Supplementary material

RELATIONSHIPS OF THE NUTRIENT CONTENT OF THE SOIL WITH ATMOSPHERIC N DEPOSITION, CLIMATE, AND NEEDLE N, P AND S CONCENTRATIONS AND N:P RATIO

In the subsample of the 67 plots of the ICP Forests database containing long-term series of needle and soil-solution data, N bulk deposition was positively correlated with needle N and S concentrations and N:P ratio (Figs. S13, Table S7), and in the lineal models we observed that N bulk deposition had a positive relationship with needle N concentration and N:P ratio and a negative relationship with needle P concentration (Table S2). When we used throughfall N deposition from ICP Forests data we observed similar results than with bulk deposition data (Table S2, Table S3). In fact when we compared the througfall N data from the ICP Forests database with the corresponding bulk deposition data from EMEP we observed that the projected data from EMEP, at least in these set of studied European sites and *P. sylvestris* forests, could underestimate actual N and S deposition in most sites (Fig. S7). Bulk and throughfall N deposition were positively correlated with the concentrations of NO_3^-, K^+, and SO_4^{2-} in the soil solutions (Fig. S14 and S15, Tables S4 and S5), and in general the analysis results were very similar when using bulk deposition data from EMEP program than when using the corresponding throughfall deposition data from the ICP Forests Level II plots (Tables S2-S5).

Post-print of Sardans, Jordi et al. «Foliar and soil concentrations and stoichiometry of N and P across European *Pinus sylvestris* forests: relationships with climate, N deposition and tree growth» in Functional Ecology (Wiley). Vol 30, Issue 5 (May 2016), p. 676-689. The final version is available at DOI 10.1111/1365-2435.12541

Table S1. Results of the GLM analyses without and with spatial correction (upper and lower cells), with needle N and P concentrations and N:P ratio as dependent variables and climatic (MAP and MAT) variables and N deposition (EMEP model) and their significant interactions as independent variables, in the studied 2245 *P. sylvestris* stands across Europe. The letter b indicates the slope of the corresponding factor, t= t-Student z = Z-statistic. The corresponding percentage of the explained total variance of each significant independent factor or interaction is also shown. Bold type indicates factor statistical significant effect at P < 0.05 level.

Dependent variables								
	Log MAP	Log MAT	Log N dep.	Log MAP^Log MAT	Log MAP^Log N dep.	Log MAT^Log N dep.	Log MAP^Log MAT^Log N dep.	Whole model
Log [N]	**b = - 0.27** **t = - 12.5** ***P* < 0.0001** **7.0%**	b = - 0.0012 t = 0.097 *P* = 0.92	**b = 0.18** **t = 4.87** ***P* < 0.0001** **1.1%**	NS	NS	NS	NS	***R* = 0.27** ***P* < 0.0001** **AIC = -4301**
	b = - 0.255 **z = - 12.2** ***P* < 0.00001**	b = - 0.019 z = - 1.019 *P* = 0.29	**b = 0.078** **z = 5.50** ***P* < 0.00001**	NS	NS	NS	NS	**z = -62.3** ***P* < 0.00001** **AIC = -4428.5**
Log [P]	**b = - 6.79** **t = - 7.44** ***P* < 0.0001** **2.5%**	**b = - 23.3** **t = - 8.86** ***P* < 0.0001** **3.4%**	**b = - 6.18** **t = - 6.28** ***P* < 0.0001** **1.8%**	**b = 8.83** **t = 9.20** ***P* < 0.0001** **3.7%**	**b = 2.40** **t = 6.86** ***P* < 0.0001** **2.1%**	**b = 8.41** **t = 8.61** ***P* < 0.0001** **3.3%**	**b = - 3.20** **t = - 9.16** ***P* < 0.0001** **3.7%**	**R = 0.48** ***P* < 0.0001** **AIC = -3566.1**
	b = - 6.93 **z = - 7.45** ***P* < 0.0001** **2.5%**	**b = - 23.9** **z = - 8.74** ***P* < 0.0001** **3.4%**	**b = - 6.27** **z = - 6.33** ***P* < 0.0001** **1.8%**	**b = 9.03** **z = 9.08** ***P* < 0.0001** **3.7%**	**b = 8.58** **z = 6.91** ***P* < 0.0001** **2.1%**	**b = 2.44** **z = 8.59** ***P* < 0.0001** **3.3%**	**b = - 3.26** **z = - 9.12** ***P* < 0.0001** **3.7%**	**R = 0.48** ***P* < 0.0001** **AIC = -3605.8**
Log N:P ratio	**b = 5.01** **t = 6.15** ***P* < 0.0001** **1.7%**	**b = 17.3** **t = 7.39** ***P* < 0.0001** **2.5%**	**b = 4.19** **t = 4.77** ***P* < 0.0001** **1.2%**	**b = - 6.65** **t = - 7.77** ***P* < 0.0001** **2.7%**	**b = - 1.66** **t = - 5.31** ***P* < 0.0001** **1.3%**	**b = - 5.74** **t = - 6.59** ***P* < 0.0001** **2.2%**	**b = 2.23** **t = 7.16** ***P* < 0.0001** **2.3%**	**R = 0.43** ***P* < 0.0001** **AIC = -4080.7**
	b = 4.60 **z = 5.36** ***P* < 0.0001** **2.5%**	**b = 15.0** **z = 6.13** ***P* < 0.0001** **3.4%**	**b = -3.91** **z = 4.27** ***P* < 0.0001** **2.8%**	**b = -5.80** **z = 6.50** ***P* < 0.0001** **3.7%**	**b = -1.55** **z = -4.74** ***P* < 0.0001** **2.1%**	**b = 2-5.03** **z = -5.58** ***P* < 0.0001** **3.3%**	**b = 1.98** **z = 6.11** ***P* < 0.0001** **3.7%**	**R = 0.48** ***P* < 0.0001** **AIC = -4134.1**

NS = **not significant**

Table S2. Results of the GLM without and with spatial correction (upper and lower cells), with needle N, P, and S concentrations and N:P ratio as dependent variables and climatic (MAP and MAT) variables and N deposition (EMEP model) and their significant interactions as independent variables, in 167S12 European *P. sylvestris* stands monitored by the ICP Forests Level II programme. The letter b indicates the slope of the corresponding factor, t= t-Student z = Z-statistic. Bold type indicates factor statistical significant effect at P < 0.05 level.

Dependent variables	Independent variables							
	Log MAP	Log MAT	Log N dep.	Log MAP^Log MAT	Log MAP^Log N dep.	Log MAT^Log N dep.	Log MAP^Log MAT^Log N dep.	Whole model
Log needle [N]	**b = - 1.39** **t = - 3.28** ***P* = 0.0017**	**b = - 2.07** **t = - 3.23** ***P* = 0.002**	**b = 0.11** **t = 4.27** ***P* < 0.0001**	**b = 0.78** **t = 3.29** ***P* = 0.0017**	NS	NS	NS	**R = 0.85** ***P* < 0.0001** **AIC = -233.05**
	b = - 1.3 **z = - 3.05** ***P* = 0.00123**	**b = - 1.92** **z = - 2.96** ***P* = 0.003**	**b = 0.11** **z = 4.24** ***P* < 0.0001**	**b = 0.72** **z = 3.01** ***P* = 0.0026**	NS	NS	NS	**AIC = -236.81**
Log needle [P]	**b = - 1.02** **t = - 3.02** ***P* = 0.0037**	**b = - 1.65** **t = - 3.25** ***P* = 0.0019**	**b = -0.11** **t = - 2.52** ***P* = 0.014**	**b = 0.6** **t = 3.25** ***P* = 0.0019**	**b = 0.4** **t = 2.54** ***P* = 0.014**	**b = 0.65** **t = 2.80** ***P* = 0.0068**	**b = - 0.24** **t = - 2.81** ***P* = 0.0067**	**R = 0.46** ***P* = 0.04** **AIC = -201.65**
	b = - 0.93 **z = - 2.83** ***P* = 0.00123**	**b = - 1.53** **z = - 3.06** ***P* = 0.003**	**b = -0.09** **z = -2.31** ***P* < 0.0001**	**b = 0.58** **z = 3.08** ***P* = 0.0026**	**b = 0.36** **z = 2.34** ***P* = 0.003**	**b = 0.58** **z = 2.61** ***P* < 0.0001**	**b = -0.21** **z = -2.63** ***P* = 0.0026**	**AIC = -206.3**
Log needle N:P ratio	**b = 0.78** **t = 2.27** ***P* = 0.27**	**b = 1.19** **t = 2.31** ***P* = 0.024**	**b = 0.096** **t = 2.15** ***P* = 0.036**	**b = - 0.44** **t = - 2.35** ***P* = 0.022**	**b = - 0.35** **t = - 2.17** ***P* = 0.034**	**b = - 0.53** **t = - 2.28** ***P* = 0.026**	**b = 1.97** **t = 2.33** ***P* = 0.023**	**R = 0.61** ***P*< 0.0001** **AIC = -199.55**
	b = 0.77 **z = 2.29** ***P* = 0.00123**	**b = 1.17** **z = 2.31** ***P* = 0.003**	**b = 0.094** **z = 2.19** ***P* < 0.0001**	**b = -0.43** **z = -2.35** ***P* = 0.0026**	**b = -0.35** **z = -2.22** ***P* = 0.003**	**b = -0.53** **z = -2.31** ***P* < 0.0001**	**b = 1.95** **z = 2.36** ***P* = 0.0026**	**AIC = -201.57**
Log needle [S, mg g^{-1}]	**b = - 1.52** **t = - 2.52** ***P* = 0.014**	**b =- 2.85** **t = - 3.42** ***P* = 0.0011**	**b = - 0.30** **t = - 2.23** ***P* = 0.030**	**b = 0.88** **t = 2.64** ***P* = 0.011**	NS	**b = 0.21** **t = 2.93** ***P* = 0.0047**	NS	**R =0.83** ***P*< 0.0001** **AIC = -204.99**
	b = -1.02 z = -1.77 P = 0.076	**b = -2.47** **z = 2.31** **P = 0.013**	b = -0.199 z = -1.63 P = 0.1	b = 0.60 z = 1.85 P = 0.065	NS	**b = 0.18** **z = 2.72** ***P* = 0.0065**	NS	**AIC =** = -212.74

NS = **n**ot significant

Table S3. Results of the GLM without and with spatial correction (upper and lower cells), with needle N, P, and S concentrations and N:P ratio as dependent variables and climatic (MAP and MAT) variables and throughfall N deposition (ICP) and their significant interactions as independent variables, in 55 European *P. sylvestris* stands monitored by the ICP Forests Level II programme. The letter b indicates the slope of the corresponding factor, t= t-Student z = Z-statistic. Bold type indicates factor statistical significant effect at P < 0.05 level.

Dependent variables	Independent variables							
	Log MAP	Log MAT	Log N dep.	Log MAP^Log MAT	Log MAP^Log N dep.	Log MAT^Log N dep.	Log MAP^Log MAT^Log N dep.	Whole model
Log needle [N]	**b = - 0.12** **t = - 2.23** ***P* = 0.030**	b = 0.027 t = 0.94 *P* = 0.35	**b = 0.14** **t = 4.67** ***P* < 0.0001**	NS	NS	NS	NS	**R = 0.80** ***P* < 0.0001** **AIC = -169.41**
	b = - 0.12 **z = - 2.25** ***P* = 0.013**	b = 0.027 z = 0.85 *P* = 0.40	**b = 0.14** **z = 4.24** ***P* < 0.0001**	NS	NS	NS	NS	**AIC = -167.67**
Log needle [P]	**b = - 0.13** **t = - 2.58** ***P* = 0.012**	**b = - 0.00065** **t = - 3.2** ***P* = 0.0024**	**b = 0.011** **t = 2.09** ***P* = 0.042**	**b = 0.08** **t = 3.19** ***P* = 0.0025**	**b = -0.04** **t = -2.07** ***P* = 0.044**	NS	NS	**R = 0.45** ***P* = 0.044** **AIC = -170.94**
	b = - 0.13 **z = - 2.74** ***P* = 0.0062**	**b = - 0.00065** **z = - 3.39** ***P* = 0.0007**	**b = 0.011** **z = 2.21** ***P* = 0.021**	**b = 0.08** **z = 3.37** ***P* = 0.0007**	**b = -0.04** **z = -2.19** ***P* = 0.029**	NS	NS	**AIC = -168.94**
Log needle N:P ratio	b = -0.05 t = -0.98 *P* = 0.33	b = 0.04 t = 1.4 *P* = 0.16	**b = 0.12** **t = 3.99** ***P* = 0.00021**	**NS**		NS	NS	**R = 0.83** ***P*< 0.0001** **AIC = -156.99**
	b = -0.05 z = -0.92 *P* = 0.41	b = 0.04 z = 1.5 *P* = 0.11	**b = 0.12** **z = 3.56** ***P* = 0.001**	NS		NS	NS	**AIC = -154.84**
Log needle [S, mg g^{-1}]	**b = - 0.14** **t = - 1.88** ***P* = 0.066**	b = 0.007 t = 0.18 *P* = 0.86	**b = 0.17** **t = 4.07** ***P* = 0.00017**	NS	NS	NS	NS	**R =0.69** ***P*< 0.0001** **AIC = -204.99**
	b = - 0.14 **z = -2.77** **P = 0.0057**	b = 0.007 z = 0.13 *P* = 0.89	**b = 0.17** **z = 2.83** ***P* = 0.0046**	NS	NS	NS	NS	**AIC = -212.74**

NS = **n**ot significant

Table S4. Results of the GLM analyses without and with spatial correction (upper and lower cells), with soil chemical traits as dependent variables and climatic (MAP and MAT) variables and N deposition (EMEP model) and their significant interactions as independent variables, in 54-67 European *P. sylvestris* stands monitored by the ICP Forests Level II programme. The letter b indicates the slope of the corresponding factor, t= t-Student z = Z-statistic.. The corresponding percentage of the explained total variance of each significant independent factor or interaction is also shown. Bold type indicates factor statistical significant effect at $P < 0.05$ level.

Dependent variables	Independent variables							
	Log MAP	Log MAT	Log N dep.	Log MAP^Log MAT	Log MAP^Log N dep.	Log MAT^Log N dep.	Log MAP^Log MAT^Log N dep.	Whole model
Log total soil [N]	**b = 0.59** **t = 2.09** ***P* = 0.041** **7.0%**	b = - 0.026 t = - 0.25 *P* = 0.81	b = 0.11 t = 0.88 *P* = 0.32	NS	NS	NS	NS	***R* = 0.38** ***P* = 0.038** **AIC = -21.16**
	b = 0.48 **z = 1.81** ***P* = 0.070**	b = - 0.080 z = - 0.89 *P* = 0.37	b = 0.12 z = 1.05 *P* = 0.29	NS	NS	NS	NS	**AIC = -22.93**
Log [Olsen P]	**b = 0.43** **t = 4.28** ***P* = 0.029** **8.0%**	b = 0.037 t = 0.51 *P* = 0.50	**b = - 0.23** **t = - 2.95** ***P* = 0.005** **13.8%**	NS	NS	NS	NS	***R* = 0.50** ***P* = 0.0021** **AIC = -64.593**
	b = 0.43 **z = 2.45** ***P* = 0.014**	b = 0.035 z = 0.53 *P* = 0.60	**b = -0.24** **z = -3.09** ***P* = 0.002**	NS	NS	NS	NS	**AIC = -66.937**
Log total soil N:Olsen P ratio	b = 0.15 t = 0.35 *P* = 0.67	b = - 0.03 t = - 0.22 *P* = 0.82	**b = 0.31** **t = 2.14** ***P* = 0.037** **7.4%**	NS	NS	NS	NS	***R* = 0.44** ***P* = 0.011** **AIC = 0.647**
	b = 0.031 z = 0.096 *P* = 0.92	b = - 0.058 z = - 0.48 *P* = 0.63	**b = 0.33** **z = 2.32** ***P* = 0.02**	NS	NS	NS	NS	**AIC = - 1.4753**
Log soil [K]	b = - 0.93 t = - 1.86 *P* = 0.069	b = 0.011 t = 0.059 *P* = 0.59	b = 0.22 t = 0.20 *P* = 0.26	NS	NS	NS	NS	*R* = 0.30 *P* = 0.18 AIC = 35.572
	b = - 1.07 **z = - 2.44** ***P* = 0.015**	b = 0.047 z = 0.3 *P* = 0.76	b = *0.35* *z = 1.83* *P <= 0.067*	NS	NS	NS	NS	AIC = 30.106

Log soil [Ca]	b = - 0.34 t = - 1.36 *P* = 0.18	b = 0.14 t = 1.56 *P* = 0.13	b = - 0.14 t = - 1.44 *P* = 0.16	NS	NS	NS	NS	*R* = 0.28 *P* = 0.24 AIC = -42.701
	b = - 0.34 z = - 1.92 *P* = 0.055	b = 0.13 z = 1.57 *P* = 0.12	b = - 0.11 z = - 1.13 *P* = 0.26	NS	NS	NS	NS	AIC = -45.035
Log soil [Mg]	b = 0.042 t = 0.097 *P* = 0.92	b = 0.20 t = 1.29 *P* = 0.20	b = - 0.30 t = - 1.75 *P* = 0.087	NS	NS	NS	NS	*R* = 0.24 *P* = 0.39 AIC = 20.892
	b = - 0.086 z = - 0.21 *P* = 0.83	b = 0.28 z = 1.95 *P* = 0.051	b = - 0.22 z = - 1.29 *P* = 0.20	NS	NS	NS	NS	AIC = 18.046
Log soil-solution [NO_3^-]	b = - 1.29 t = - 1.14 *P* = 0.11	b = 0.53 t = 1.67 *P* = 0.10	**b = 1.60** **t = 5.05** ***P* < 0.0001** **15.9%**	NS	NS	NS	NS	***R* = 0.78** ***P* < 0.0001** **AIC = 125.13**
	b = - 1.13 **z = -1.48** ***P* = 0.14**	**b = 0.65** **z = 2.27** ***P* = 0.023**	**b = 1.61** **z = 5.09** ***P* < 0.0001**	NS	NS	NS	NS	**AIC = 124.84**
Log soil-solution NO_3^-:Olsen P ratio	**b = - 2.03** **t = - 2.077** ***P* = 0.043** **8%**	b = 0.37 t = 1.03 *P* = 0.32	**b = 2.01** **t = 5.11** ***P* < 0.0001** **16.9%**	NS	NS	NS	NS	***R* = 0.80** ***P* < 0.0001** **AIC = 110.98**
	b = - 1.84 **z = - 2.0** ***P* = 0.045**	b = 0.47 z = 1.36 *P* = 0.17	**b = 2.10** **z = 5.28** ***P* < 0.0001**	NS	NS	NS	NS	AIC = 110.24
Log soil-solution [P]	**b = - 1.99** **t = - 2.15** ***P* = 0.038** **8.2%**	b = - 0.10 t = - 0.27 *P* = 0.79	b = 1.20 t = 2.7 *P* = 0.10 12.9%	NS	NS	NS	NS	***R* = 0.57** ***P* = 0.0015** **AIC = 91.98**
	b = - 1.83 **z = - 2.0** ***P* = 0.043**	b = - 0.09 z = 1.06 *P* = 0.27	b = 1.10 z = 2.28 *P* = 0.24	NS	NS	NS	NS	AIC = 90.24
Log soil-solution NO_3^-:P ratio	b = 1.4 t = 1.54 *P* = 0.13	**b = - 6.67** **t = - 3.21** ***P* = 0.0027** **14.0%**	**b = - 5.84** **t = - 3.27** ***P* = 0.0023** **14.5%**	**b = 3.22** **t = 3.6** ***P* = 0.009** **17.5%**	NS	NS	NS	***R* = 0.71** ***P* < 0.0001** **AIC = 111.04**
	b = 1.83	**b = - 6.09**	**b = - 5.10**	**b = 3.30**	NS	NS	NS	**AIC = 109.34**

	z = 1.43 *P* = 0.43	**z = - 3.06** ***P* = 0.007**	**z = - 3.28** ***P* = 0.0024**	**z = 3.8** ***P* = 0.001**				
Log soil-solution [SO_4^{2-}]	**b = - 1.65** **t = - 4.17** ***P* < 0.0001** **9.0%**	**b = - 2.66** **t = - 3.09** ***P* = 0.003** **4.9%**	**b = - 1.55** **t = - 2.13** ***P* = 0.037** **2.3%**	NS	NS	**b = 1.28** **t = 3.44** ***P* = 0.0010** **6.1%**	NS	***R* = 0.83** ***P* < 0.0001**
	b = - 1.63 **z = - 4.50** ***P* = 0.0004**	**b = - 2.42** **z = - 3.78** ***P* = 0.005**	**b = - 1.53** **z = - 2.33** ***P* = 0.02**	NS	NS	**b = 1.28** **z = 3.44** ***P* = 0.0010**	NS	
Log soil-solution [K^+]	**b = - 1.43** **t = - 2.96** ***P* < 0.0001**	b = 0.34 t = 1.75 *P* =0.0009	**b = 0.30** **t = 2.56** ***P* = 0.015**	NS	NS	NS	NS	***R* = 0.46** ***P* = 0.04** **AIC = 57.492**
	b = - 1.48 **z = -3.50** ***P* = 0.0004**	**b = 0.42** **z = 2.78** ***P* = 0.005**	**b = 0.43** **z = 2.33** ***P* = 0.02**	NS	NS	NS	NS	**AIC = 49.358**
Log soil-solution [Ca^{2+}]	**b = - 2.38** **t = - 4.20** ***P* < 0.0001**	**b = 0.52** **t = 2.29** ***P* = 0.025**	**b = 0.45** **t = 2.02** ***P* = 0.048**	NS	NS	NS	NS	***R* = 0.83** ***P* < 0.0001** **AIC = 78.89**
	b = - 2.48 **z = - 5.09** ***P* < 0.0001**	**b = 0.67** **z = 3.90** ***P* < 0.0001**	**b = 0.63** **z = 3.0** ***P* = 0.002**	NS	NS	NS	NS	**AIC = 68.327**

NS = **n**ot significant

Table S5. Results of the GLM analyses without and with spatial correction (upper and lower cells), with soil chemical traits as dependent variables and climatic (MAP and MAT) variables and throughfall N deposition (ICP) and their significant interactions as independent variables, in 36 European *P. sylvestris* stands monitored by the ICP Forests Level II programme. The letter b indicates the slope of the corresponding factor, t= t-Student z = Z-statistic. The corresponding percentage of the explained total variance of each significant independent factor or interaction is also shown. Bold type indicates factor statistical significant effect at $P < 0.05$ level.

Dependent variables	Independent variables							
	Log MAP	Log MAT	Log N dep.	Log MAP^Log MAT	Log MAP^Log N dep.	Log MAT^Log N dep.	Log MAP^Log MAT^Log N dep.	Whole model
Log total soil [N]	b = 0.38 t = 1.68 *P* = 0.10	b = - 0.009 t = - 0.11 *P* = 0.92	b = 0.11 t = 0.63 *P* = 0.53	NS	NS	NS	NS	***R* = 0.46** ***P* = 0.057** **AIC = -27.327**
	b = 0.38 z = 1.47 *P* = 0.14	b = - 0.009 z = - 0.08 *P* = 0.94	b = 0.11 z = 0.74 *P* = 0.46	NS	NS	NS	NS	**AIC = -21.956**
Log [Olsen P]	**b = 0.43** **t = 2.4** ***P* = 0.023** **8.0%**	b = 0.008 t = 1.21 *P* = 0.24	**b = - 0.27** **t = - 3.62** ***P* = 0.001** **16%**	NS	NS	NS	NS	***R* = 0.54** ***P* = 0.011** **AIC = -43.149**
	b = 0.43 **z = 21.38** ***P* = 0.17**	b = 0.008 z = 1.30 *P* = 0.19	**b = -0.27** **z = -3.51** ***P* = 0.00045**	NS	NS	NS	NS	**AIC = -42.127**
Log soil [K]	b = - 0.26 t = - 0.74 *P* = 0.47	b = - 0.009 t = - 0.71 *P* = 0.48	b = 0.12 t = 0.86 *P* = 0.39	NS	NS	NS	NS	*R* = 0.314 *P* = 0.88 AIC = 5.4114
	b = - 0.26 **z = - 0.92** ***P* = 0.36**	b = - 0.009 z = - 0.72 *P* = 0.47	b = 0.12 z = 0.97 P = 0.33	NS	NS	NS	NS	AIC = 7.1963
Log soil [Ca]	**b = - 0.52** **t = - 2.24** ***P* = 0.032** **7%**	b = 0.01 t = 0.89 *P* = 0.38	b = 0.023 t = 0.30 *P* = 0.77	NS	NS	NS	NS	*R* = 0.39 *P* = 0.15 AIC = -43.149
	b = 0.23 z = 1.37 *P* = 0.17	b = 0.01 z = 1.30 *P* = 0.19	**b = - 0.023** **z = - 3.5** ***P* = 0.00045**	NS	NS	NS	NS	AIC = -42.127
Log soil [Mg]	b = 0.021	b = 0.027	b = - 0.26	NS	NS	NS	NS	*R* = 0.20

	t = 0.002 *P* = 0.99	t = 0.74 *P* = 0.47	t = - 0.93 *P* = 0.36					*P* = 0.73 AIC = 24.256
	b = - 0.024 z = - 0.55 *P* = 0.57	b = 0.028 z = 0.61 *P* = 0.54	b = - 0.22 z = - 0.50 *P* = 0.62	NS	NS	NS	NS	AIC = 23.983
Log soil-solution $[NO_3^-]$	b = - 0.38 t = - 1.96 *P* = 0.056	b = 0.01 t = 0.90 *P* = 0.37	**b = 0.11** **t = 4.6** ***P* < 0.0001** **14.8%**	NS	NS	NS	NS	***R* = 0.75** ***P* < 0.0001** **AIC = 68.74**
	b = - 0.38 **z = -2.12** ***P* = 0.034**	**b = 0.01** **z = 0.95** ***P* = 0.34**	**b = 0.11** **z = 4.8** ***P* < 0.0001**	NS	NS	NS	NS	**AIC = 70.704**
Log soil-solution NO_3^-:Olsen P ratio	**b = - 2.15** **t = - 3.24** ***P* = 0.0028** **11%**	b = 0.11 t = 0.97 *P* = 0.34	**b = 1.56** **t = 6.7** ***P* < 0.0001** **18.1%**	NS	NS	NS	NS	***R* = 0.88** ***P* < 0.0001** **AIC = 55.183**
	b = - 2.15 **z = - 3.37** ***P* = 0.0008**	b = 0.11 z = 0.99 *P* = 0.32	**b = 1.56** **z = 57.09** ***P* < 0.0001**	NS	NS	NS	NS	AIC = 57.078
Log soil-solution $[SO_4^{2-}]$	**b = - 1.25** **t = - 3.47** ***P* = 0.0013** **8.0%**	b = - 0.11 t = - 0.84 *P* = 0.40	**b = 0.98** **t = 6.59** ***P* < 0.0001** **15%**	NS	NS	NS	NS	***R* = 0.79** ***P* < 0.0001** **AIC = 15.6**
	b = - 1.25 **z = - 3.65** ***P* = 0.00026**	b = - 0.11 z = - 1.12 *P* = 0.26	**b = 0.98** **z = 7.26** ***P* < 0.0001**	NS	NS	NS	NS	**AIC = 16.96**
Log soil-solution $[K^+]$	**b = - 0.68** **t = - 2.58** ***P* < 0.0001**	b = -0.03 t = - 0.51 *P* =0.61	**b = 1.51** **t = 3.88** ***P* = 0.00041** **12%**	NS	NS	NS	NS	***R* = 0.60** ***P* = 0.00077** **AIC = 27.82**
	b = - 0.68 **z = -2.71** ***P* = 0.0067**	b = -0.03 **z = - 0.59** ***P* = 0.58**	**b = 1.51** **z = 4.13** ***P* < 0.0001**	NS	NS	NS	NS	**AIC = 29.788**
Log soil-solution $[Ca^{2+}]$	**b = - 1.77** **t = - 3.43** ***P* =0.0015**	**b = 0.10** **t = 0.82** ***P* = 0.41**	**b = 1.98** **t = 3.63** ***P* = 0.00084** **13.5%**	NS	NS	NS	NS	***R* = 0.68** ***P* < 0.0001** **AIC =44.353**
	b = - 1.77 **z = - 3.73** ***P* =0.00019**	**b = 0.10** **z = 0.85** ***P* =0.39**	**b = 1.98** **z = 3.38** ***P* =0.00016**	NS	NS	NS	NS	**AIC = 46.039**

Table S6. Results of the GLM without and with spatial correction (upper and lower cells), with needle N, P, and S concentrations and N:P ratios as dependent variables and climatic (MAP and MAT) variables and soil-solution NO_3^- concentrations and their significant interactions as independent variables, in 67 European *P. sylvestris* stands monitored by the ICP Forests Level II programme. The letter b indicates the slope of the corresponding factor, t= t-Student z = Z-statistic. Bold type indicates factor statistical significant effect at P < 0.05 level.

Dependent variables	Independent variables							
	Log MAP	Log MAT	Log soil-solution [NO_3^-]	Log MAP^Log MAT	Log MAP^Log soil-solution [NO_3^-]	Log MAT^ Log soil-solution [NO_3^-]	Log MAP^Log MAT^ Log soil-solution [NO_3^-]	Whole model
Log needle [N, %]	**b = - 1.82** **t = - 4.65** ***P* < 0.0001**	**b = - 2.76** **t = - 4.70** ***P* < 0.0001**	**b = 0.032** **t = 4.19** ***P* < 0.0001**	**b = 1.04** **t = 4.82** ***P* < 0.0001**	NS	NS	NS	**R = 0.85** ***P* < 0.0001**
Log needle [P, mg g^{-1}]	**b = 4.48** **t = 2.29** ***P* = 0.026**	**b = 6.52** **t = 2.29** ***P* = 0.026**	**b = - 7.1** **t = - 2.26** ***P* = 0.0079**	**b = - 2.35** **t = - 2.29** ***P* = 0.026**	**b = 2.56** **t = 2.75** ***P* = 0.0079**	**b = 3.55** **t = 2.65** ***P* = 0.010**	**b = - 1.29** **t = - 2.65** ***P* = 0.010**	**R = 0.20** ***P* = 0.049**
Log needle N:P ratio	**b = - 8.56** **t = - 4.54** ***P* < 0.0001**	**b = - 12.6** **t = - 4.60** ***P* < 0.0001**	**b = 10.7** **t = 4.32** ***P* < 0.0001**	**b = 4.61** **t = 4.67** ***P* < 0.0001**	**b = - 3.87** **t = - 4.32** ***P* < 0.0001**	**b = - 5.59** **t = - 4.34** ***P* < 0.0001**	**b = 2.03** **t = 4.34** ***P* < 0.0001**	**R = 0.80** ***P* < 0.0001**
Log needle [S, mg g^{-1}]	**b = - 2.05** **t = - 4.28** ***P* < 0.0001**	**b = - 3.38** **t = - 4.80** ***P* < 0.0001**	**b = 0.085** **t = 5.1** ***P* < 0.0001**	**b = 1.25** **t = 4.83** ***P* < 0.0001**	NS	NS	NS	**R = 0.81** ***P* < 0.0001**

NS = **n**ot significant

Table S7. Correlations among the elemental and ionic concentrations and ratios of needles and soil solutions in 67 European *P. sylvestris* stands monitored by the ICP Forests Level II programme. In the multiple correlations, we used false discovery rate to correct the alpha inflation (García, 2004). Bold type indicates factor statistical significant effect at $P < 0.001$ level.

	Coordinates		Soil solution				Needle chemistry							Abiotic gradients		
	Latitude	Longitude	Log [NO_3^-]	Log [K^+]	Log [Ca^{2+}]	Log [SO_4^{2-}]	Log [N]	Log [P]	Log [K]	Log [Ca]	Log [Mg]	Log [S]	Log N:P ratio	Log MAP	Log MAT	Log N deposition
Latitude		***R*=0.71 *P*<0.001**	***R*=-0.63 *P*<0.001**	***R*=-0.43 *P*<0.001**	***R*=-0.48 *P*<0.001**	***R*=-0.55 *P*<0.001**	***R*=-0.61 *P*<0.001**	*R*=0.021 *P*=0.87	***R*=-0.42 *P*<0.001**	*R*=-0.33 *P*=0.006	*R*=0.24 *P*=0.05	***R*=-0.5917 *P*<0.001**	***R*=-0.60 *P*<0.001**	*R*=-0.31 *P*=0.01	*R*=-0.78 *P*<0.001	***R*=-0.81 *P*<0.001**
Longitude			***R*=-0.57 *P*<0.001**	*R*=-0.17 *P*=0.18	*R*=-0.27 *P*=0.026	*R*=-0.34 *P*=0.005	***R*=-0.56 *P*<0.001**	*R*=0.042 *P*=0.74	*R*=-0.37 *P*=0.002	*R*=-0.048 *P*=0.70	*R*=0.32 *P*=0.008	***R*=-0.61 *P*<0.001**	***R*=-0.57 *P*<0.001**	***R*=-0.54 *P*<0.001**	***R*=-0.57 *P*<0.001**	***R*=-0.55 *P*<0.001**
Log [NO_3^-]				***R*=0.54 *P*<0.001**	***R*=0.67 *P*<0.001**	***R*=0.68 *P*<0.001**	***R*=0.730 *P*<0.001**	*R*=0.14 *P*=0.26	*R*=0.31 *P*=0.010	*R*=0.17 *P*=0.16	***R*=-0.44 *P*<0.001**	***R*=0.64 *P*<0.001**	***R*=0.62 *P*<0.001**	*R*=0.09 *P*=0.45	***R*=0.66 *P*<0.001**	***R*=0.76 *P*<0.001**
Log [K^+]					***R*=0.79 *P*<0.001**	***R*=0.60 *P*<0.001**	*R*=0.361 *P*=0.003	*R*=0.17 *P*=0.17	*R*=0.37 *P*=0.002	*R*=0.069 *P*=0.58	*R*=-0.071 *P*=0.57	*R*=0.34 *P*=0.005	*R*=0.24 *P*=0.055	*R*=-0.17 *P*=0.17	***R*=0.40 *P*=0.001**	***R*=0.41 *P*=0.001**
Log [Ca^{2+}]						***R*=0.76 *P*<0.001**	***R*=0.49 *P*<0.001**	*R*=0.29 *P*=0.016	*R*=0.30 *P*=0.013	*R*=0.33 *P*=0.006	*R*=-0.089 *P*=0.48	***R*=0.53 *P*<0.001**	*R*=0.27 *P*=0.027	*R*=-0.24 *P*=0.056	***R*=0.46 *P*<0.001**	***R*=0.48 *P*<0.001**
Log [SO_4^{2-}]							***R*=0.66 *P*<0.001**	*R*=0.30 *P*=0.014	*R*=0.31 *P*=0.010	*R*=0.22 *P*=0.078	*R*=-0.35 *P*=0.004	***R*=0.71 *P*<0.001**	***R*=0.44 *P*<0.001**	*R*=-0.11 *P*=0.38	***R*=0.59 *P*<0.001**	***R*=0.72 *P*<0.001**
Log [N]								*R*=0.32 *P*=0.009	***R*=0.43 *P*<0.001**	*R*=0.083 *P*=0.50	***R*=-0.43 *P*<0.001**	***R*=0.85 *P*<0.001**	***R*=0.75 *P*<0.001**	*R*=0.22 *P*=0.077	***R*=0.70 *P*<0.001**	***R*=0.82 *P*<0.001**
Log [P]									*R*=0.28 *P*=0.022	*R*=0.023 *P*=0.86	*R*=0.095 *P*=0.45	***R*=0.42 *P*<0.001**	***R*=-0.39 *P*=0.001**	*R*=-0.15 *P*=0.22	*R*=0.082 *P*=0.51	*R*=0.10 *P*=0.42
Log [K]										*R*=-0.19 *P*=0.13	*R*=-0.13 *P*=0.29	***R*=0.54 *P*<0.001**	*R*=0.23 *P*=0.066	*R*=0.38 *P*=0.002	*R*=0.30 *P*=0.015	***R*=0.39 *P*=0.001**
Log [Ca]											*R*=0.047 *P*=0.71	*R*=0.15 *P*=0.24	*R*=0.065 *P*=0.602	*R*=-0.013 *P*=0.92	*R*=0.31 *P*=0.012	*R*=0.26 *P*=0.031
Log [Mg]												*R*=-0.30 *P*=0.015	***R*=-0.48 *P*<0.001**	*R*=-0.051 *P*=0.69	*R*=-0.37 *P*=0.002	***R*=-0.46 *P*<0.001**
Log [S]													***R*=0.54 *P*<0.001**	*R*=0.23 *P*=0.059	***R*=0.59 *P*<0.001**	***R*=0.72 *P*<0.001**
Log N:P ratio														*R*=0.32 *P*=0.009	***R*=0.62 *P*<0.001**	***R*=0.73 *P*<0.001**
Log MAP															*R*=0.32 *P*=0.008	*R*=0.25 *P*=0.040
Log MAT																***R*=0.78 *P*<0.001**

Table S8. Comparison (one way ANOVA) of the main needle and soil studied chemical variables between plots with podzols (11) and plots with arenosols (19).

Variables	Soil type		
	Podzol	Arenosol	*P*-value
Needle [N, mg g^{-1}]	15.6 ± 0.7	15.0 ± 0.6	*P* = 0.61
Needle [P, mg g^{-1}]	**1.51 ± 0.04**	**1.36 ± 0.04**	***P* = 0.011**
Needle [Ca, mg g^{-1}]	3.22 ± 0.18	3.41 ± 0.20	*P* = 0.52
Needle [Mg, mg g^{-1}]	0.935 ± 0.065	0.832 ± 0.044	*P* = 0.18
Needle [K, mg g^{-1}]	5.40 ± 0.28	5.08 ± 0.10	*P* = 0.22
Needle N:P ratio	10.3 ± 0.5	11.2 ± 0.6	*P* = 0.31
Needle N:K ratio	2.92 ± 0.14	2.96 ± 0.12	*P* = 0.83
Needle P:K ratio	0.285 ± 0.013	0.268 ± 0.007	*P* = 0.23
Needle Ca:Mg ratio	3.58 ± 0.26	4.36 ± 0.38	*P* = 0.16
Needle N:Ca ratio	5.01 ± 0.40	4.54 ± 0.22	*P* = 0.27
Needle N:Mg ratio	18.0 ± 2.1 ±	19.3 ± 1.6	*P* = 0.62
Needle P:Ca ratio	0.486 ± 0.034	0.419 ± 0.026	*P* = 0.13
Needle P:Mg ratio	1.70 ± 0.13	1.71 ± 0.09	*P* = 0.95
Needle K:Ca ratio	1.78 ± 0.20	1.58 ± 0.09	*P* = 0.32
Needle K:Mg ratio	6.25 ± 0.78	6.39 ± 0.33	*P* = 0.85
BD growth (cm y^{-1})	0.254 ± 0.023	0.237 ± 0.021	*P* = 0.61
DB growth (%)	0.013 ± 0.001	0.011 ± 0.001	*P* = 0.36
Soil pH	4.60 ± 0.13	4.79 ± 0.20	*P* = 0.48
Soil solution [K^{+}, mg L^{-1}]	1.54 ± 0.31	1.51 ± 0.26	*P* = 0.96
Soil solution [Ca^{2+}, mg L^{-1}]	3.73 ± 1.08	8.60 ± 3.42	*P* = 0.29
Soil solution [Mg^{2+}, mg L^{-1}]	1.49 ± 0.61	1.30 ± 0.45	*P* = 0.80
Soil solution [N-NO_3^{-}, mg L^{-1}]	1.77 ± 1.17	2.55 ± 1.16	*P* = 0.66
Soil solution [SO_4^{2-}, mg L^{-1}]	4.73 ± 2.52	5.96 ± 1.51	*P* = 0.66
Soil solution [N-NH_4^{+}, mg L^{-1}]	0.335 ± 0.114	0.453 ± 0.152	*P* = 0.59

Figure S1. Location of the 67 *P. sylvestris* ICP Forests Level II plots with soil data.

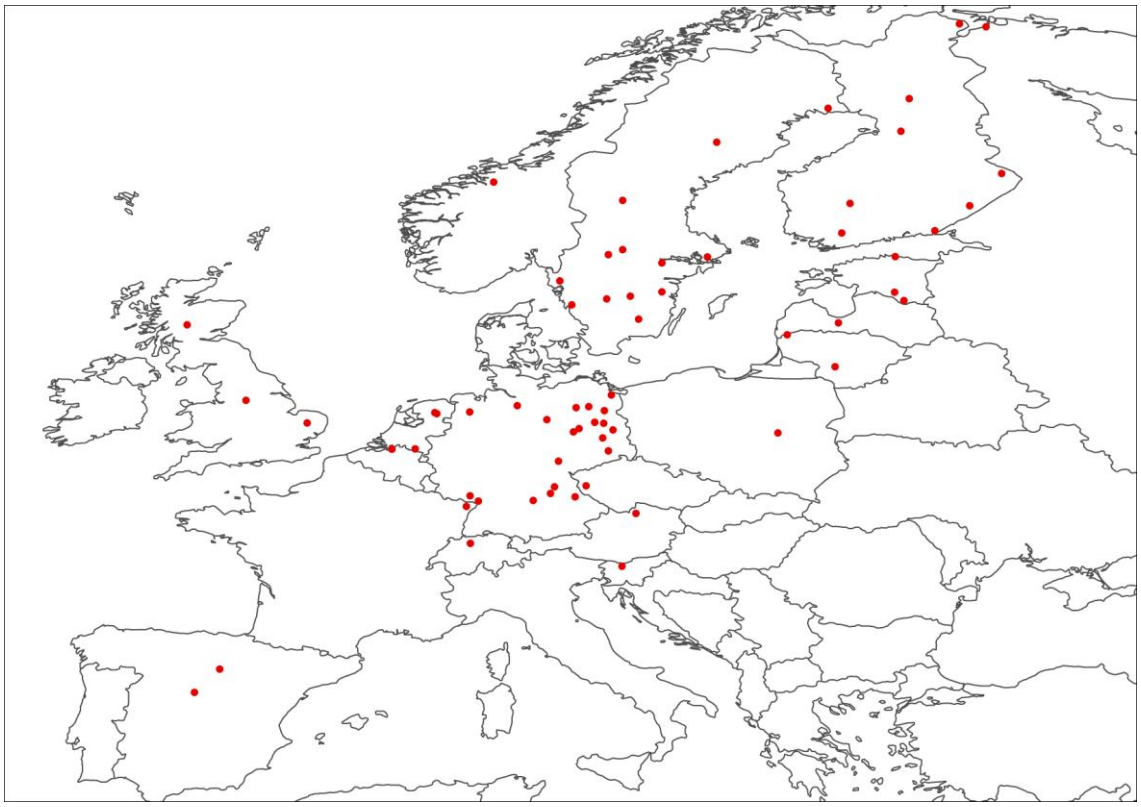
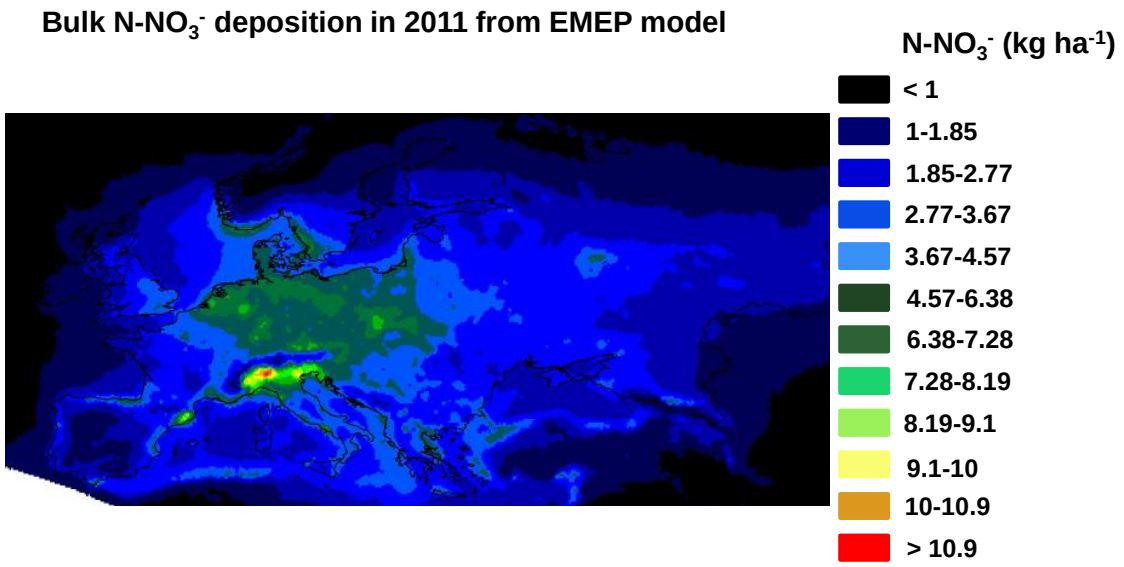


Figure S2. Maps of bulk $N\text{-}NO_3^-$ and $N\text{-}NH_4^+$ deposition (kg ha^{-1}) corresponding to the projections for 2011 from EMEP model.



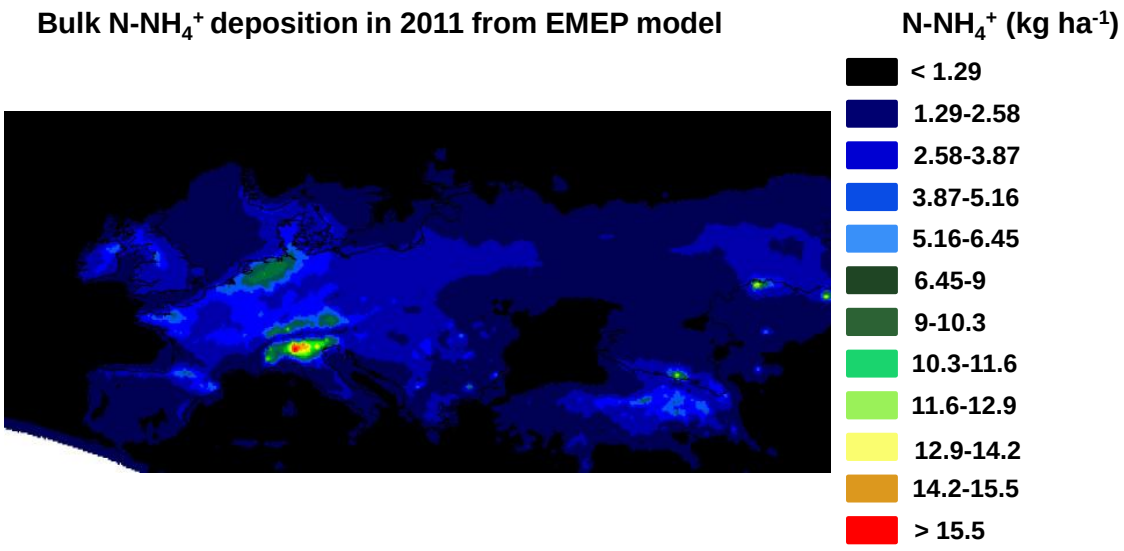


Figure S3. Latitudinal gradient of bulk atmospheric N deposition (average from 1991-2006, from EMEP model) in *P. sylvestris* forests across Europe. The maximum deposition on average occurs at 52ºN.

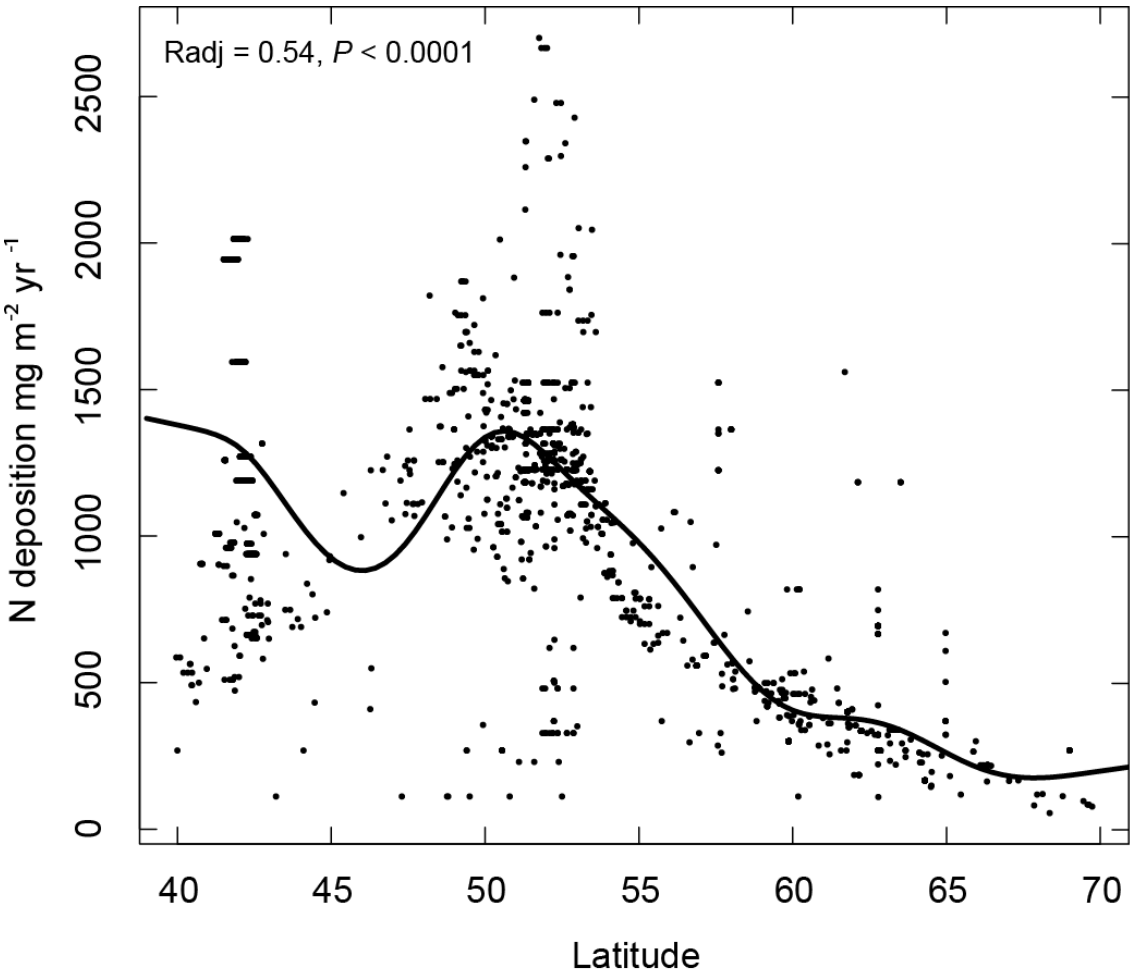
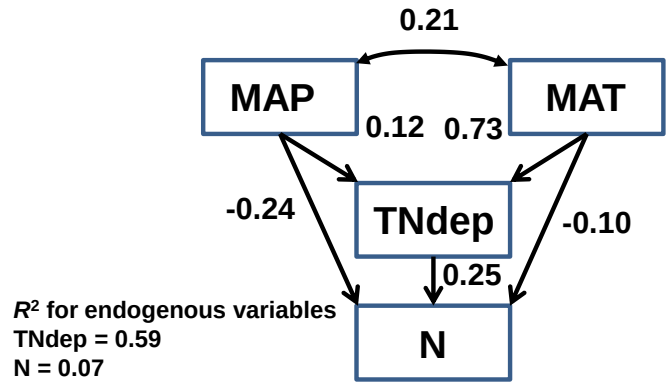
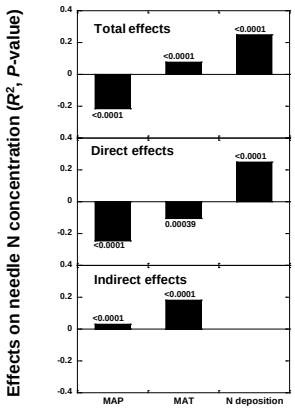
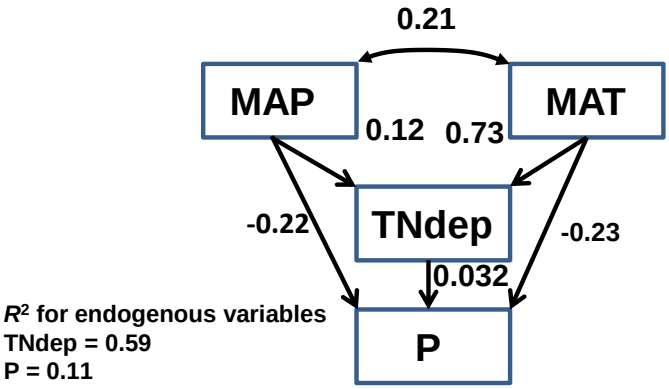
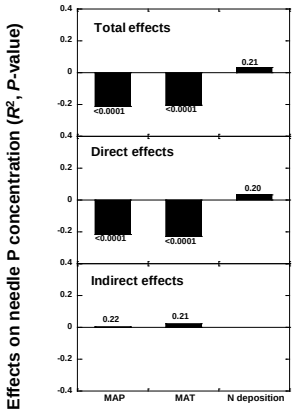


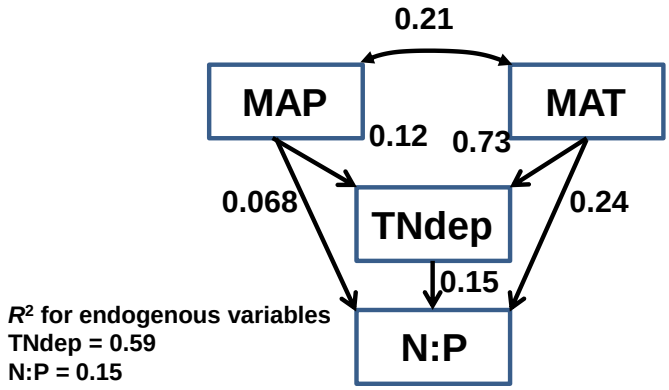
Figure S4. Structural equation modeling results of the direct and indirect relationships (by bulk N deposition) of MAP and MAT on needle N and P concentrations and N:P ratio data for 2245 forest plots of *P. sylvestris* spread across its entire range of distribution.











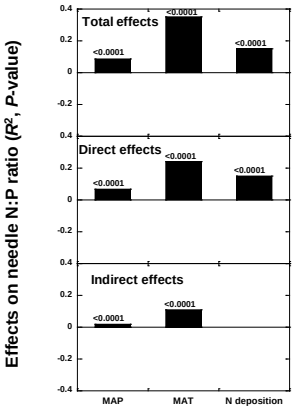


Figure S5. Relationship of needle S concentration with N troughfall deposition (from ICP forests model) in 52 European *P. sylvestris* stands monitored by ICP Forests (Level II). Data are an annual average obtained in the period 1995-2005.

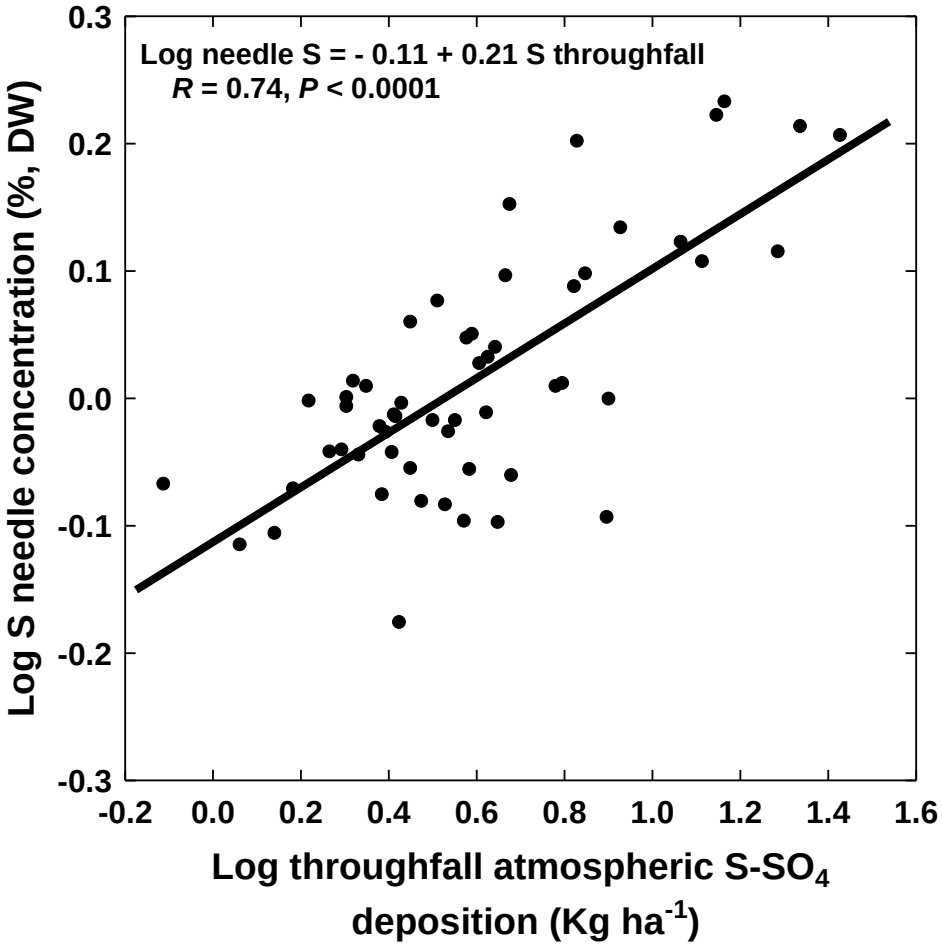


Figure S6. Relationship of needle S concentration with throughfall N deposition in 52 European *P. sylvestris* stands monitored by ICP Forests (Level II). Data are an annual average obtained in the period 1995-2005.

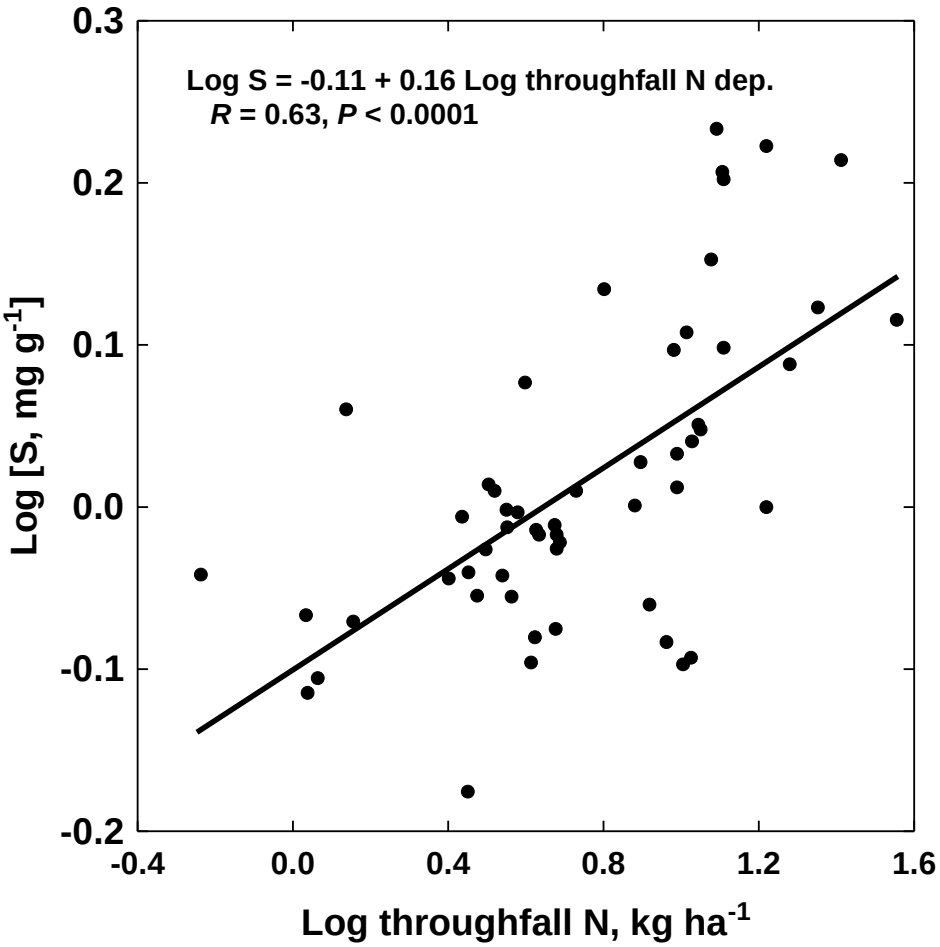


Figure S7. Relationships of the NO_3^- (a), NH_4^+ (b), total N (c) and SO_4^{2-} (d) deposition observed values for throughfall deposition (ICP Forests Level II) with the expected values by the EMEP model within the period from 1995 to 2011 in 98 different *P. sylvestris* forests along 18 European countries.

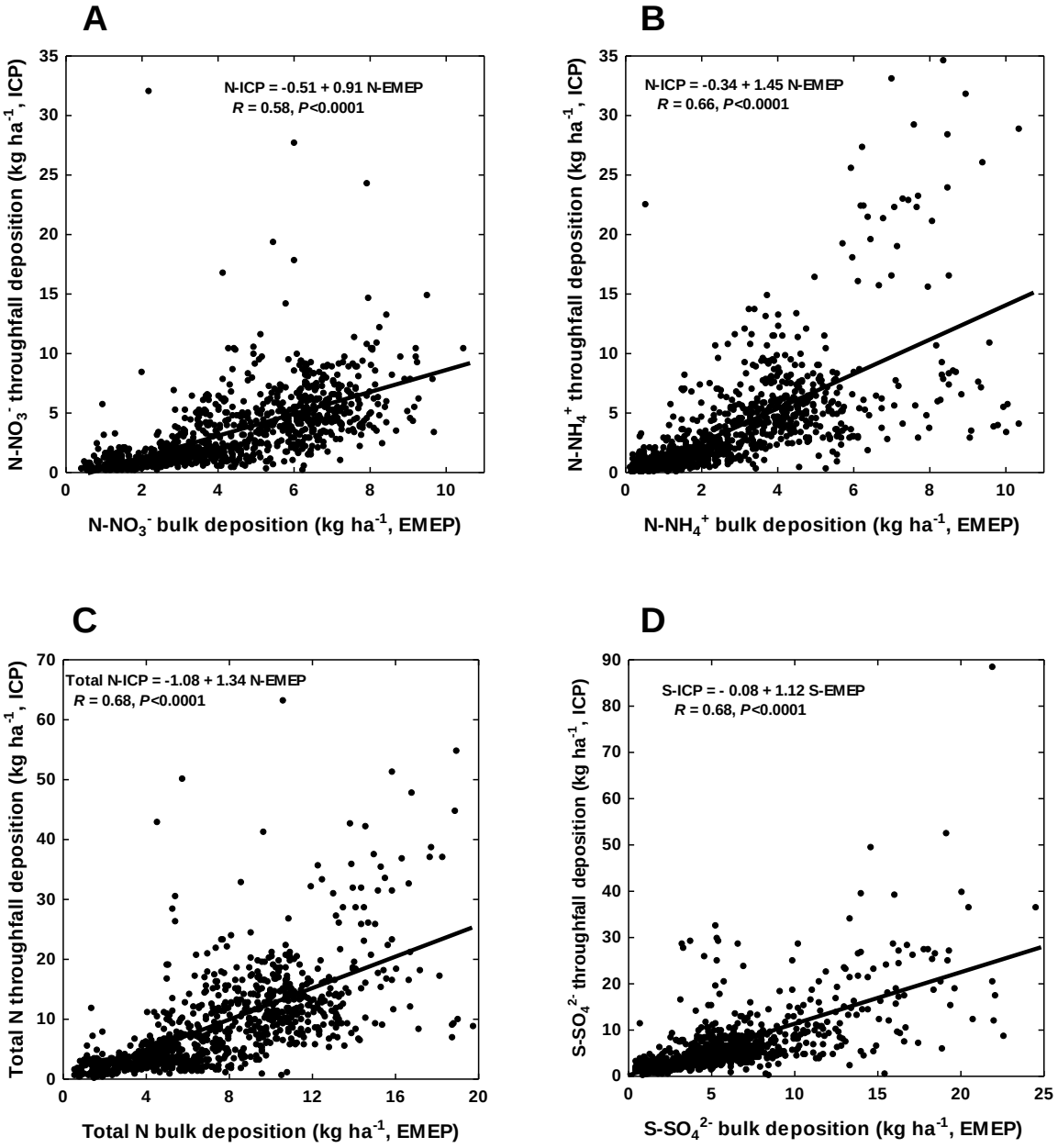


Figure S8. Relationships of needle N (a) and P (b) concentrations and S concentration (c) and N:P ratio (d) with soil-solution NO_3^- concentration and of needle S concentration with soil-solution SO_4^{2-} concentration (e) in 67 European *P. sylvestris* stands monitored by ICP Forests (Level II). Data are an annual average obtained in the period 1995-2005.

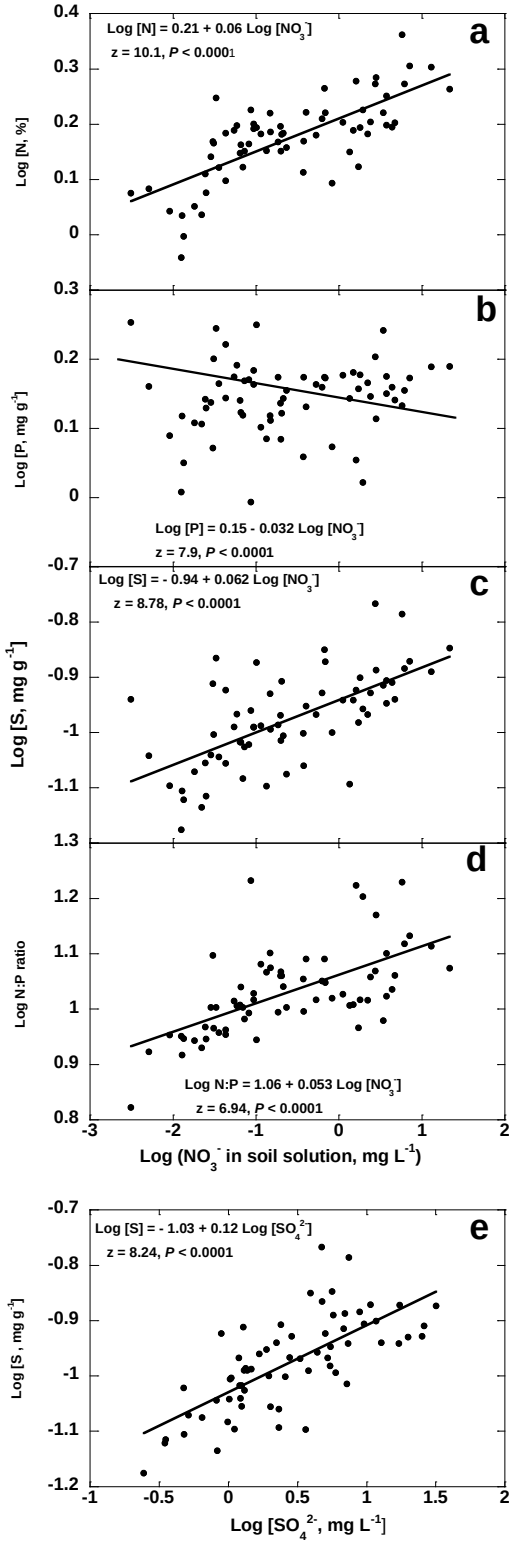


Figure S9. Relationships of soil Olsen P concentration (a), total soil N:Olsen P ratio (b), soil-solution P concentration (c), and soil-solution NO_3^-:P ratio (d) with N deposition in 55 European *P. sylvestris* stands monitored by ICP Forests (Level II). Data are an annual average obtained in the period 1995-2005.

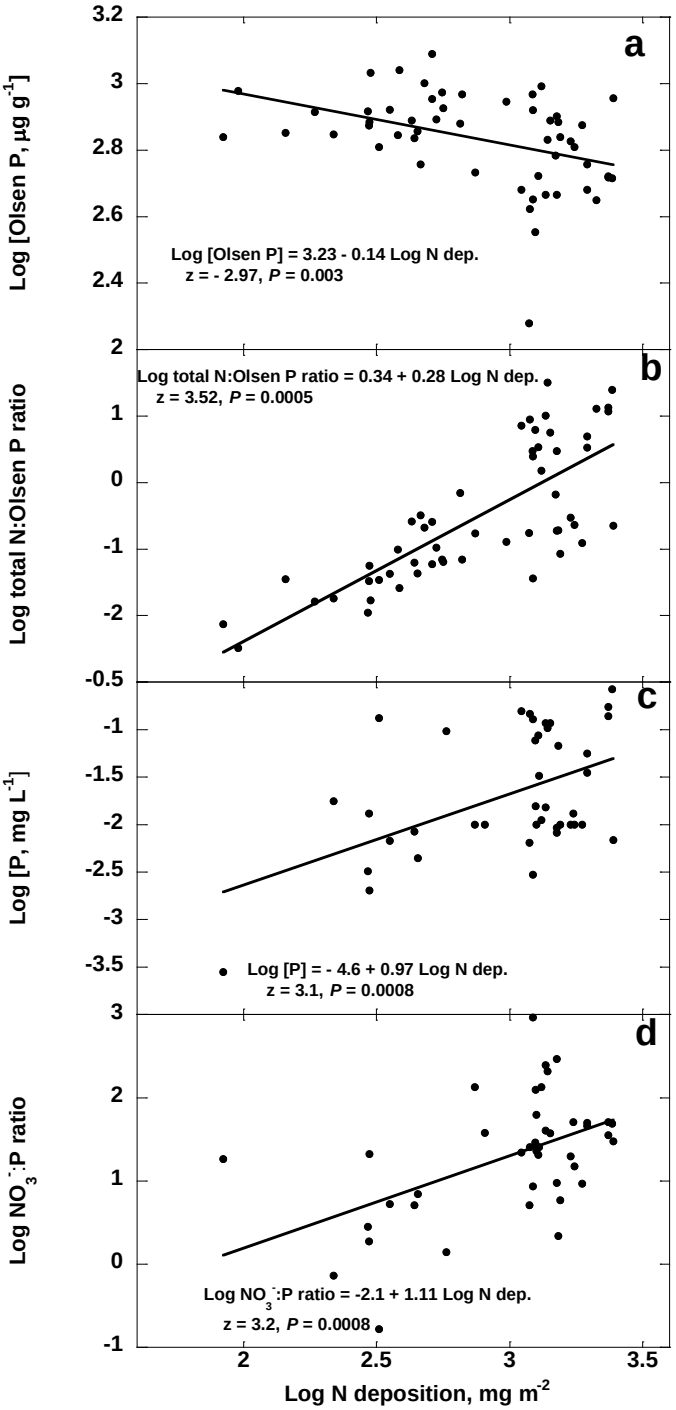


Figure S10. Relationships of annual absolute basal diameter (BD) growth with total annual througfall N deposition (from ICP Forests data).

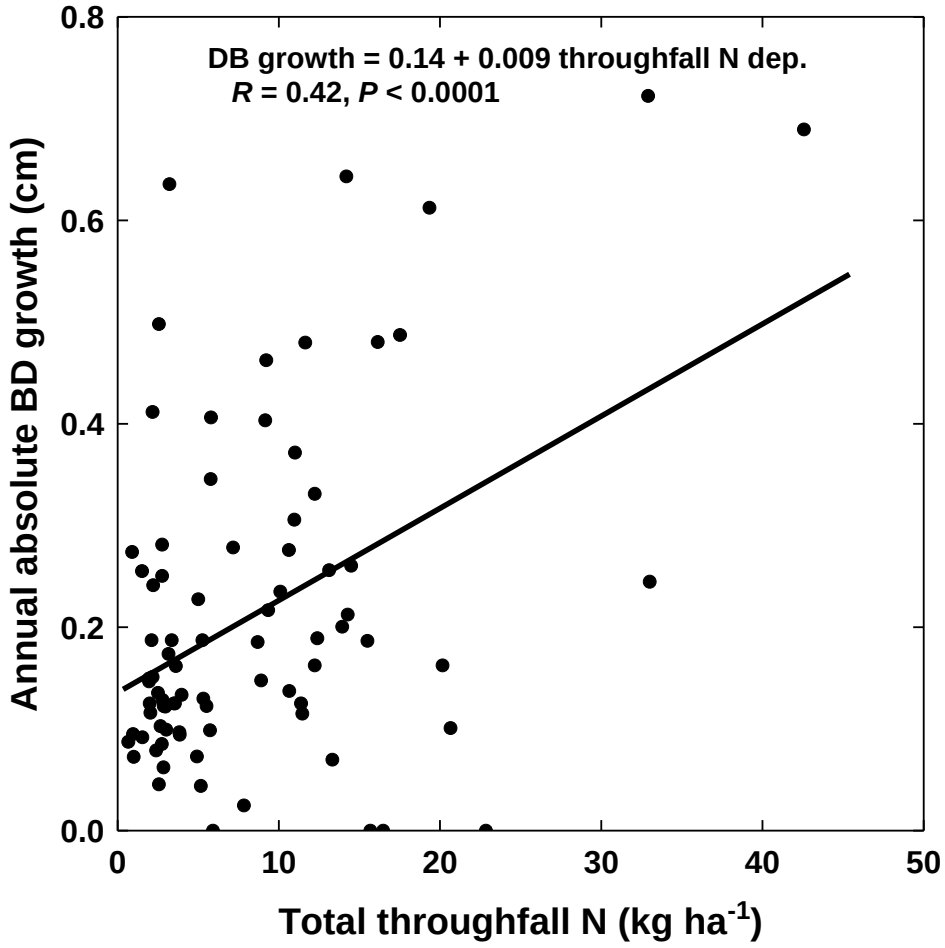


Figure S11. 3D representation of the relationship between absolute DB annual growth (a) and relative BD annual growth (b) with needle N and P concentrations.

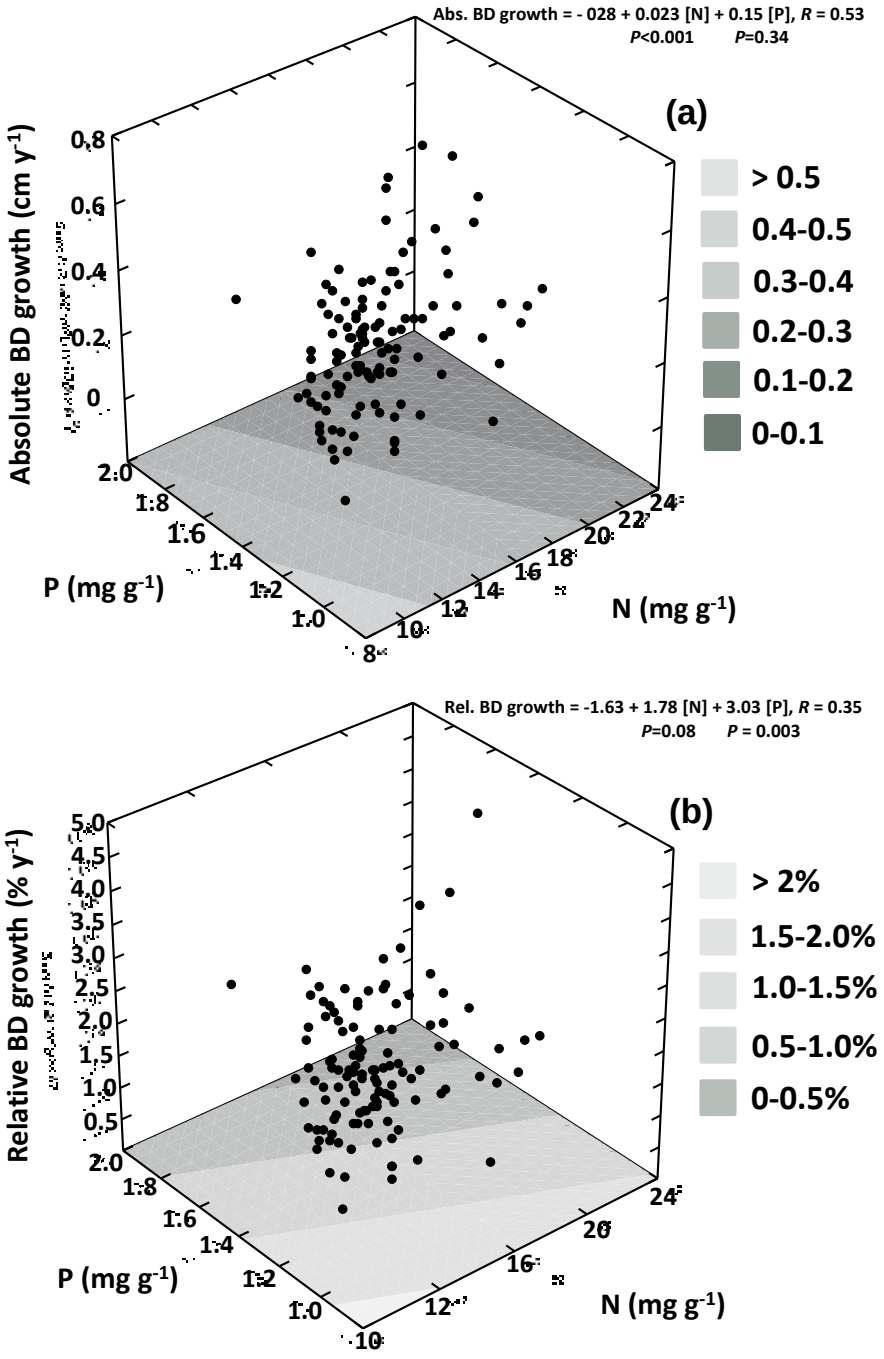


Figure S12. Relationship between absolute BD annual growth (cm) and needle K concentration (mg g^{-1}).

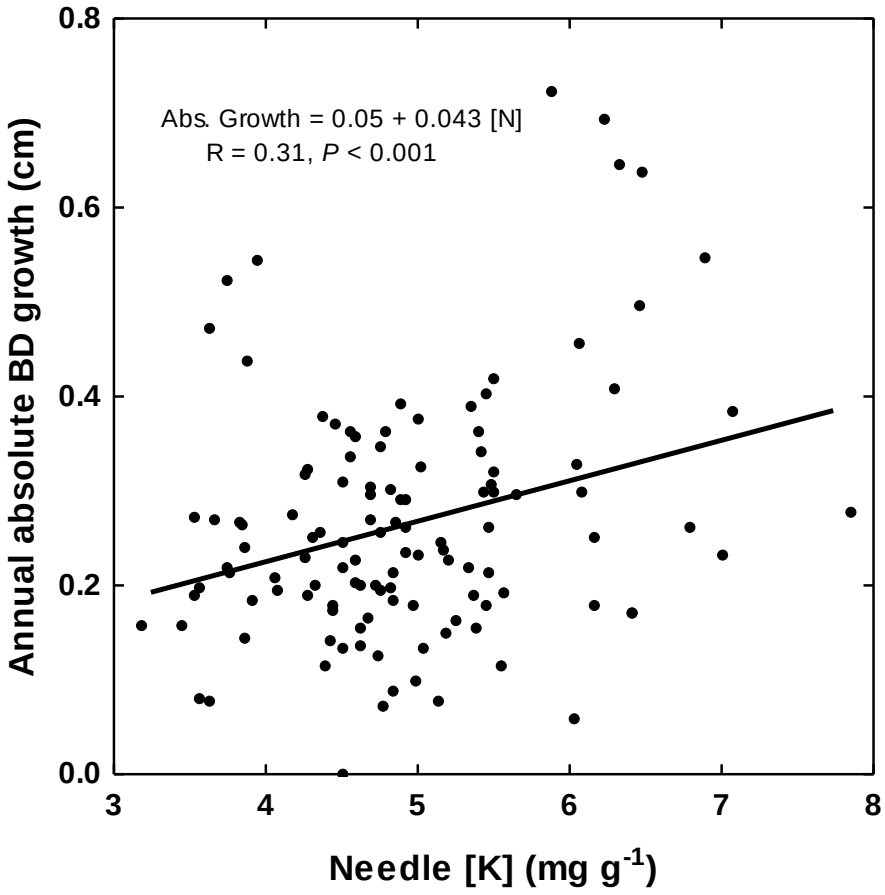


Figure S13. Relationships of needle N concentrations (a), P needle concentrations (b), needle N:P ratio (c) with N deposition in 67 European *P. sylvestris* stands monitored by ICP Forests (Level II). Data are an annual average obtained in the period 1995-2005.

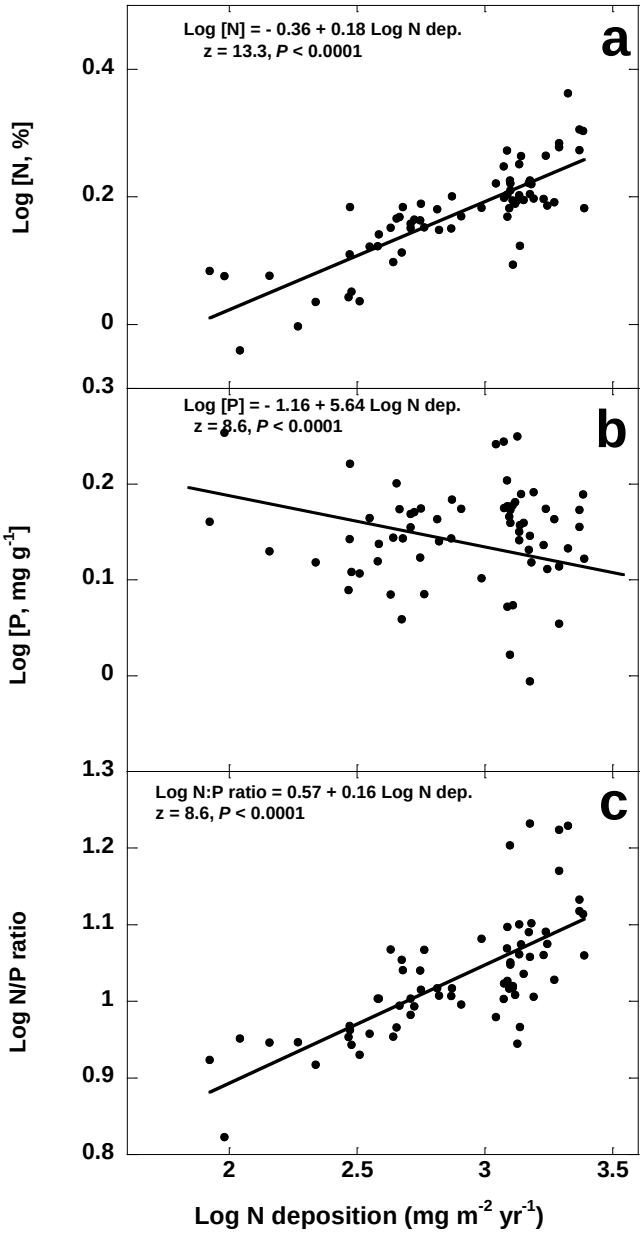


Fig. S14 Relationships of soil-solution NO_3^- (a), K^+ (b), and SO_4^{2-} (c) concentrations with bulk N deposition (EMEP model) in 67 European *P. sylvestris* stands monitored by ICP Forests (Level II). Data are an annual average obtained in the period 1995-2005.

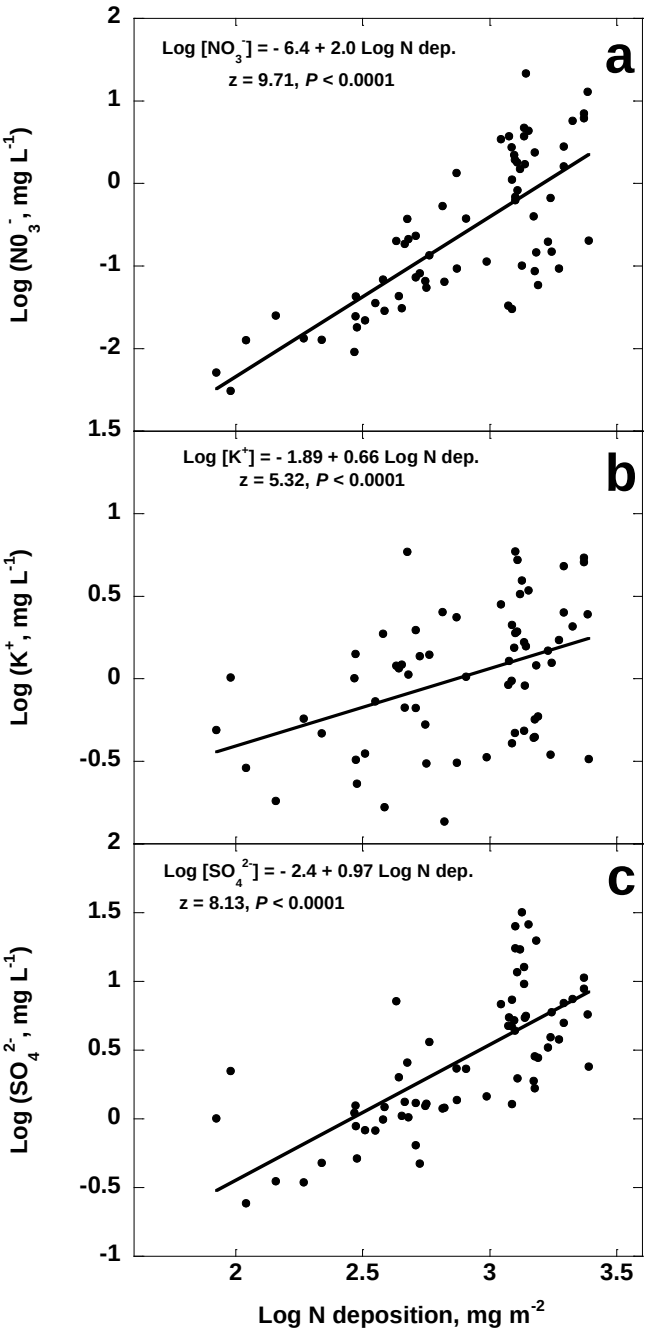


Figure S15. Relationships of soil-solution NO_3^- (a), K^+ (b), SO_4^{2-} (c) and Olsen_P (d) concentrations, and with throughfall N deposition (ICP Forests (Level II) data) in 41 (36 for P-Olsen) European *P. sylvestris* stands monitored by ICP Forests (Level II). Data are an annual average obtained in the period 1995-2005.