
	M	N/A	N/A	N/A	N/A	N/A
	S	N/A	N/A	N/A	N/A	N/A
Actual/attainable MAI (method 2)	entire Sweden	slope = -25 ± 8 $P < 0.01$ intercept = 113 ± 26 $P < 0.01$ $R^2 = 0.117$ $n = 61$	slope = -17 ± 4 $P < 0.01$ intercept = 90 ± 14 $P < 0.01$ $R^2 = 0.176$ $n = 62$	slope = -20 ± 2 $P < 0.01$ intercept = 106 ± 8 $P < 0.01$ $R^2 = 0.154$ $n = 360$	slope = -19 ± 9 $P = 0.03$ intercept = 102 ± 29 $P < 0.01$ $R^2 = 0.093$ $n = 38$	slope = -16 ± 3 $P < 0.01$ intercept = 91 ± 9 $P < 0.01$ $R^2 = 0.082$ $n = 391$

135 **Table S6** (continued)**.**

Normalized productivity response	**Region**	**Mineral soil sand [%]**				
		Histosol	**Gleysol**	**Regosol**	**Leptosol**	**Podzol**
Residual MAI (method 1)	N	P = 0.44 n_{tot} = 174	P = 0.21 n_{tot} = 95	P = 0.74 n = 217	P = 0.48 n_{tot} = 181	slope = -0.004 ± 0.002 P = 0.09 intercept = 0.3 ± 0.2 P = 0.04 R^2 = 0.007 n = 268
	M	P = 0.44 n_{tot} = 174	P = 0.21 n_{tot} = 95	P = 0.98 n = 277	P = 0.48 n_{tot} = 181	slope = 0.008 ± 0.003 P < 0.01 intercept = -0.4 ± 0.2 P = 0.05 R^2 = 0.016 n = 401
	S	P = 0.44 n_{tot} = 174	P = 0.21 n_{tot} = 95	P = 0.93 n = 374	P = 0.48 n_{tot} = 181	P = 0.69 n = 324
Actual/attainable MAI (method 2)	entire Sweden	P = 0.75 n = 64	P = 0.65 n = 63	slope = -0.06 ± 0.03 P = 0.05 intercept = 45 ± 2 P < 0.01 R^2 = 0.008 n = 377	P = 0.87 n = 71	slope = -0.06 ± 0.03 P = 0.03 intercept = 43 ± 2 P < 0.01 R^2 = 0.009 n = 399

Table S6 (continued)**.**

Normalized productivity response	**Region**	**Mineral soil clay [%]**				
		Histosol	**Gleysol**	**Regosol**	**Leptosol**	**Podzol**
Residual MAI (method 1)	N	P = 0.82 n_{tot} = 176	slope = -0.02 ± 0.01 P = 0.05 intercept = -0.1 ± 0.1 P = 0.31 R^2_{tot} = 0.031 n_{tot} = 97	P = 0.11 n_{tot} = 870	P = 0.76 n_{tot} = 183	P = 0.26 n_{tot} = 995
	M	P = 0.82 n_{tot} = 176	slope = -0.02 ± 0.01 P = 0.05 intercept = -0.1 ± 0.1 P = 0.31 R^2_{tot} = 0.031 n_{tot} = 97	P = 0.11 n_{tot} = 870	P = 0.76 n_{tot} = 183	P = 0.26 n_{tot} = 995
	S	P = 0.82 n_{tot} = 176	slope = -0.02 ± 0.01 P = 0.05 intercept = -0.1 ± 0.1 P = 0.31 R^2_{tot} = 0.031 n_{tot} = 97	P = 0.11 n_{tot} = 870	P = 0.76 n_{tot} = 183	P = 0.26 n_{tot} = 995
Actual/attainable MAI (method 2)	entire Sweden	P = 0.61 n = 64	P = 0.54 n = 63	slope = 0.23 ± 0.09 P = 0.01 intercept = 40 ± 1 P < 0.01 R^2 = 0.014 n = 377	P = 0.66 n = 71	slope = 0.2 ± 0.1 P = 0.08 intercept = 38 ± 1 P < 0.01 R^2 = 0.005 n = 399

Table S6 (continued)**.**

Normalized productivity response	**Region**	**ln TEB stock $_{0\text{-}20cm}$ [$cmol_+ m^{-2}$]**				
		Histosol	**Gleysol**	**Regosol**	**Leptosol**	**Podzol**
Residual MAI (method 1)	N	P = 0.27 n = 56	P = 0.17 n_{tot} = 89	slope = 0.25 ± 0.06 P < 0.01 intercept = -0.9 ± 0.2 P < 0.01 R^2 = 0.070 n = 203	P = 0.21 n_{tot} = 71	slope = 0.23 ± 0.08 P < 0.01 intercept = -0.7 ± 0.3 P < 0.01 R^2 = 0.029 n = 266
	M	P = 0.51 n = 50	P = 0.17 n_{tot} = 89	slope = 0.25 ± 0.09 P < 0.01 intercept = -0.9 ± 0.3 P = 0.01 R^2 = 0.026 n = 262	P = 0.21 n_{tot} = 71	slope = 0.15 ± 0.08 P = 0.08 intercept = -0.4 ± 0.3 P = 0.18 R^2 = 0.005 n = 390
	S	slope = 0.7 ± 0.2 P < 0.01 intercept = -4.4 ± 0.9 P < 0.01 R^2 = 0.096 n = 93	P = 0.17 n_{tot} = 89	slope = -0.15 ± 0.09 P = 0.08 intercept = 1.0 ± 0.4 P < 0.01 R^2 = 0.006 n = 358	P = 0.21 n_{tot} = 71	P = 0.6 n = 322
Actual/attainable MAI (method 2)	entire Sweden	P = 0.13 n = 56	P = 0.30 n = 59	slope = 1.4 ± 0.8 P = 0.09 intercept = 36 ± 4 P < 0.01 R^2 = 0.005 n = 350	P = 0.15 n = 27	slope = 2 ± 1 P = 0.09 intercept = 32 ± 4 P < 0.01 R^2 = 0.005 n = 390

Table S6 (continued)**.**

Normalized productivity response	**Region**	**pH_{KCl} 0-20cm**				
		Histosol	**Gleysol**	**Regosol**	**Leptosol**	**Podzol**
Residual MAI (method 1)	N	quad = -0.1 ± 0.3 *P* = 0.65 lin = 2 ± 2 *P* = 0.48 intercept = 0 ± 2 *P* = 0.84 R^2_{tot} = 0.037 n_{tot} = 156	quad = -0.3 ± 0.2 *P* = 0.23 lin = 2 ± 2 *P* = 0.19 intercept = -5 ± 4 *P* = 0.16 R^2_{tot} = 0.099 n_{tot} = 89	quad = -0.45 ± 0.09 *P* < 0.01 lin = 3.4 ± 0.7 *P* < 0.01 intercept = -6 ± 1 *P* < 0.01 R^2_{tot} = 0.049 n_{tot} = 822	*P* = 0.42 n_{tot} = 71	quad = -0.6 ± 0.2 *P* < 0.01 lin = 4 ± 1 *P* < 0.01 intercept = -7 ± 2 *P* < 0.01 R^2_{tot} = 0.029 n_{tot} = 977
	M	quad = -0.1 ± 0.3 *P* = 0.65 lin = 1 ± 2 *P* = 0.55 intercept = -4 ± 4 *P* = 0.28 R^2_{tot} = 0.037 n_{tot} = 156	quad = -0.3 ± 0.2 *P* = 0.23 lin = 4 ± 2 *P* = 0.05 intercept = -10 ± 4 *P* = 0.01 R^2_{tot} = 0.099 n_{tot} = 89	quad = -0.45 ± 0.09 *P* < 0.01 lin = 3.9 ± 0.7 *P* < 0.01 intercept = -8 ± 1 *P* < 0.01 R^2_{tot} = 0.049 n_{tot} = 822	*P* = 0.42 n_{tot} = 71	quad = -0.6 ± 0.2 *P* < 0.01 lin = 4 ± 1 *P* < 0.01 intercept = -7 ± 2 *P* < 0.01 R^2_{tot} = 0.029 n_{tot} = 977
	S	quad = -0.1 ± 0.3 *P* = 0.65 lin = 2 ± 2 *P* = 0.36 intercept = -2 ± 1 *P* = 0.30 R^2_{tot} = 0.037 n_{tot} = 156	quad = -0.3 ± 0.2 *P* = 0.23 lin = 3 ± 2 *P* = 0.16 intercept = -7 ± 4 *P* = 0.08 R^2_{tot} = 0.099 n_{tot} = 89	quad = -0.45 ± 0.09 *P* < 0.01 lin = 3.6 ± 0.7 *P* < 0.01 intercept = -8 ± 1 *P* < 0.01 R^2_{tot} = 0.049 n_{tot} = 822	*P* = 0.42 n_{tot} = 71	quad = -0.6 ± 0.2 *P* < 0.01 lin = 5 ± 1 *P* < 0.01 intercept = -8 ± 2 *P* < 0.01 R^2_{tot} = 0.029 n_{tot} = 977
Actual/attainable MAI (method 2)	entire Sweden	*P* = 0.42 *n* = 56	*P* = 0.50 *n* = 59	*P* = 0.11 *n* = 350	*P* = 0.63 *n* = 27	*P* = 0.92 *n* = 389

Table S7. Overall mean squared error (ms) after 10-fold cross-validation for the most relevant candidate model structures that explain variation in normalized productivity according to method 1 (residual mean annual increment - MAI) by soil variables (0-20 cm depth or mineral soil only) for Swedish spruce and pine forests. The selected model is marked in gray. Abbreviations: C:N = soil carbon to nitrogen ratio; pH = pH_{KCl}; SOC = soil organic carbon concentration; $CLAY_{min.soil}$ = clay fraction in the mineral soil; TEB = total exchangeable bases. REGION is a factor with north, middle and south as levels.

Variables in model	Overall ms	Variables in model	Overall ms
LN^2(SOC), LN(SOC), C:N, $CLAY_{min.soil}$, LN(TEB), pH^2, pH, REGION, all interactions with REGION	1.24	*LN^2(SOC), LN(SOC), C:N, LN(TEB), pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION, LN(SOC):REGION, LN(TEB):REGION*	*1.23*
LN^2(SOC), LN(SOC), C:N, $CLAY_{min.soil}$, LN(TEB), pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION	1.24		
LN^2(SOC), LN(SOC), C:N, $CLAY_{min.soil}$, LN(TEB), pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION, LN(TEB): REGION	1.24	LN^2(SOC), LN(SOC), C:N, pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION, LN(SOC):REGION, LN(TEB):REGION	1.24
LN^2(SOC), LN(SOC), C:N, $CLAY_{min.soil}$, LN(TEB), pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION, LN(TEB):REGION, $CLAY_{min.soil}$:REGION	1.24	LN^2(SOC), LN(SOC), C:N, LN(TEB), pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION, LN(SOC):REGION, LN(TEB):REGION, pH^2:REGION	1.24
LN^2(SOC), LN(SOC), C:N, LN(TEB), pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION, LN(TEB):REGION	1.23	LN^2(SOC), LN(SOC), C:N, LN(TEB), pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION, LN(SOC):REGION, LN(TEB):REGION, C:N:REGION	1.25
LN^2(SOC), LN(SOC), C:N, LN(TEB), pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION, LN(TEB):REGION, pH^2:REGION	1.24	LN(SOC), C:N, LN(TEB), pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION, LN(SOC):REGION, LN(TEB):REGION	1.26
LN^2(SOC), LN(SOC), C:N, pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION, pH^2:REGION	1.24		
		all models including LN(N stock)	≥ 1.24

Table S8. Overall mean squared error (ms) after 10-fold cross-validation for the most relevant candidate model structures that explain variation in normalized productivity according to method 2 (actual/attainable mean annual increment - MAI) by soil variables (0-20 cm or mineral soil only) for Swedish spruce and pine forests. The selected model is marked in gray. Abbreviations: C:N = soil carbon to nitrogen ratio; TEB = total exchangeable bases; pH = pH_{KCl}; $CLAY_{min.soil}$ = clay fraction in the mineral soil; SOC = soil organic carbon concentration. For soil C:N, data of depth 0-10 cm were used instead of 0-20 cm as the mean squared error of the single regression model was lowest in the former case (Table 2).

Variables in model	Overall ms
LN^2(SOC), LN(SOC), LN(N stock), LN(C:N), $SAND_{min.soil}$, $CLAY_{min.soil}$, LN(TEB), pH	138
LN^2(SOC), LN(SOC), LN(N stock), LN(C:N), $SAND_{min.soil}$, LN(TEB), pH	138
LN^2(SOC), LN(SOC), LN(N stock), LN(C:N), $SAND_{min.soil}$, pH	*138*
LN^2(SOC), LN(SOC), LN(N stock), LN(C:N), pH	139
LN^2(SOC), LN(SOC), LN(N stock), LN(C:N), $SAND_{min.soil}$	143

Table S9. Tests of variable implementation in the IIASA-metric of constraints on nutrient availability, based on the complete Swedish database. Associations between residuals of normalized productivities in Fig. 9 and soil variables in the IIASA-metric are shown. For (near) significant variables (i.e. $P < 0.10$), parameter estimates ± s.e.m. and the proportion of variation explained (R^2) are given. Abbreviations: N = north; M = middle; S = south; SOC = soil organic carbon concentration; TEB = total exchangeable bases; pH_w = pH measured in water; quad = parameter estimate for quadratic term; lin = parameter estimate for linear term of a quadratic function. Note that TEB is expressed here according to the standard definition (per kg dry weight as defined for the IIASA-metric), whereas elsewhere in this paper, TEB is referred to as a stock, i.e. an amount per m² in the upper 20 cm of the soil, thus better representing the actual number of base cations available to plants. Error bars represent the s.e.m.

Residuals of	**Region**	**ln $SOC_{0\text{-}20cm}$ [%]**	**$Sand_{0\text{-}20cm}$ [%]**	**ln $TEB_{0\text{-}20cm}$ [$cmol_+$ kg^{-1}]**	**$pH_{w,0\text{-}20cm}$**
Residual MAI (method 1)	N (n = 542)	slope = -0.11 ± 0.03 $P < 0.01$ $R^2 = 0.022$	slope = 0.005 ± 0.001 $P < 0.01$ $R^2 = 0.025$	slope = -0.04 ± 0.02 $P = 0.09$ $R^2 = 0.003$	quad = -0.3 ± 0.1 lin = 2.7 ± 0.9 $P < 0.01$ $R^2 = 0.019$
	M (n = 777)	slope = -0.31 ± 0.03 $P < 0.01$ $R^2 = 0.092$	slope = 0.012 ± 0.002 $P < 0.01$ $R^2 = 0.065$	slope = -0.20 ± 0.03 $P < 0.01$ $R^2 = 0.052$	quad = -0.4 ± 0.1 lin = 4 ± 1 $P < 0.01$ $R^2 = 0.055$
	S (n = 946)	slope = -0.56 ± 0.04 $P < 0.01$ $R^2 = 0.141$	slope = 0.015 ± 0.002 $P < 0.01$ $R^2 = 0.076$	slope = -0.39 ± 0.04 $P < 0.01$ $R^2 = 0.099$	quad = -0.86 ± 0.07 lin = 8.4 ± 0.6 $P < 0.01$ $R^2 = 0.166$
Actual/attainable MAI (method 2)	entire Sweden (n = 955)	$P = 0.41$	$P = 0.33$	slope = -0.6 ± 0.4 $P = 0.08$ $R^2 = 0.002$	$P = 0.73$

Table S10. Associations between single key soil variables and normalized productivity (method 1) for spruce and pine forests in southern Sweden. Significance (*P*-values) of single soil variable effects on residual productivity (mean annual increment - MAI [m^3 ha^{-1} yr^{-1}]) are given. For (near) significant variables (i.e. $P < 0.10$), parameter estimates ± s.e.m. and the proportion of variation explained (R^2) are shown as well. Note that the results presented here deviate slightly from the data presented in Table 2, as separate regression analyses were performed for southern Sweden here instead of ANCOVA analyses with region as the factor, and results were based on a calibration subset here, instead of the complete database Moreover, pH_w was used instead of pH_{KCl} to keep the same variable for soil pH as in the original nutrient availability metric. Abbreviations: S = south; SOC = soil organic carbon concentration; Soil C:N = soil carbon to nitrogen ratio; quad = parameter estimate for quadratic term; lin = parameter estimate for linear term of a quadratic function.

Normalized productivity response	**Region**	**ln $SOC_{0\text{-}20cm}$ [%]**	**Soil $C:N_{0\text{-}20cm}$**	**$pH_{w,0\text{-}20cm}$**
Residual MAI	S (n = 473)	quad = -0.18 ± 0.06 $P < 0.01$ lin = 0.3 ± 0.3 $P = 0.22$ intercept = 0.4 ± 0.3 $P = 0.19$ $R^2_{tot} = 0.134$	slope = -0.082 ± 0.009 $P < 0.01$ intercept = 2.0 ± 0.2 $P < 0.01$ $R^2 = 0.134$	quad = -0.9 ± 0.1 $P < 0.01$ lin = 8.4 ± 0.9 $P < 0.01$ intercept = -19 ± 2 $P < 0.01$ $R^2_{tot} = 0.172$

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Table S11. Associations between single key soil variables and normalized productivity (method 2) for spruce forests in Sweden. Significance (*P*-values) of single soil variable effects on actual/attainable productivity (mean annual increment - MAI [$m^3\ ha^{-1}\ yr^{-1}$]) are given. For (near) significant variables (i.e. $P < 0.10$), parameter estimates ± s.e.m. and the proportion of variation explained (R^2) are shown as well. Note that the results presented here deviate slightly from the data presented in Table 2, as they were based on a calibration subset here, instead of the complete database. Moreover, pH_w was used instead of pH_{KCl} to keep the same variable for soil pH as in the original nutrient availability metric. Abbreviations: S = south; SOC = soil organic carbon concentration; Soil C:N = soil carbon to nitrogen ratio; quad = parameter estimate for quadratic term; lin = parameter estimate for linear term of a quadratic function.

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Normalized productivity response	**ln $SOC_{0\text{-}20cm}$ [%]**	**ln soil $C:N_{0\text{-}10cm}$**	**$pH_{w,0\text{-}20cm}$**
Actual/attainable MAI (n = 475)	quad = -2.8 ± 0.6 $P < 0.01$ lin = 12 ± 3 $P < 0.01$ intercept = 31 ± 2 $P < 0.01$ $R^2 = 0.049$	slope = -19 ± 2 $P < 0.01$ intercept = 102 ± 7 $P < 0.01$ $R^2 = 0.138$	slope = 2 ± 1 $P = 0.08$ intercept = 31 ± 5 $P < 0.01$ $R^2 = 0.004$

250 **Table S12.** Performance of adjusted metric 1 per soil moisture class. Significance (*P*-values) of metric-normalized productivity (mean annual increment - MAI [$m^3\ ha^{-1}\ yr^{-1}$]) associations are given. For (near) significant relationships (i.e. $P < 0.10$), parameter estimates ± s.e.m. and the proportion of variation explained (R^2) are shown as well. Abbreviations: N = north; M = middle; S = south.

Normalized productivity response	**Region**	**Adjusted metric 1 [$m^3\ ha^{-1}\ yr^{-1}$]**			
		Dry	**Fresh**	**Fresh-moist**	**Moist**
Residual MAI (method 1)	N	$P = 0.99$ $n = 10$	slope = 0.5 ± 0.1 $P < 0.01$ $R^2 = 0.071$ $n = 322$	slope = 0.3 ± 0.1 $P < 0.01$ $R^2 = 0.030$ $n = 201$	slope = 1.0 ± 0.1 $P = 0.01$ $R^2 = 0.539$ $n = 8$
	M	$P = 0.78$ $n = 16$	slope = 0.8 ± 0.1 $P < 0.01$ $R^2 = 0.089$ $n = 488$	slope = 0.9 ± 0.1 $P < 0.01$ $R^2 = 0.135$ $n = 262$	$P = 0.45$ $n = 10$
	S	$P = 0.51$ $n = 6$	slope = 1.4 ± 0.2 $P < 0.01$ $R^2 = 0.089$ $n = 488$	slope = 1.7 ± 0.2 $P < 0.01$ $R^2 = 0.258$ $n = 183$	$P = 0.95$ $n = 8$
Actual/attainable MAI (method 2)	entire Sweden	$P = 0.20$ $n = 19$	slope = 3 ± 2 $P = 0.08$ $R^2 = 0.003$ $n = 640$	slope = 4 ± 2 $P = 0.02$ $R^2 = 0.017$ $n = 285$	$P = 0.67$ $n = 10$

Table S13. Performance of adjusted metric 1 per soil type. Significance (*P*-values) of metric-normalized productivity (mean annual increment - MAI [$m^3\ ha^{-1}\ yr^{-1}$]) associations are given. For (near) significant relationships (i.e. $P < 0.10$), parameter estimates ± s.e.m. and the proportion of variation explained (R^2) are shown as well. Abbreviations: N = north; M = middle; S = south.

Normalized productivity response	**Region**	**Adjusted metric 1 [$m^3\ ha^{-1}\ yr^{-1}$]**				
		Histosol	**Gleysol**	**Regosol**	**Leptosol**	**Podzol**
Residual MAI (method 1)	N	slope = 1.4 ± 0.6 $P = 0.03$ $R^2 = 0.297$ $n = 13$	$P = 0.86$ $n = 30$	slope = 0.4 ± 0.1 $P < 0.01$ $R^2 = 0.036$ $n = 203$	$P = 0.31$ $n = 14$	slope = 0.3 ± 0.1 $P = 0.02$ $R^2 = 0.017$ $n = 266$
	M	slope = 1.2 ± 0.5 $P = 0.03$ $R^2 = 0.074$ $n = 50$	$P = 0.31$ $n = 25$	slope = 0.4 ± 0.2 $P < 0.01$ $R^2 = 0.023$ $n = 261$	$P = 0.49$ $n = 17$	slope = 0.6 ± 0.1 $P < 0.01$ $R^2 = 0.040$ $n = 390$
	S	$P = 0.22$ $n = 53$	$P = 0.11$ $n = 16$	slope = 0.9 ± 0.3 $P < 0.01$ $R^2 = 0.060$ $n = 179$	$P = 0.95$ $n = 20$	slope = 0.7 ± 0.3 $P = 0.04$ $R^2 = 0.021$ $n = 154$
Actual/attainable MAI (method 2)	entire Sweden	slope = 18 ± 7 $P = 0.01$ $R^2 = 0.094$ $n = 56$	$P = 0.72$ $n = 59$	slope = 5 ± 2 $P = 0.01$ $R^2 = 0.015$ $n = 348$	$P = 0.38$ $n = 27$	slope = 5 ± 2 $P = 0.01$ $R^2 = 0.013$ $n = 389$

Table S14. Performance of adjusted metric 2 per soil moisture class. Significance (*P*-values) of metric-normalized productivity (mean annual increment - MAI [$m^3\ ha^{-1}\ yr^{-1}$]) associations are given. For (near) significant relationships (i.e. $P < 0.10$), parameter estimates ± s.e.m. and the proportion of variation explained (R^2) are shown as well. Abbreviations: N = north; M = middle; S = south.

Normalized productivity response	**Region**	**Adjusted metric 2 [%]**			
		Dry	**Fresh**	**Fresh-moist**	**Moist**
Residual MAI (method 1)	N	slope = 0.07 ± 0.03 $P = 0.02$ $R^2 = 0.148$ $n = 32$	slope = 0.07 ± 0.01 $P < 0.01$ $R^2 = 0.055$ $n = 383$	slope = 0.14 ± 0.02 $P < 0.01$ $R^2 = 0.240$ $n = 122$	$P = 0.26$ $n = 4$
	M	$P = 0.39$ $n = 47$	slope = 0.10 ± 0.02 $P < 0.01$ $R^2 = 0.042$ $n = 514$	slope = 0.18 ± 0.03 $P < 0.01$ $R^2 = 0.141$ $n = 208$	$P = 0.33$ $n = 7$
	S	$P = 0.95$ $n = 44$	slope = 0.11 ± 0.03 $P < 0.01$ $R^2 = 0.026$ $n = 669$	slope = 0.27 ± 0.04 $P < 0.01$ $R^2 = 0.211$ $n = 216$	slope = 0.5 ± 0.2 $P = 0.02$ $R^2 = 0.233$ $n = 17$
Actual/attainable MAI (method 2)	entire Sweden	slope = 5 ± 2 $P = 0.03$ $R^2 = 0.334$ $n = 11$	slope = 2.7 ± 0.3 $P < 0.01$ $R^2 = 0.167$ $n = 320$	slope = 2.0 ± 0.4 $P < 0.01$ $R^2 = 0.132$ $n = 135$	$P = 0.92$ $n = 6$

255 **Table S15.** Performance of adjusted metric 2 per soil type. Significance (*P*-values) of metric-normalized productivity (mean annual increment - MAI [$m^3\ ha^{-1}\ yr^{-1}$]) associations are given. For (near) significant relationships (i.e. $P < 0.10$), parameter estimates ± s.e.m. and the proportion of variation explained (R^2) are shown as well. Abbreviations: N = north; M = middle; S = south.

Normalized productivity response	**Region**	**Adjusted metric 2 [%]**				
		Histosol	**Gleysol**	**Regosol**	**Leptosol**	**Podzol**
Residual MAI (method 1)	N	slope = 0.23 ± 0.08 $P = 0.01$ $R^2 = 0.381$ $n = 13$	slope = 0.08 ± 0.04 $P = 0.06$ $R^2 = 0.091$ $n = 30$	slope = 0.07 ± 0.02 $P < 0.01$ $R^2 = 0.064$ $n = 203$	slope = 0.16 ± 0.05 $P < 0.01$ $R^2 = 0.370$ $n = 14$	slope = 0.07 ± 0.02 $P < 0.01$ $R^2 = 0.051$ $n = 266$
	M	slope = 0.19 ± 0.07 $P = 0.01$ $R^2 = 0.098$ $n = 50$	slope = 0.2 ± 0.1 $P = 0.10$ $R^2 = 0.072$ $n = 25$	slope = 0.08 ± 0.03 $P < 0.01$ $R^2 = 0.027$ $n = 261$	$P = 0.99$ $n = 17$	slope = 0.13 ± 0.03 $P < 0.01$ $R^2 = 0.059$ $n = 390$
	S	slope = 0.36 ± 0.08 $P < 0.01$ $R^2 = 0.172$ $n = 93$	$P = 0.23$ $n = 34$	slope = 0.12 ± 0.03 $P < 0.01$ $R^2 = 0.032$ $n = 358$	$P = 0.79$ $n = 40$	slope = 0.14 ± 0.04 $P < 0.01$ $R^2 = 0.036$ $n = 322$
Actual/attainable MAI (method 2)	entire Sweden	$P = 0.40$ $n = 25$	slope = 1.9 ± 0.8 $P = 0.02$ $R^2 = 0.141$ $n = 30$	slope = 3.3 ± 0.5 $P < 0.01$ $R^2 = 0.232$ $n = 170$	slope = 2.0 ± 0.9 $P = 0.04$ $R^2 = 0.205$ $n = 15$	slope = 2.5 ± 0.5 $P < 0.01$ $R^2 = 0.133$ $n = 199$

Table S16. Tests of variable implementation in adjusted nutrient availability metric 1, based on the complete Swedish database. Associations between residuals of normalized productivities in Fig. 10 and soil variables in adjusted metric 2 are shown. For (near) significant variables (i.e. $P < 0.10$), parameter estimates ± s.e.m. and the proportion of variation explained (R^2) are given. Abbreviations: N = north; M = middle; S = south; SOC = soil organic carbon concentration; Soil C:N = soil carbon to nitrogen ratio; pH_w = pH measured in water. Error bars represent the s.e.m.

Residuals of	**Region**	**ln $SOC_{0\text{-}20cm}$ [%]**	**Soil $C:N_{0\text{-}20cm}$**	**$pH_{w,0\text{-}20cm}$**
Residual MAI (method 1)	N (n = 542)	P = 0.40	P = 0.24	P = 0.28
	M (n = 777)	slope = -0.06 ± 0.03 P = 0.08 R^2 = 0.003	slope = 0.011 ± 0.005 P = 0.03 R^2 = 0.005	P = 0.14
	S (n = 473)	P = 0.36	P = 0.73	P = 0.28
Actual/attainable MAI (method 2)	entire Sweden (n = 955)	slope = 1.7 ± 0.4 P < 0.01 R^2 = 0.016	slope = -0.33 ± 0.07 P < 0.01 R^2 = 0.021	P = 0.17

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Table S17. Tests of variable implementation in adjusted nutrient availability metric 2, based on the complete Swedish database. Associations between residuals of normalized productivities in Fig. 11 and soil variables in adjusted metric 2 are shown. For (near) significant variables (i.e. $P < 0.10$), parameter estimates ± s.e.m. and the proportion of variation explained (R^2) are given. Abbreviations: N = north; M = middle; S = south; SOC = soil organic carbon concentration; Soil C:N = soil carbon to nitrogen ratio; pH_w = pH measured in
290 water. Error bars represent the s.e.m.

Residuals of	**Region**	**ln $SOC_{0\text{-}20cm}$ [%]**	**ln soil $C{:}N_{0\text{-}10cm}$**	**$pH_{w,0\text{-}20cm}$**
Residual MAI (method 1)	N (n = 545)	slope = -0.11 ± 0.03 $P < 0.01$ $R^2 = 0.023$	$P = 0.55$	slope = 0.16 ± 0.07 $P = 0.02$ $R^2 = 0.008$
	M (n = 780)	slope = -0.30 ± 0.03 $P < 0.01$ $R^2 = 0.093$	$P = 0.94$	slope = 0.37 ± 0.09 $P = 0.02$ $R^2 = 0.020$
	S (n = 950)	slope = -0.37 ± 0.04 $P < 0.01$ $R^2 = 0.067$	$P = 0.16$	$P = 0.60$
Actual/attainable MAI (method 2)	entire Sweden (n = 475)	slope = 1.0 ± 0.6 $P = 0.09$ $R^2 = 0.004$	$P = 0.34$	slope = -5 ± 1 $P < 0.01$ $R^2 = 0.036$

Table S18. Tests of variable implementation in adjusted nutrient availability metric 1, based on selected nutrient availability gradients in Sweden. Associations between residuals of normalized productivities in Table 4 and soil variables in adjusted metric 1 are shown. For (near) significant variables (i.e. $P < 0.10$), parameter estimates ± s.e.m. and the proportion of variation explained (R^2) are given. For Norway spruce, no TEB gradient without substantial variation in climate was found, so that only for Scots pine, there was a gradient in TEB. Abbreviations: SOC = soil organic carbon concentration; Soil C:N = soil carbon to nitrogen ratio; pH_w = pH measured in water; TEB = total exchangeable bases. Error bars represent the s.e.m.

Dominant tree species	**Gradient type**	**ln $SOC_{0\text{-}20cm}$ [%]**	**Soil $C:N_{0\text{-}20cm}$**	**$pH_{w,0\text{-}20cm}$**
Norway spruce	Soil moisture (n = 132)	P = 0.80	P = 0.38	P = 0.89
	Productivity (n = 78)	P = 0.62	slope = -0.06 ± 0.03 P = 0.06 R^2 = 0.033	slope = 1.0 ± 0.4 P < 0.01 R^2 = 0.083
Scots pine	Soil moisture (n = 141)	P = 0.83	P = 0.62	P = 0.79
	TEB (n = 59)	P = 0.35	P = 0.70	P = 0.22
	Productivity (n = 67)	P = 0.94	P = 0.50	P = 0.84

Table S19. Tests of variable implementation in adjusted nutrient availability metric 2, based on selected nutrient availability gradients in Sweden. Associations between residuals of productivities in Table 5 and soil variables in adjusted metric 2 are shown. For (near) significant variables (i.e. $P < 0.10$), parameter estimates ± s.e.m. and the proportion of variation explained (R^2) are given. For Norway spruce, no TEB gradient without substantial variation in climate was found, so that only for Scots pine, there was a gradient in TEB. Abbreviations: SOC = soil organic carbon concentration; Soil C:N = soil carbon to nitrogen ratio; pH_w = pH measured in water; TEB = total exchangeable bases. Error bars represent the s.e.m.

Dominant tree species	**Gradient type**	**ln $SOC_{0\text{-}20cm}$ [%]**	**ln soil $C:N_{0\text{-}10cm}$**	**$pH_{w,0\text{-}20cm}$**
Norway spruce	Soil moisture (n = 132)	slope = -0.3 ± 0.1 P = 0.02 R^2 = 0.031	P = 0.96	P = 0.88
	Productivity (n = 78)	slope = -0.5 ± 0.2 P < 0.01 R^2 = 0.111	slope = -1.9 ± 0.7 P = 0.01 R^2 = 0.065	slope = 0.6 ± 0.4 P = 0.09 R^2 = 0.025
Scots pine	Soil moisture (n = 141)	slope = -0.37 ± 0.09 P < 0.01 R^2 = 0.098	P = 0.77	slope = 0.6 ± 0.3 P = 0.03 R^2 = 0.026
	TEB (n = 59)	slope = -0.3 ± 0.1 P = 0.03 R^2 = 0.065	P = 0.86	P = 0.58
	Productivity (n = 67)	P = 0.31	P = 0.78	P = 0.71

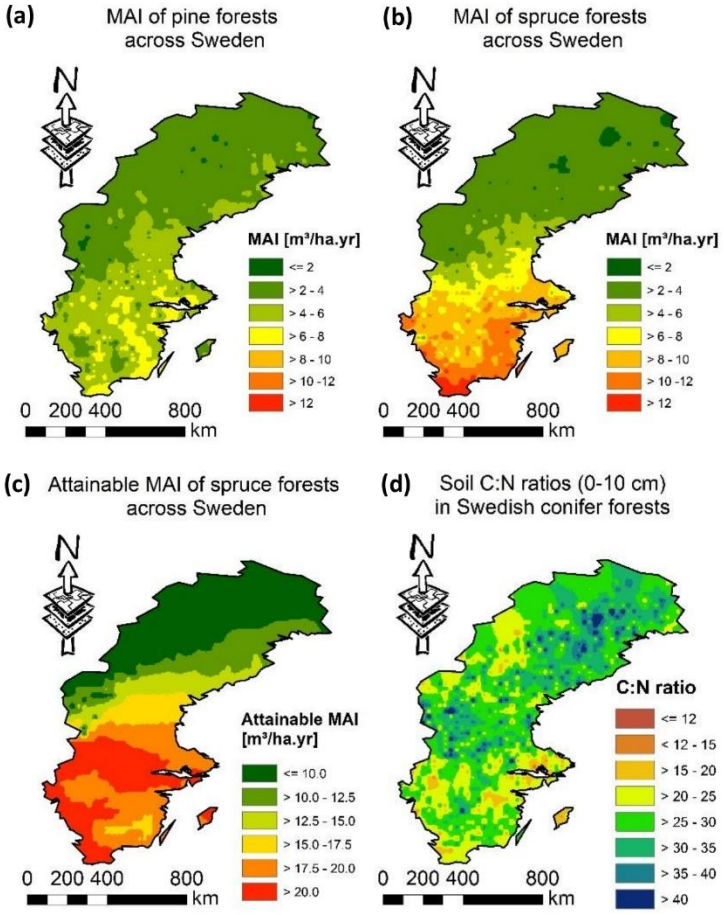

Figure S1. Productivities (mean annual increment - MAI) of (a) pine and (b) spruce, (c) attainable productivity for spruce (Bergh et al., 2005) and (d) soil carbon to nitrogen (C:N) ratio of conifer forests in Sweden.

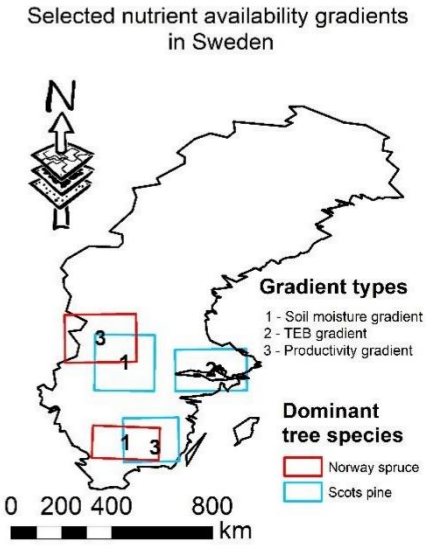

Figure S2. Overview of the selected nutrient availability gradients in Sweden. Gradients were selected by manually searching for regions with high spatial variation in either soil moisture, total exchangeable bases (TEB) or productivity for spruce and pine forests, using the ArcGIS software (ESRI, 2011). For Norway spruce, no TEB gradient without substantial variation in climate was found, so that only for Scots pine, there was a gradient in TEB. Each gradient consisted of ≥ 40 data points, and thus represented a sub-selection of the complete Swedish database.

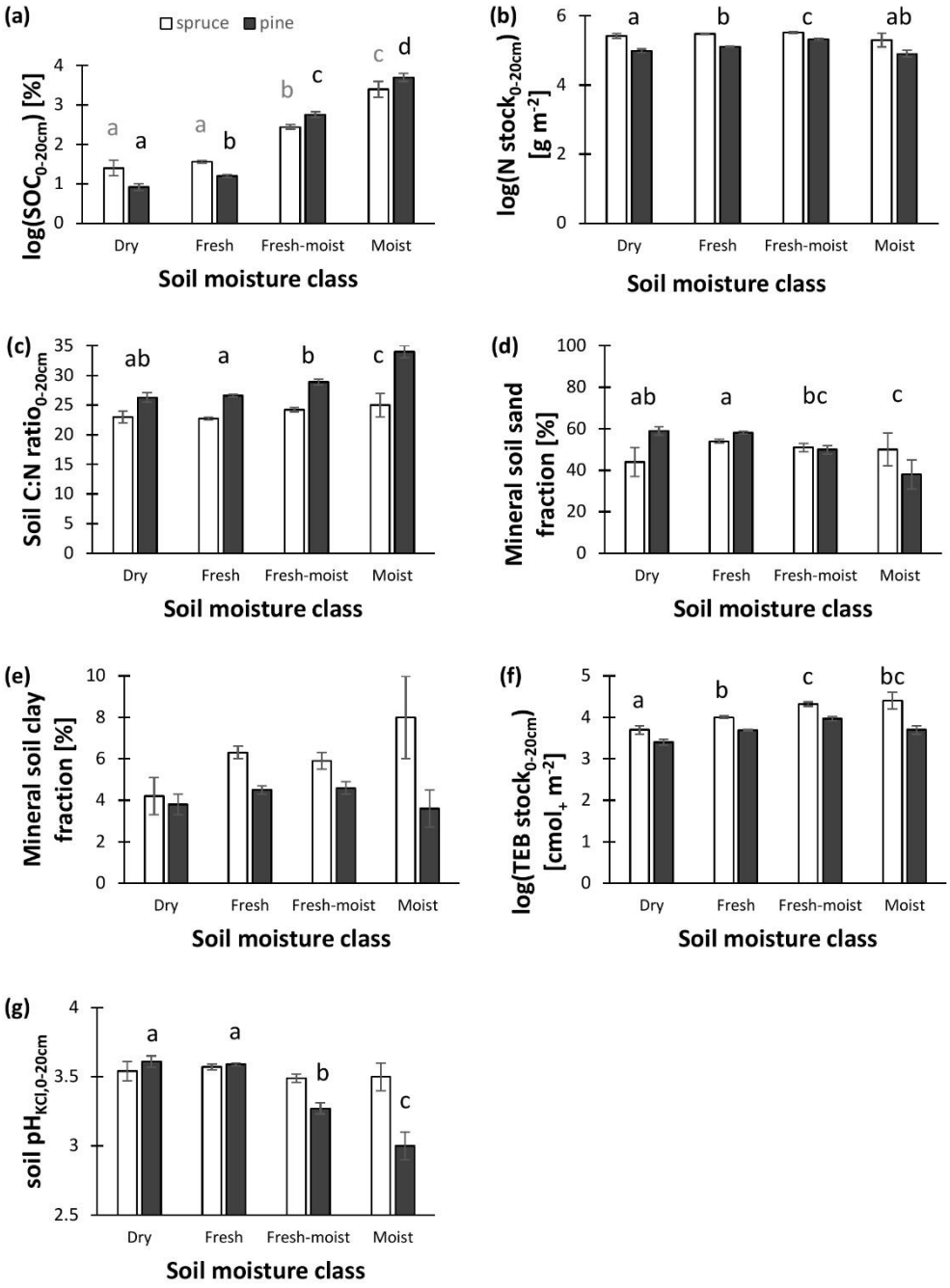

Figure S3. Soil conditions in spruce and pine forests with varying soil moisture. Abbreviations: SOC = soil organic carbon concentration; soil C:N ratio = soil carbon to nitrogen ratio; TEB = total exchangeable bases. Letters indicate statistical differences among moisture classes, either within spruce and pine forests (if the moisture x species interaction was included in the model after cross-validation) or for spruce and pine forests combined (if the moisture x species interaction was not included in the final model). Error bars represent the s.e.m.

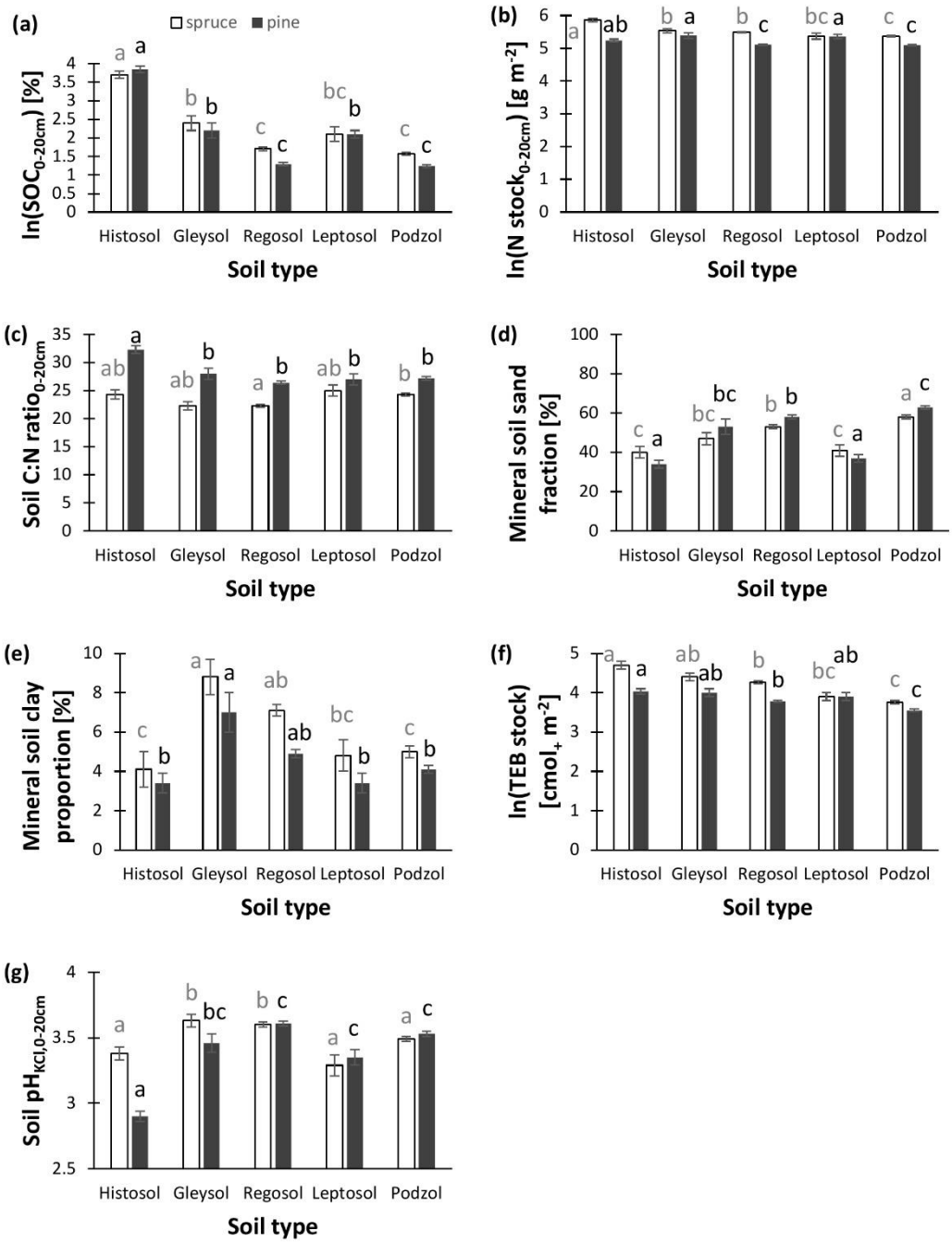

Figure S4. Soil conditions in spruce and pine forests for the most common soil types in Sweden. Abbreviations: SOC = soil organic carbon concentration; soil C:N ratio = soil carbon to nitrogen ratio; TEB = total exchangeable bases. Letters indicate statistical differences among soil types, for each panel within spruce and pine forests (the moisture x species interaction was included in each model after cross-validation). Error bars represent the s.e.m.

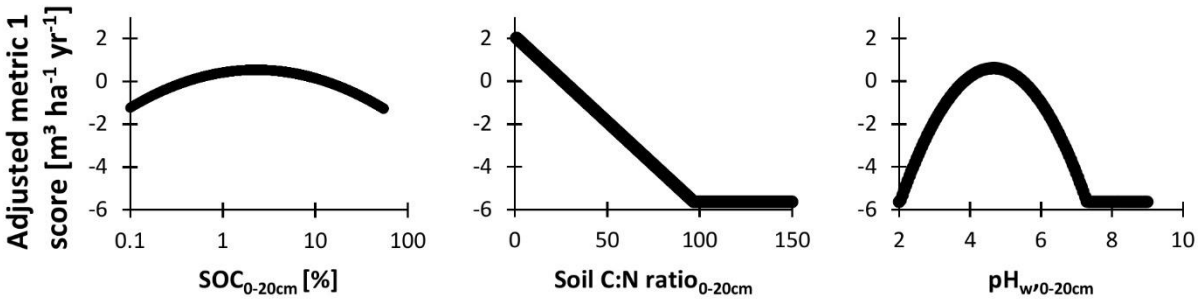

Figure S5. Adjusted soil scores in nutrient availability metric 1 for soil organic carbon concentration (SOC), soil carbon to nitrogen (C:N) ratio and pH measured in water (pH_w). Curves were drawn based on regression equations from Table S10. Minimum constraints were added to avoid artefacts if applied to other databases.

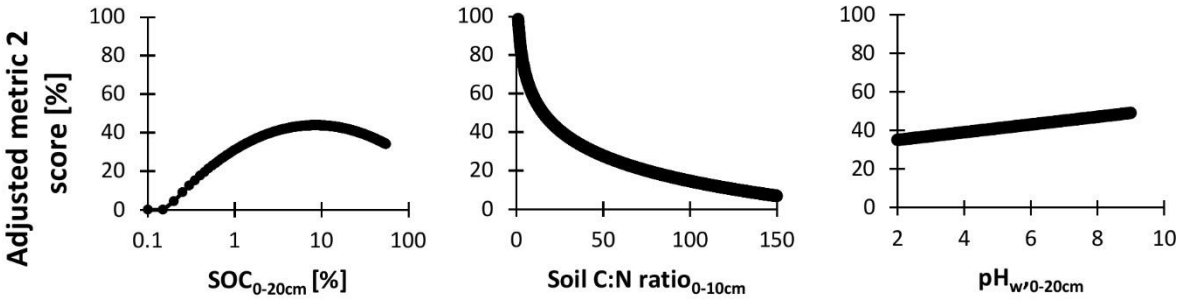

Figure S6. Adjusted soil scores in nutrient availability metric 2 for soil organic carbon concentration (SOC), soil carbon to nitrogen (C:N) ratio and pH measured in water (pH_w). Curves were drawn based on regression equations from Table S11. Minimum constraints were added to avoid artefacts if applied to other databases.