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Nitrogen concentrations in boreal and temperate tree tissues vary with tree age/size, growth rate, and climate

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Supporting Information

S1 Web of Science search criteria

Keywords:
TS=((stem OR root OR branch OR sapwood OR bole OR trunk OR twig OR xylem)
NEAR nitrogen)
AND
TS=(abies OR acer OR alnus OR betula OR carpinus OR carya OR castanea OR cedrus OR chamaecyparis OR cornus OR cryptomeria OR cupressus OR fagus OR fraxinus OR juglans OR juniperus OR larix OR liriodendron OR lithocarpus OR magnolia OR notholithocarpus OR nyssa OR oxydendrum OR phellodendron OR picea OR pinus OR platanus OR populus OR prunus OR pseudotsuga OR quercus OR robinia OR salix OR sequoia OR sequioadendron OR sorbus OR taxodium OR thuja OR tilia OR tsuga OR ulmus)

Date of search:
05.04.2020

S2 Data sources

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S3 Classification of tree species into Growth / Leaf type classes

Broadleaf deciduous, fast-growing

Acer campestre, Acer davidii, Acer macrophyllum, Acer negundo, Acer negundo subsp. californicum, Acer pictum, Acer platanoides, Acer pseudoplatanus, Acer rubrum, Aesculus hippocastanum, Alnus cordata, Alnus glutinosa, Alnus hirsuta, Alnus incana, Alnus incana subsp. rugosa, Alnus rhombifolia, Alnus rubra, Alnus rugosa, Betula alleghaniensis, Betula ermanii, Betula lenta, Betula nigra, Betula papyrifera, Betula pendula, Betula platyphylla, Betula platyphylla subsp. mandshurica, Betula populifolia, Betula pubescens, Betula tortuosa, Betula utilis, Betula verrucosa, Cornus alternifolia, Cornus controversa, Cornus walteri, Fraxinus americana, Fraxinus angustifolia, Fraxinus angustifolia subsp. oxycarpa, Fraxinus excelsior, Fraxinus pennsylvanica, Juglans mandshurica, Juglans nigra, Liquidambar styraciflua, Platanus occidentalis, Populus alba, Populus balsamifera, Populus cathayana, Populus deltoides, Populus deltoides subsp. monilifera, Populus euphratica, Populus fremontii, Populus gileadensis, Populus grandidentata, Populus hopeiensis, Populus koreana, Populus nigra, Populus robusta, Populus simonii, Populus suaveolens, Populus tremula, Populus tremula var. Davidiana, Populus tremula x tremuloides, Populus tremuloides, Populus trichocarpa, Prunus avium, Prunus pensylvanica, Prunus persica, Prunus serotina, Prunus virginiana, Quercus cerris, Quercus dentata, Quercus lobata, Quercus nigra, Quercus rubra, Quercus texana, Robinia pseudoacacia, Robinia pseudoacacia var. Inermis, Salix amygdaloides, Salix atrocinerea, Salix babylonica, Salix bebbiana, Salix caprea, Salix cinerea, Salix dunnii, Salix eleagnos subsp. eleagnos, Salix fragilis, Salix hultenii, Salix lasiolepis, Salix lucida, Salix lucida ssp. lasiandra, Salix pentandra, Salix rorida, Salix triandra, Salix udensis, Salix viminalis, Sorbus alnifolia, Sorbus torminalis, Ulmus glabra, Ulmus minor, Ulmus pumila

Broadleaf deciduous, slow-/medium-growing

Acer buergerianum, Acer caudatum subsp. ukurundense, Acer davidii subsp. grosseri, Acer japonicum, Acer mandshuricum, Acer monspessulanum, Acer opalus, Acer opalus subsp. obtusatum, Acer palmatum, Acer pensylvanicum, Acer pseudosieboldianum, Acer saccharum, Acer saccharum subsp. floridanum, Acer spicatum, Acer tataricum subsp. ginnala, Acer tegmentosum, Acer truncatum, Aesculus californica, Betula albosinensis, Betula costata, Betula dahurica, Carpinus betulus, Carya alba, Carya glabra, Carya ovata, Castanea dentata, Castanea mollissima, Castanea sativa, Cornus florida, Cornus kousa subsp. chinensis, Cornus kousa subsp. kousa, Cornus macrophylla, Cornus mas, Cornus officinalis, Fagus crenata, Fagus grandifolia, Fagus sylvatica, Fraxinus chinensis, Fraxinus chinensis subsp. rhynchophylla, Fraxinus mandshurica, Fraxinus nigra, Ilex verticillata, Juglans ailanthifolia, Juglans californica, Juglans cinerea, Juglans hindsii, Juglans regia, Liquidambar formosana, Liriodendron tulipifera, Magnolia fraseri, Magnolia kobus, Magnolia obovata, Magnolia officinalis, Malus baccata, Malus sylvestris, Nyssa sylvatica, Oxydendrum arboreum, Phellodendron amurense, Prunus armeniaca, Prunus cerasifera, Prunus davidiana, Prunus domestica, Prunus padus, Quercus acutissima, Quercus alba, Quercus aliena var. acutiserrata, Quercus bicolor, Quercus chenii, Quercus coccinea, Quercus douglasii, Quercus ellipsoidalis, Quercus faginea, Quercus falcata, Quercus gambelii, Quercus ilicifolia, Quercus kelloggii, Quercus laevis, Quercus macrocarpa, Quercus michauxii, Quercus mongolica, Quercus mongolica subsp. crispula, Quercus petraea, Quercus prinus, Quercus pubescens, Quercus pyrenaica, Quercus robur, Quercus serrata subsp. serrata, Quercus variabilis, Quercus velutina, Robinia neomexicana, Sorbus americana, Sorbus aria, Sorbus aucuparia, Sorbus commixta, Tilia americana, Tilia amurensis, Tilia cordata, Tilia japonica, Tilia mandshurica, Tilia mongolica, Tilia platyphyllos, Ulmus americana, Ulmus davidiana, Ulmus davidiana var. japonica, Ulmus laciniata, Ulmus parvifolia

Needleleaf deciduous, fast-growing

Larix decidua, Larix decidua x leptolepis, Larix kaempferi, Larix leptolepis, Larix occidentalis, Larix x eurolepis, Taxodium distichum

Needleleaf deciduous, slow-/medium-growing

Larix dahurica, Larix gmelinii, Larix gmelinii var. olgensis, Larix laricina, Larix lyallii, Larix olgensis, Larix principis-rupprechtii, Larix sibirica

Needleleaf evergreen, fast-growing

Abies alba, Abies bornmulleriana, Abies fraseri, Abies grandis, Cryptomeria fortunei, Cryptomeria japonica, Picea abies, Picea crassifolia, Picea glauca, Picea omorika, Picea rubens, Picea sitchensis, Pinus banksiana, Pinus brutia, Pinus contorta, Pinus monticola, Pinus muricata, Pinus nigra, Pinus nigra var. calabrica, Pinus palustris, Pinus pinaster, Pinus radiata, Pinus strobus, Pinus sylvestris, Pseudotsuga menziesii, Sequoia sempervirens, Thuja plicata, Tsuga heterophylla

Needleleaf evergreen, slow-/medium-growing

Abies amabilis, Abies balsamea, Abies concolor, Abies firma, Abies lasiocarpa, Abies mayriana, Abies nephrolepis, Abies sachalinensis, Abies sibirica, Cedrus deodara, Chamaecyparis obtusa, Juniperus communis, Juniperus deppeana, Juniperus monosperma, Juniperus osteosperma, Juniperus oxycedrus, Juniperus oxycedrus var. oxycedrus, Juniperus scopulorum, Juniperus virginia, Juniperus virginiana, Picea engelmannii, Picea jezoensis, Picea mariana, Picea mariana x rubens, Picea meyeri, Picea obovata, Picea orientalis, Picea wilsonii, Pinus albicaulis, Pinus aristata, Pinus armandii, Pinus bungeana, Pinus cembra, Pinus densiflora, Pinus echinata, Pinus edulis, Pinus flexilis, Pinus halepensis, Pinus jeffreyi, Pinus koraiensis, Pinus massoniana, Pinus monophylla, Pinus pinea, Pinus ponderosa, Pinus resinosa, Pinus rigida, Pinus serotina, Pinus sibirica, Pinus strobiformis, Pinus tabulaeformis, Pinus tabuliformis, Pinus taeda, Pinus thunbergii, Pinus uncinata, Thuja occidentalis, Tsuga canadensis, Tsuga chinensis, Tsuga mertensiana, Tsuga sieboldii

S4 Generalized additive models

A total of 17 generalized additive models (GAMs) are implemented for each tree tissue N concentration, using different combinations of explanatory variables. While GAMs (1) – (9) consider plant trait variables, GAMs (10) – (12) consider environmental condition variables. GAMs (13) – (17) incorporate plant traits and environmental conditions:

(1) Leaf types (LT; broadleaf deciduous, needleleaf deciduous, needleleaf evergreen)
(2) Growth rate (GR) classes (slow-/medium growing, fast-growing)
(3) Leaf type / growth rate (LT/GR) classes
(4) Tree age
(5) Tree height
(6) Compartment biomass
(7) LT/GR + Age
(8) LT/GR + Height
(9) LT/GR + Biomass
(10) MAT + MAP
(11) Soil N concentration
(12) MAT + MAP + Soil N
(13) LT/GR + Soil N
(14) LT + MAT + MAP + Soil N
(15) LT + Age + MAT + MAP
(16) LT + Height + MAT + MAP
(17) LT + Biomass + MAT + MAP

Table S1: Modelling efficiencies (MEFs) of all the 17 applied generalized additive models (GAMs) for modelling leaf N concentration using different combinations of explanatory variables. n indicates the number of available measurements for each GAM.

GAM	Variables	Formula	n	MEF
(1)	Leaf Type (LT)	Leaf_N ~ factor(LT)	5944	0.51
(2)	Growth Rate (GR)	Leaf_N ~ factor(GR)	5944	0.032
(3)	Leaf Type / Growth Rate (LT/GR)	Leaf_N ~ factor(LTGR)	5944	0.524
(4)	Age	Leaf_N ~ s(Age)	428	0.07
(5)	Height	Leaf_N ~ s(Height)	416	0.336

(6)	Biomass	Leaf_N ~ s(Biomass)	73	0.368
(7)	LT/GR + Age	Leaf_N ~ s(Age) + factor(LTGR)	428	0.454
(8)	LT/GR + Height	Leaf_N ~ s(Height, by = LTGR) + factor(LTGR)	416	0.743
(9)	LT/GR + Biomass	Leaf_N ~ s(Biomass, by = LTGR)	73	0.772
(10)	MAT + MAP	Leaf_N ~ s(MAT) + s(MAP) + te(MAT, MAP)	5944	0.134
(11)	Soil N	Leaf_N ~ s(Soil_N)	624	0.27
(12)	MAT + MAP + Soil N	Leaf_N ~ s(MAT) + s(MAP) + s(Soil_N) + te(MAT, MAP) + te(MAT, Soil_N) + te(MAP, Soil_N)	624	0.516
(13)	LT/GR + Soil N	Leaf_N ~ s(Soil_N, by = LTGR)	624	0.616
(14)	LT + MAT + MAP + Soil N	Leaf_N ~ s(MAT, by = LT) + s(MAP, by = LT) + s(Soil_N, by = LT) + factor(LT) + te(MAT, Soil_N) + te(MAP, Soil_N)	624	0.698
(15)	LT + Age + MAT + MAP	Leaf_N ~ s(MAT, by = LT) + s(MAP, by = LT) + s(Age, by = LT) + factor(LT) + te(MAT, Age)	428	0.618
(16)	LT + Height + MAT + MAP	Leaf_N ~ s(MAT, by = LT) + s(MAP, by = LT) + s(Height, by = LT) + factor(LT) + te(MAP, Height)	416	0.761
(17)	LT + Biomass + MAT + MAP	Leaf_N ~ s(MAT) + s(MAP) + s(Biomass) + factor(LT) + te(MAT, Biomass)	73	0.779

Table S2: Modelling efficiencies (MEFs) of all the 17 applied generalized additive models (GAMs) for modelling branch N concentration using different combinations of explanatory variables. n indicates the number of available measurements for each GAM.

GAM	Variables	Formula	n	MEF
(1)	Leaf Type (LT)	Branch_N ~ factor(LT)	599	0.078
(2)	Growth Rate (GR)	Branch_N ~ factor(GR)	599	0.019
(3)	Leaf Type / Growth Rate (LT/GR)	Branch_N ~ factor(LTGR)	599	0.146
(4)	Age	Branch_N ~ s(Age)	437	0.248
(5)	Height	Branch_N ~ s(Height)	312	0.041
(6)	Biomass	Branch_N ~ s(Biomass)	300	0.022
(7)	LT/GR + Age	Branch_N ~ s(Age, by = LTGR)	437	0.402
(8)	LT/GR + Height	Branch_N ~ s(Height, by = LTGR)	312	0.348
(9)	LT/GR + Biomass	Branch_N ~ s(Biomass, by = LTGR)	300	0.379
(10)	MAT + MAP	Branch_N ~ s(MAT) + s(MAP) + te(MAT, MAP)	599	0.428
(11)	Soil N	Branch_N ~ s(Soil_N)	201	0.087
(12)	MAT + MAP + Soil	Branch_N ~ s(MAT) + s(MAP) + s(Soil_N) + te(MAT, MAP) + te(MAT,	201	0.692

	N	Soil_N)		
(13)	LT/GR + Soil N	Branch_N ~ s(Soil_N, by = LTGR)	201	0.55
(14)	LT + MAT + MAP + Soil N	Branch_N ~ s(MAT) + s(MAP) + s(Soil_N) + factor(LT) + te(MAT, MAP) + te(MAT, Soil_N)	201	0.701
(15)	LT + Age + MAT + MAP	Branch_N ~ s(MAT, by = LT) + s(MAP, by = LT) + s(Age, by = LT) + factor(LT) + te(MAT, MAP) + te(MAP, Age)	437	0.599
(16)	LT + Height + MAT + MAP	Branch_N ~ s(MAT, by = LT) + s(MAP, by = LT) + s(Height, by = LT) + te(MAT, Height) + te(MAP, Height)	312	0.573
(17)	LT + Biomass + MAT + MAP	Branch_N ~ s(MAT, by = LT) + s(MAP, by = LT) + s(Biomass, by = LT) + te(MAT, MAP) + te(MAT, Biomass) + te(MAP, Biomass)	300	0.702

Table S3: Modelling efficiencies (MEFs) of all the 17 applied generalized additive models (GAMs) for modelling stem N concentration using different combinations of explanatory variables. n indicates the number of available measurements for each GAM.

GAM	Variables	Formula	n	MEF
(1)	Leaf Type (LT)	Stem_N ~ factor(LT)	1048	0.119
(2)	Growth Rate (GR)	Stem_N ~ factor(GR)	1048	0
(3)	Leaf Type / Growth Rate (LT/GR)	Stem_N ~ factor(LTGR)	1048	0.122
(4)	Age	Stem_N ~ s(Age)	823	0.366
(5)	Height	Stem_N ~ s(Height)	515	0.315
(6)	Biomass	Stem_N ~ s(Biomass)	320	0.228
(7)	LT/GR + Age	Stem_N ~ s(Age, by = LTGR)	823	0.605
(8)	LT/GR + Height	Stem_N ~ s(Height, by = LTGR) + factor(LTGR)	515	0.555
(9)	LT/GR + Biomass	Stem_N ~ s(Biomass, by = LTGR) + factor(LTGR)	320	0.416
(10)	MAT + MAP	Stem_N ~ s(MAT) + s(MAP) + te(MAT, MAP)	1048	0.151
(11)	Soil N	Stem_N ~ s(Soil_N)	323	0.002
(12)	MAT + MAP + Soil N	Stem_N ~ s(MAT) + s(MAP) + s(Soil_N) + te(MAT, MAP) + te(MAT, Soil_N)	323	0.488
(13)	LT/GR + Soil N	Stem_N ~ s(Soil_N, by = LTGR) + factor(LTGR)	323	0.724
(14)	LT + MAT + MAP + Soil N	Stem_N ~ s(MAT, by = LT) + s(MAP, by = LT) + s(Soil_N, by = LT) + te(MAT, MAP) + te(MAT, Soil_N) + te(MAP, Soil_N)	323	0.922
(15)	LT + Age + MAT + MAP	Stem_N ~ s(MAT, by = LT) + s(MAP, by = LT) + s(Age, by = LT) + te(MAT, Age)	823	0.682
(16)	LT + Height + MAT + MAP	Stem_N ~ s(MAT, by = LT) + s(MAP, by = LT) + s(Height, by = LT) + te(MAT, MAP) + te(MAT, Height) + te(MAP, Height)	515	0.669
(17)	LT + Biomass +	Stem_N ~ s(MAT, by = LT) + s(MAP, by = LT) + s(Biomass, by = LT) +	320	0.657

	MAT + MAP	factor(LT) + te(MAT, MAP) + te(MAT, Biomass) + te(MAP, Biomass)		

Table S4: Modelling efficiencies (MEFs) of all the 17 applied generalized additive models (GAMs) for modelling root N concentration using different combinations of explanatory variables. n indicates the number of available measurements for each GAM.

GAM	Variables	Formula	n	MEF
(1)	Leaf Type (LT)	Root_N ~ factor(LT)	267	0.118
(2)	Growth Rate (GR)	Root_N ~ factor(GR)	267	0
(3)	Leaf Type / Growth Rate (LT/GR)	Root_N ~ factor(LTGR)	267	0.193
(4)	Age	Root_N ~ s(Age)	245	0.232
(5)	Height	Root_N ~ s(Height)	98	0.046
(6)	Biomass	Root_N ~ s(Biomass)	111	0.147
(7)	LT/GR + Age	Root_N ~ s(Age, by = LTGR) + factor(LTGR)	245	0.455
(8)	LT/GR + Height	Root_N ~ s(Height, by = LTGR) + factor(LTGR)	98	0.568
(9)	LT/GR + Biomass	Root_N ~ s(Biomass, by = LTGR)	111	0.403
(10)	MAT + MAP	Root_N ~ s(MAT) + s(MAP) + te(MAT, MAP)	267	0.352
(11)	Soil N	Root_N ~ s(Soil_N)	136	0.552
(12)	MAT + MAP + Soil N	Root_N ~ s(MAT) + s(MAP) + s(Soil_N) + te(MAT, Soil_N) + te(MAP, Soil_N)	136	0.862
(13)	LT/GR + Soil N	Root_N ~ s(Soil_N, by = LTGR) + factor(LTGR)	136	0.826
(14)	LT + MAT + MAP + Soil N	Root_N ~ s(MAT, by = LT) + s(MAP, by = LT) + s(Soil_N, by = LT)	136	0.871
(15)	LT + Age + MAT + MAP	Root_N ~ s(MAT, by = LT) + s(MAP, by = LT) + s(Age, by = LT) + te(MAT, MAP) + te(MAP, Age)	245	0.775
(16)	LT + Height + MAT + MAP	Root_N ~ s(MAT) + s(MAP) + s(Height) + factor(LT) + te(MAT, MAP)	98	0.757
(17)	LT + Biomass + MAT + MAP	Root_N ~ s(MAT, by = LT) + s(MAP, by = LT) + s(Biomass, by = LT) + te(MAT, MAP)	111	0.928

S5 N concentration summary statistics

Table S5: Leaf N Concentration [gN g^{-1}] summary statistics for all growth / leaf type classes.

Leaf N Concentration [gN g^{-1}]	1st quartile	Median	Mean	3rd quartile
Broadleaf Deciduous Fast-growing	0.0194	0.0241	0.0238	0.0282
Broadleaf Deciduous Slow-/Medium-growing	0.0183	0.0215	0.0216	0.0247
Needleleaf Deciduous Fast-growing	0.0167	0.0194	0.0193	0.0213
Needleleaf Deciduous Slow-/Medium-growing	0.0133	0.0172	0.0172	0.0211
Needleleaf Evergreen Fast-growing	0.0107	0.0125	0.0126	0.0143
Needleleaf Evergreen Slow-/Medium-growing	0.0099	0.0118	0.0122	0.0148
All Broadleaf Deciduous	0.0185	0.0222	0.0224	0.0260
All Needleleaf Deciduous	0.0155	0.0185	0.0183	0.0213
All Needleleaf Evergreen	0.0105	0.0124	0.0125	0.0144
All Fast-growing	0.0118	0.0144	0.0168	0.0209
All Slow-/Medium-growing	0.0147	0.0194	0.0192	0.0234
All	0.0124	0.0167	0.0179	0.0226

Table S6: Branch N Concentration [gN g^{-1}] summary statistics for all growth / leaf type classes.

Branch N Concentration [gN g^{-1}]	1st quartile	Median	Mean	3rd quartile
Broadleaf Deciduous Fast-growing	0.0035	0.0053	0.0063	0.0076
Broadleaf Deciduous Slow-/Medium-growing	0.0026	0.0038	0.0041	0.0053
Needleleaf Deciduous Fast-growing	0.0047	0.0050	0.0053	0.0055
Needleleaf Deciduous Slow-/Medium-growing	0.0038	0.0048	0.0044	0.0053
Needleleaf Evergreen Fast-growing	0.0024	0.0033	0.0036	0.0049
Needleleaf Evergreen Slow-/Medium-growing	0.0020	0.0027	0.0032	0.0038
All Broadleaf Deciduous	0.0029	0.0042	0.0050	0.0059
All Needleleaf Deciduous	0.0040	0.0049	0.0046	0.0053
All Needleleaf Evergreen	0.0022	0.0030	0.0035	0.0045
All Fast-growing	0.0025	0.0039	0.0044	0.0054
All Slow-/Medium-growing	0.0022	0.0032	0.0037	0.0049
All	0.0024	0.0035	0.0040	0.0051

Table S7: Stem N Concentration [gN g^{-1}] summary statistics for all growth / leaf type classes.

Stem N Concentration [gN g^{-1}]	1st quartile	Median	Mean	3rd quartile
Broadleaf Deciduous Fast-growing	0.0010	0.0016	0.0023	0.0026
Broadleaf Deciduous Slow-/Medium-growing	0.0013	0.0018	0.0021	0.0025
Needleleaf Deciduous Fast-growing	0.0006	0.0007	0.0008	0.0009
Needleleaf Deciduous Slow-/Medium-growing	0.0009	0.0010	0.0013	0.0013
Needleleaf Evergreen Fast-growing	0.0006	0.0008	0.0011	0.0012
Needleleaf Evergreen Slow-/Medium-growing	0.0003	0.0006	0.0009	0.0010
All Broadleaf Deciduous	0.0012	0.0017	0.0022	0.0025
All Needleleaf Deciduous	0.0008	0.0010	0.0013	0.0013
All Needleleaf Evergreen	0.0005	0.0008	0.0010	0.0011
All Fast-growing	0.0007	0.0010	0.0014	0.0015
All Slow-/Medium-growing	0.0007	0.0010	0.0014	0.0017
All	0.0007	0.0010	0.0014	0.0016

Table S8: Root N Concentration [gN g^{-1}] summary statistics for all growth / leaf type classes.

Root N Concentration [gN g^{-1}]	1st quartile	Median	Mean	3rd quartile
Broadleaf Deciduous Fast-growing	0.0052	0.0078	0.0094	0.0111
Broadleaf Deciduous Slow-/Medium-growing	0.0035	0.0045	0.0056	0.0068
Needleleaf Deciduous Fast-growing	0.0026	0.0032	0.0032	0.0033
Needleleaf Deciduous Slow-/Medium-growing	0.0058	0.0074	0.0073	0.0093
Needleleaf Evergreen Fast-growing	0.0015	0.0033	0.0045	0.0075
Needleleaf Evergreen Slow-/Medium-growing	0.0016	0.0046	0.0045	0.0062
All Broadleaf Deciduous	0.0039	0.0064	0.0077	0.0089
All Needleleaf Deciduous	0.0051	0.0071	0.0070	0.0091
All Needleleaf Evergreen	0.0015	0.0038	0.0045	0.0070
All Fast-growing	0.0024	0.0052	0.0060	0.0079
All Slow-/Medium-growing	0.0038	0.0061	0.0062	0.0085
All	0.0033	0.0060	0.0061	0.0083

S6 Significance of differences between leaf, branch, stem, and root N concentration

The significance of differences between leaf, branch, stem, and root N concentration is quantified by the p-values of pairwise t-tests (Table S9).

Table S9: P-values of pairwise t-tests of N concentration in all compartments.

p-value	Leaf N Concentration	Branch N Concentration	Stem N Concentration
Branch N Concentration	$< 2*10^{-16}$	–	–
Stem N Concentration	$< 2*10^{-16}$	$< 2*10^{-16}$	–
Root N Concentration	$< 2*10^{-16}$	$3.2*10^{-6}$	$< 2*10^{-16}$

S7 Differences between tree species

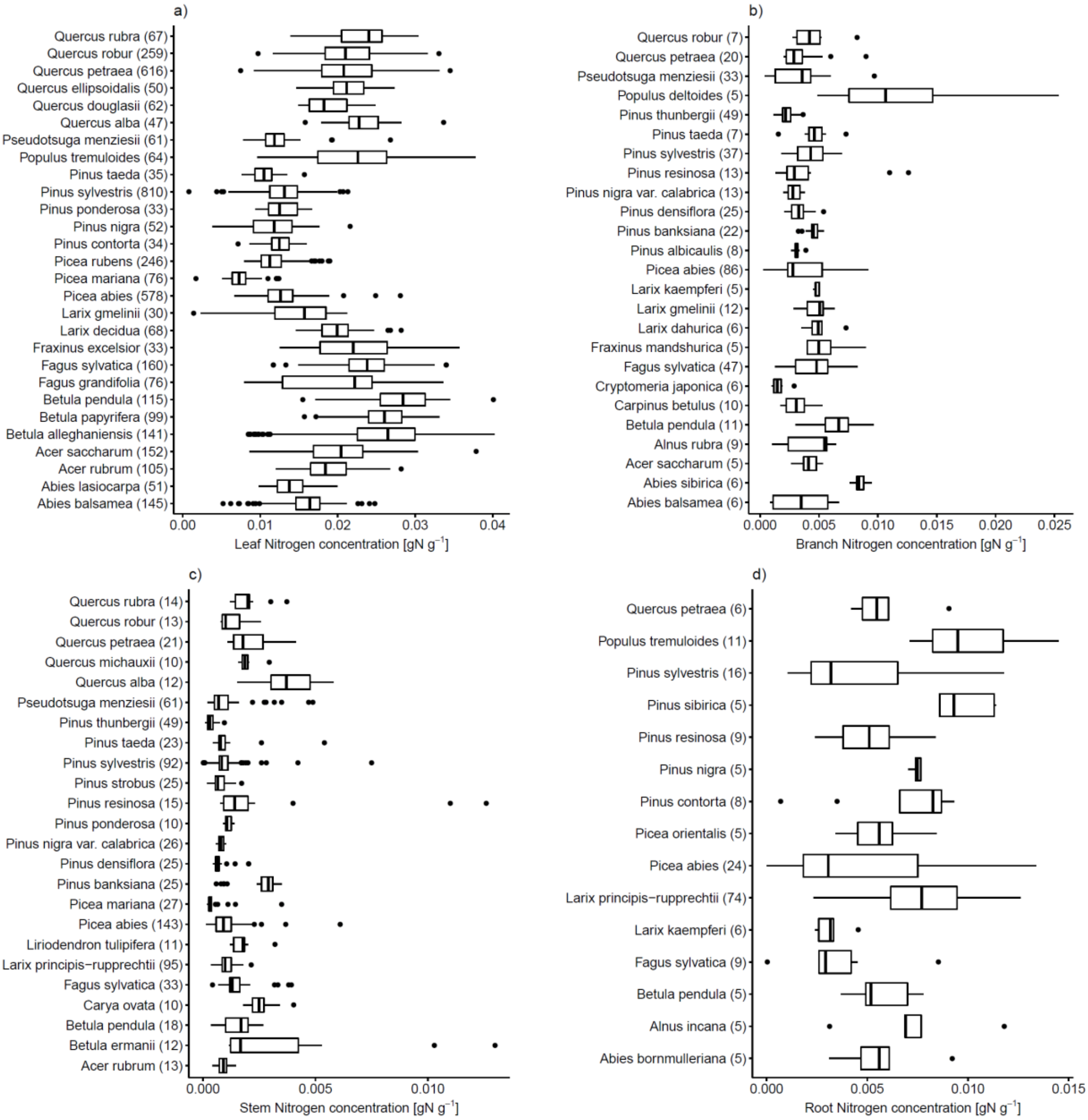

Fig. S1: a) Leaf, b) branch, c) stem and d) root N concentration [gN g^{-1}] for the most common tree species in the database. Only tree species with at least 30 in case of leaf, 10 in case of stem, and 5 in case of branch and root N concentration measurements are included in this figure.

Table S10: Leaf N Concentration [gN g^{-1}] summary statistics for all species with at least 30 measurements.

Leaf N Concentration [gN g^{-1}]	1st quartile	Median	Mean	3rd quartile
Abies balsamea	0.0146	0.0164	0.0159	0.0177
Abies lasiocarpa	0.0122	0.0138	0.0139	0.0155
Acer rubrum	0.0165	0.0184	0.0189	0.0211
Acer saccharum	0.0169	0.0204	0.0197	0.0232

Betula alleghaniensis	0.0225	0.0265	0.0248	0.03
Betula papyrifera	0.024	0.026	0.0258	0.0283
Betula pendula	0.0255	0.0284	0.0281	0.0313
Fagus grandifolia	0.0129	0.0222	0.02	0.0244
Fagus sylvatica	0.0215	0.0238	0.0235	0.026
Fraxinus excelsior	0.0177	0.022	0.0225	0.0264
Larix decidua	0.018	0.02	0.0198	0.0214
Larix gmelinii	0.0119	0.0157	0.0148	0.0185
Picea abies	0.011	0.0126	0.0127	0.0142
Picea mariana	0.0064	0.0072	0.0075	0.0081
Picea rubens	0.0101	0.0113	0.0116	0.0127
Pinus contorta	0.0115	0.0125	0.0124	0.0137
Pinus nigra	0.0091	0.0118	0.0115	0.0141
Pinus ponderosa	0.0111	0.0125	0.0128	0.0148
Pinus sylvestris	0.0112	0.0132	0.0131	0.0148
Pinus taeda	0.0093	0.0105	0.0105	0.0115
Populus tremuloides	0.0174	0.0226	0.0223	0.0263
Pseudotsuga menziesii	0.0107	0.0118	0.0122	0.0131
Quercus alba	0.0215	0.0228	0.0231	0.0252
Quercus douglasii	0.0163	0.0182	0.0189	0.0212
Quercus ellipsoidalis	0.0194	0.0212	0.0214	0.0233
Quercus petraea	0.0179	0.0208	0.0211	0.0244
Quercus robur	0.0184	0.021	0.0213	0.0241
Quercus rubra	0.0205	0.024	0.0232	0.0257

Table S11: Branch N Concentration [gN g^{-1}] summary statistics for all species with at least 5 measurements.

Branch N Concentration [gN g^{-1}]	1st quartile	Median	Mean	3rd quartile
Abies balsamea	0.0011	0.0035	0.0036	0.0058
Abies sibirica	0.0082	0.0084	0.0085	0.0088
Acer saccharum	0.0037	0.0041	0.0041	0.0048
Alnus rubra	0.0024	0.0055	0.0044	0.0057

Betula pendula	0.0055	0.0067	0.0066	0.0075
Carpinus betulus	0.0022	0.0031	0.0032	0.0038
Cryptomeria japonica	0.0012	0.0015	0.0016	0.0018
Fagus sylvatica	0.003	0.0048	0.0045	0.0058
Fraxinus mandshurica	0.004	0.005	0.0056	0.006
Larix dahurica	0.0044	0.0049	0.005	0.0052
Larix gmelinii	0.004	0.0051	0.0048	0.0054
Larix kaempferi	0.0047	0.0047	0.0048	0.005
Picea abies	0.0024	0.0028	0.0036	0.0053
Pinus albicaulis	0.003	0.003	0.0031	0.0032
Pinus banksiana	0.0044	0.0046	0.0046	0.0049
Pinus densiflora	0.0027	0.0033	0.0033	0.0037
Pinus nigra var. calabrica	0.0024	0.0028	0.0029	0.0034
Pinus resinosa	0.0023	0.0029	0.0043	0.0041
Pinus sylvestris	0.0032	0.0043	0.0043	0.0053
Pinus taeda	0.0042	0.0046	0.0046	0.0052
Pinus thunbergii	0.0019	0.0022	0.0023	0.0026
Populus deltoides	0.0076	0.0107	0.0126	0.0147
Pseudotsuga menziesii	0.0013	0.0036	0.0034	0.0043
Quercus petraea	0.0022	0.0029	0.0034	0.0036
Quercus robur	0.0031	0.0042	0.0045	0.0051

Table S12: Stem N Concentration [gN g^{-1}] summary statistics for all species with at least 10 measurements.

Stem N Concentration [gN g^{-1}]	1st quartile	Median	Mean	3rd quartile
Acer rubrum	0.0007	0.0009	0.0009	0.001
Betula ermanii	0.0012	0.0017	0.0037	0.0042
Betula pendula	0.001	0.0017	0.0015	0.002
Carya ovata	0.0022	0.0025	0.0026	0.0027
Fagus sylvatica	0.0012	0.0013	0.0016	0.0016
Larix principis-rupprechtii	0.0009	0.001	0.0011	0.0012
Liriodendron tulipifera	0.0014	0.0018	0.0018	0.0018

Picea abies	0.0006	0.0009	0.001	0.0013
Picea mariana	0.0003	0.0003	0.0005	0.0004
Pinus banksiana	0.0026	0.0029	0.0025	0.0031
Pinus densiflora	0.0006	0.0006	0.0008	0.0007
Pinus nigra var. calabrica	0.0007	0.0008	0.0008	0.0009
Pinus ponderosa	0.001	0.0011	0.0011	0.0012
Pinus resinosa	0.0009	0.0014	0.0029	0.002
Pinus strobus	0.0005	0.0007	0.0008	0.0009
Pinus sylvestris	0.0007	0.0008	0.001	0.0011
Pinus taeda	0.0007	0.0008	0.0011	0.001
Pinus thunbergii	0.0002	0.0003	0.0003	0.0004
Pseudotsuga menziesii	0.0005	0.0007	0.001	0.0011
Quercus alba	0.003	0.0037	0.0039	0.0048
Quercus michauxii	0.0017	0.0019	0.0019	0.002
Quercus petraea	0.0014	0.0018	0.0022	0.0027
Quercus robur	0.0009	0.001	0.0013	0.0016
Quercus rubra	0.0014	0.002	0.002	0.0021

Table S13: Root N Concentration [gN g^{-1}] summary statistics for all species with at least 5 measurements.

Root N Concentration [gN g^{-1}]	1st quartile	Median	Mean	3rd quartile
Abies bornmulleriana	0.0047	0.0056	0.0057	0.0061
Alnus incana	0.0069	0.0069	0.0073	0.0077
Betula pendula	0.0049	0.0052	0.0057	0.007
Fagus sylvatica	0.0026	0.0029	0.0035	0.0042
Larix kaempferi	0.0026	0.0032	0.0032	0.0033
Larix principis-rupprechtii	0.0062	0.0077	0.0077	0.0095
Picea abies	0.0018	0.0031	0.0046	0.0075
Picea orientalis	0.0045	0.0056	0.0057	0.0062
Pinus contorta	0.0066	0.0083	0.0069	0.0087
Pinus nigra	0.0074	0.0075	0.0074	0.0077
Pinus resinosa	0.0038	0.0051	0.0051	0.0061

Pinus sibirica	0.0086	0.0093	0.0098	0.0113
Pinus sylvestris	0.0022	0.0032	0.0043	0.0065
Populus tremuloides	0.0082	0.0095	0.0102	0.0118
Quercus petraea	0.0048	0.0055	0.0058	0.0061

S8 Partial correlations

Table S14: Partial correlation (in brackets: respective p-values) between leaf, branch, stem, and root N and tree age, mean annual temperature (MAT), mean annual precipitation sum (MAP), and soil N concentration, controlled for the other respective explanatory variables, and for leaf types (BD: broadleaf deciduous, ND: needleleaf deciduous, NE: needleleaf evergreen) separately. In some cases, not enough measurements are available (–).

Partial correlation (p-value)	Leaf N	Branch N	Stem N	Root N
Age (controlled for MAT); BD	0.056 (0.487)	-0.327 (0.004)	-0.380 (0.001)	-0.522 (0.005)
Age (controlled for MAT); ND	-0.322 (0.335)	-0.175 (0.392)	-0.091 (0.316)	-0.014 (0.897)
Age (controlled for MAT); NE	0.313 (0.092)	-0.160 (0.030)	-0.151 (0.013)	-0.063 (0.615)
Age (controlled for MAP); BD	-0.036 (0.576)	-0.322 (0.003)	0.072 (0.364)	-0.465 (0.015)
Age (controlled for MAP); ND	-0.351 (0.219)	-0.041 (0.841)	-0.069 (0.448)	0.082 (0.456)
Age (controlled for MAP); NE	-0.255 (0.174)	0.109 (0.121)	-0.022 (0.703)	-0.134 (0.254)
Age (controlled for Soil N); BD	-0.160 (0.151)	-0.389 (0.004)	-0.438 ($2.7*10^{-4}$)	-0.579 (0.002)
Age (controlled for Soil N); ND	–	-0.187 (0.444)	-0.441 ($1.2*10^{-5}$)	0.289 (0.009)
Age (controlled for Soil N); NE	–	-0.015 (0.914)	-0.146 (0.148)	0.113 (0.636)
MAT (controlled for Age); BD	-0.286 ($2.8*10^{-4}$)	0.201 (0.086)	0.273 (0.024)	0.289 (0.143)
MAT (controlled for Age); ND	0.120 (0.726)	0.033 (0.871)	-0.143 (0.117)	0.278 (0.010)
MAT (controlled for Age); NE	0.552 (0.002)	-0.469 ($1.6*10^{-11}$)	-0.385 ($5.6*10^{-11}$)	0.101 (0.418)
MAT (controlled for MAP); BD	-0.185 ($2.8*10^{-13}$)	0.316 ($3.3*10^{-4}$)	0.236 (0.013)	0.448 (0.005)
MAT (controlled for MAP); ND	0.040 (0.753)	-0.289 (0.136)	-0.018 (0.847)	-0.089 (0.419)
MAT (controlled for MAP); NE	0.121 ($1.6*10^{-5}$)	-0.142 (0.048)	-0.247 ($1.2*10^{-5}$)	0.157 (0.180)
MAT (controlled for Soil N); BD	-0.182 ($3.2*10^{-4}$)	0.367 (0.005)	0.146 (0.326)	0.749 (0.020)
MAT (controlled for Soil N); ND	-0.044 (0.876)	-0.380 (0.120)	-0.556 ($1.3*10^{-8}$)	0.159 (0.159)
MAT (controlled for Soil N); NE	0.044 (0.592)	-0.034 (0.834)	-0.207 (0.101)	0.170 (0.598)
MAP (controlled for Age); BD	0.072 (0.268)	-0.221 (0.043)	-0.038 (0.629)	-0.255 (0.199)
MAP (controlled for Age); ND	0.753 (0.002)	0.319 (0.112)	-0.127 (0.163)	0.479 ($3.5*10^{-6}$)
MAP (controlled for Age); NE	0.234 (0.214)	-0.465 ($2.7*10^{-12}$)	-0.179 (0.002)	-0.116 (0.326)
MAP (controlled for MAT); BD	-0.067 (0.008)	-0.311 ($4.2*10^{-4}$)	-0.215 (0.023)	-0.504 (0.001)
MAP (controlled for MAT); ND	0.298 (0.018)	0.437 (0.020)	-0.026 (0.773)	0.408 ($1.1*10^{-4}$)
MAP (controlled for MAT); NE	0.317 ($< 2*10^{-16}$)	-0.269 ($1.4*10^{-4}$)	-0.057 (0.320)	-0.125 (0.287)
MAP (controlled for Soil N); BD	-0.236 ($2.7*10^{-6}$)	-0.192 (0.123)	-0.073 (0.584)	-0.838 (0.005)
MAP (controlled for Soil N); ND	-0.082 (0.771)	0.274 (0.271)	-0.342 ($9.8*10^{-4}$)	0.226 (0.044)
MAP (controlled for Soil N); NE	0.071 (0.390)	-0.491 (0.001)	0.053 (0.677)	-0.055 (0.858)
Soil N (controlled for Age); BD	-0.120 (0.282)	-0.200 (0.156)	-0.235 (0.059)	0.540 (0.004)
Soil N (controlled for Age); ND	–	-0.198 (0.417)	-0.022 (0.836)	-0.466 ($1.3*10^{-5}$)
Soil N (controlled for Age); NE	–	0.118 (0.394)	0.239 (0.017)	0.186 (0.432)
Soil N (controlled for MAT); BD	0.006 (0.905)	-0.066 (0.628)	-0.059 (0.694)	0.168 (0.666)

Soil N (controlled for MAT); ND	0.062 (0.825)	-0.344 (0.162)	-0.476 ($2.2*10^{-6}$)	-0.421 ($1.0*10^{-4}$)
Soil N (controlled for MAT); NE	0.061 (0.461)	0.054 (0.739)	-0.024 (0.853)	-0.261 (0.413)
Soil N (controlled for MAP); BD	0.058 (0.253)	-0.207 (0.095)	-0.181 (0.170)	0.825 (0.006)
Soil N (controlled for MAP); ND	0.076 (0.788)	-0.079 (0.757)	-0.201 (0.058)	-0.134 (0.238)
Soil N (controlled for MAP); NE	0.054 (0.517)	0.109 (0.504)	-0.034 (0.791)	-0.036 (0.906)

S9 Relationships between leaf N concentrations and season and needle age

We collect information on the measurement month-of-the-year (MOY) as far as this information is available from the compiled studies and the studies contained in the TRY and BAAD databases. In this additional analysis, we focus on leaf N concentration measurements, because leaf N concentrations should be more strongly affected by seasonal variations compared to the other investigated tissues. The relation between leaf N concentrations and measurement MOY for broadleaf deciduous (BD), needleleaf deciduous (ND) and needleleaf evergreen (NE) trees is shown in Fig. S2. We find that

1. the vast majority of measurements has been taken during the summer season (June – September), and
2. there is no clear pattern of lower leaf N concentrations outside the summer season evident in this data.

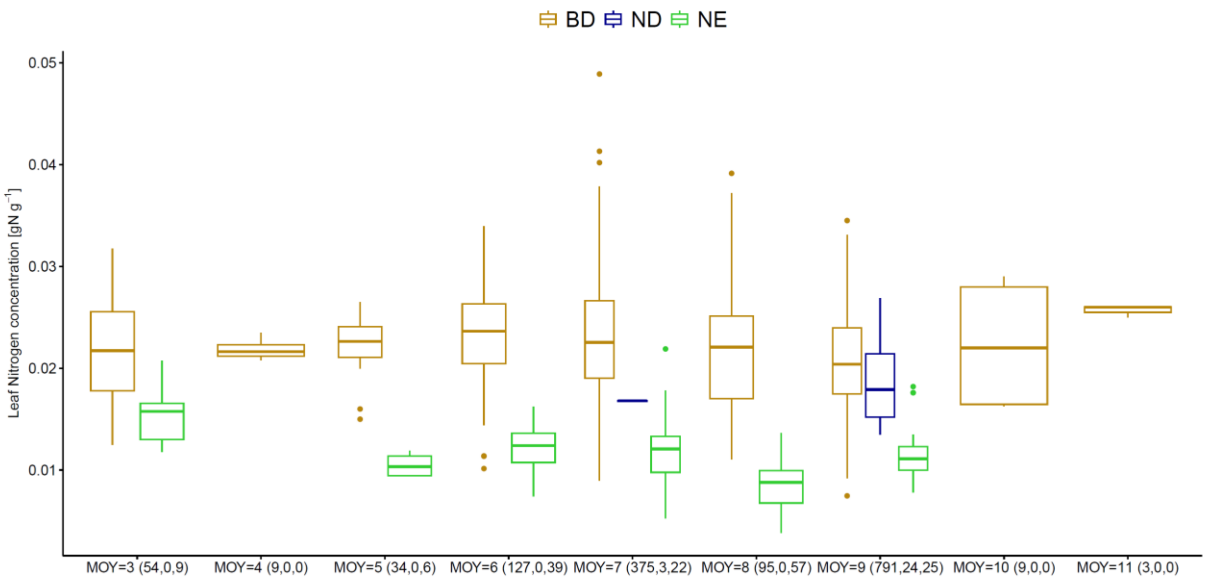

Fig. S2: Relation between leaf N concentrations and measurement month-of-the-year (MOY) for broadleaf deciduous (BD), needleleaf deciduous (ND) and needleleaf evergreen (NE) trees (number of observations for each leaf type in brackets).

We also quantify the significance of differences in leaf N concentrations between different measurement MOY by the p-values of pairwise t-tests. For BD trees, in no case we find significant differences between consecutive months at the 5% level. For NE trees, leaf N concentrations are, for instance, significantly different at the 5% level between July and August and between August and September. However, these differences show contradictory trends and are based on a limited number of measurements, and thus do not show a clear relation between leaf N concentrations and the phenological season. We conclude that our results are not strongly affected by seasonal variations in tissue N concentrations.

In addition, we collect information on needle age as far as available. The relation between leaf N concentrations and needle age for NE trees is shown in Fig. S3. Although the median of the leaf N concentration of 1-year old needles is lower than that of current year needles, again we find no significant difference at the 5% level related to needle age. Based on the few measurements where we have information on needle age, we cannot detect that needle age would strongly affect our results.

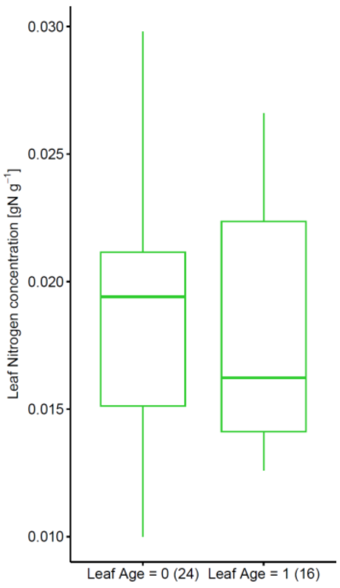

Fig. S3: Relation between leaf N concentrations and needle age for NE trees (number of observations for each leaf type in brackets).

S10 Aridity Index

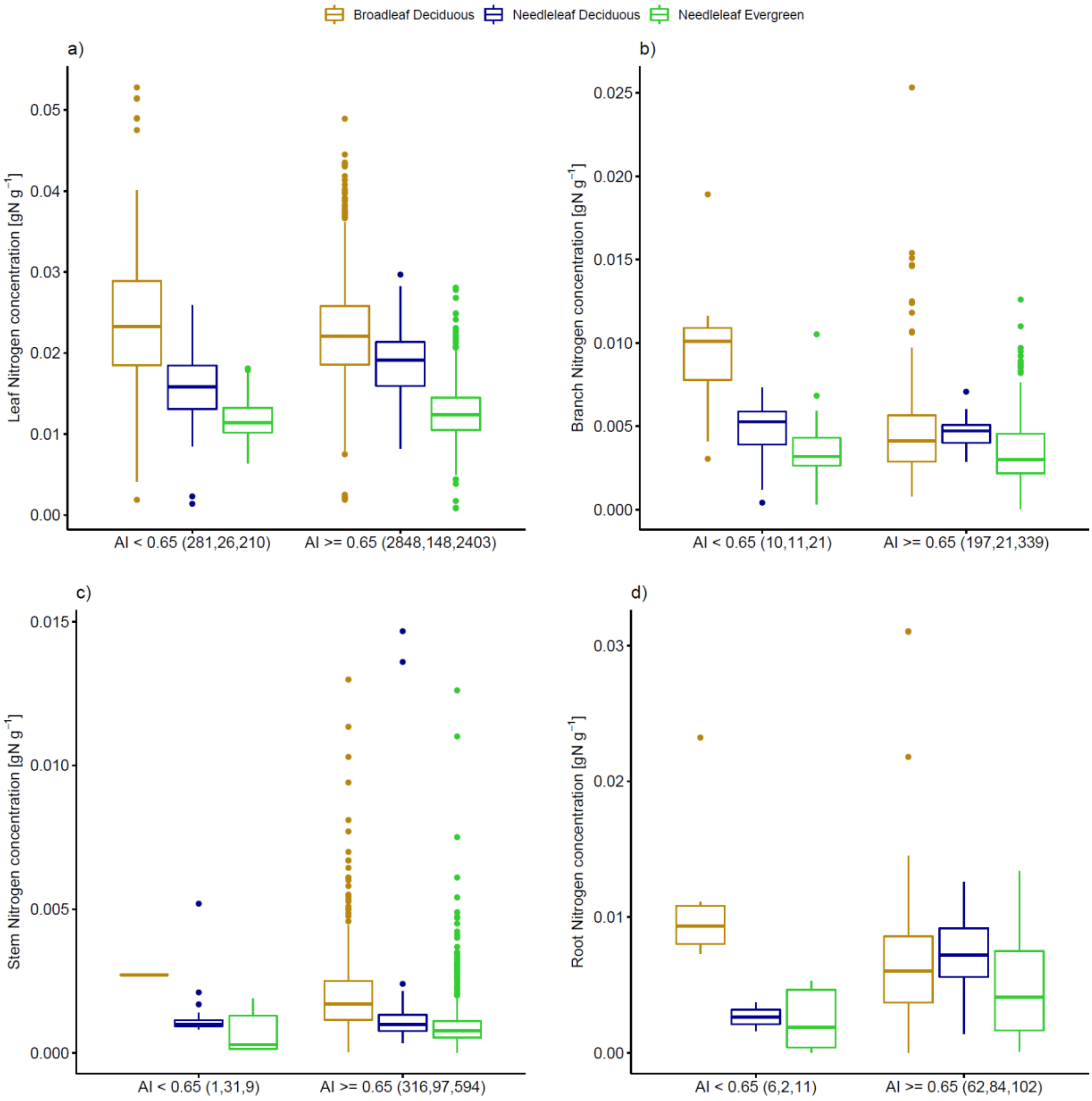

Fig. S4: The variation in a) leaf, b) branch, c) stem, and d) root N concentration for aridity index (AI) classes (AI < 0.65 vs. AI >= 0.65) and for leaf types (broadleaf deciduous, needleleaf deciduous, needleleaf evergreen) separately. The number of observations in each climatic class and for each leaf type is stated in brackets. The box-whisker plots show the median and the interquartile range of values. The whiskers extend up to the most extreme data point which is no more than 1.5 times the interquartile range away from the box. Outliers are drawn as points.

S11 Q-Q plots

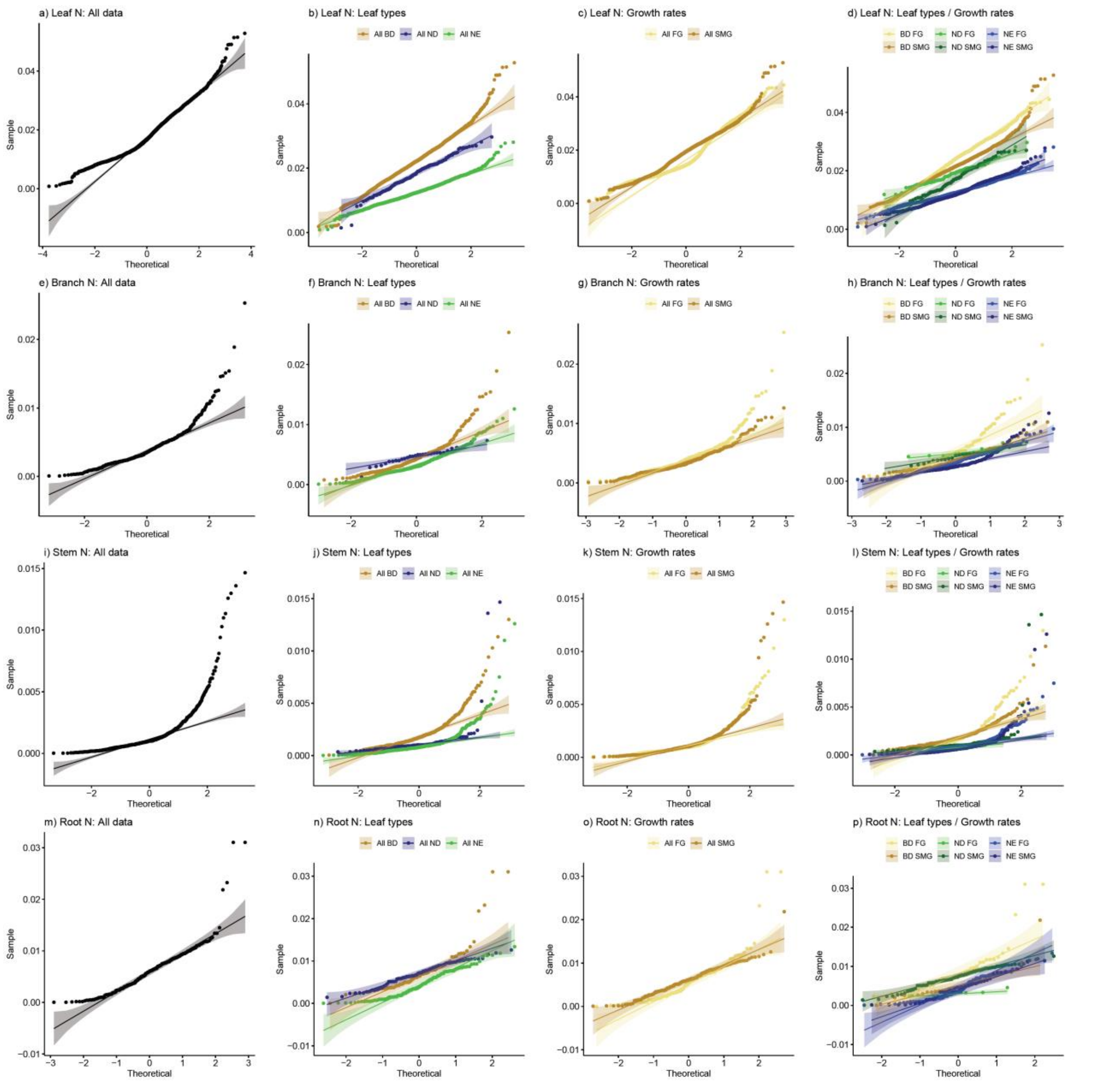

Fig. S5: Q-Q plots comparing the distributions of a-d) leaf, e-h) branch, i-l) stem, and m-p) root N concentration measurements with a standard normal distribution for leaf types and growth classes (BD = broadleaf deciduous, ND = needleleaf deciduous, NE = needleleaf evergreen, SMG = slow-/medium-growing, FG = fast-growing) separately. The straight line visualizes perfect normality, the shaded area shows 95 % confidence intervals.

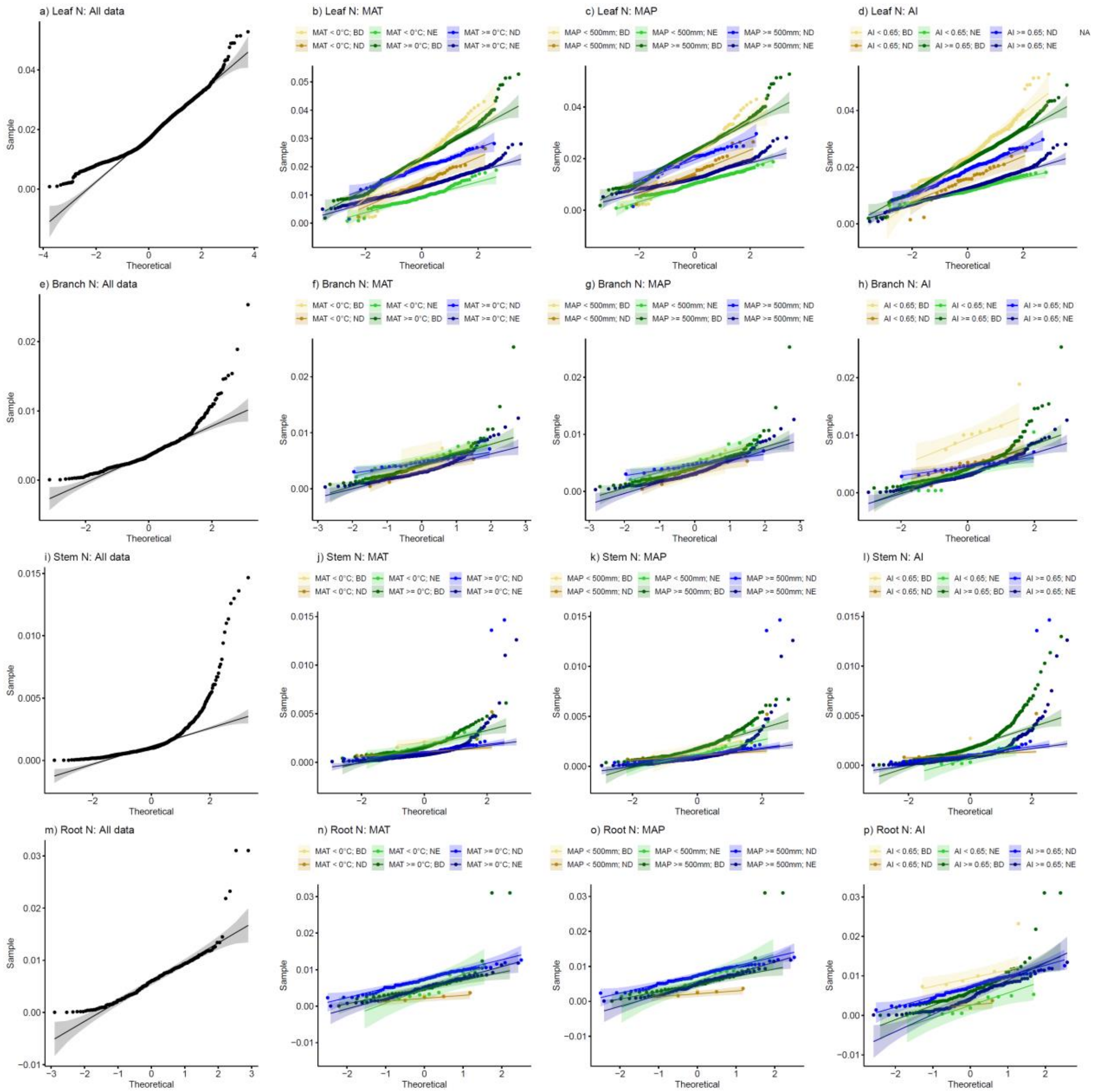

Fig. S6: Q-Q plots comparing the distributions of a-d) leaf, e-h) branch, i-l) stem, and m-p) root N concentration measurements with a standard normal distribution for mean annual temperature (MAT) classes (MAT < 0°C vs. MAT >= 0°C), mean annual precipitation sum (MAP) classes (MAP < 500mm vs. MAP >= 500mm), aridity index (AI) classes (AI < 0.65 vs. AI >= 0.65) and for leaf types (BD = broadleaf deciduous, ND = needleleaf deciduous, NE = needleleaf evergreen) separately. The straight line visualizes perfect normality, the shaded area shows 95 % confidence intervals.

S12 Residual plots

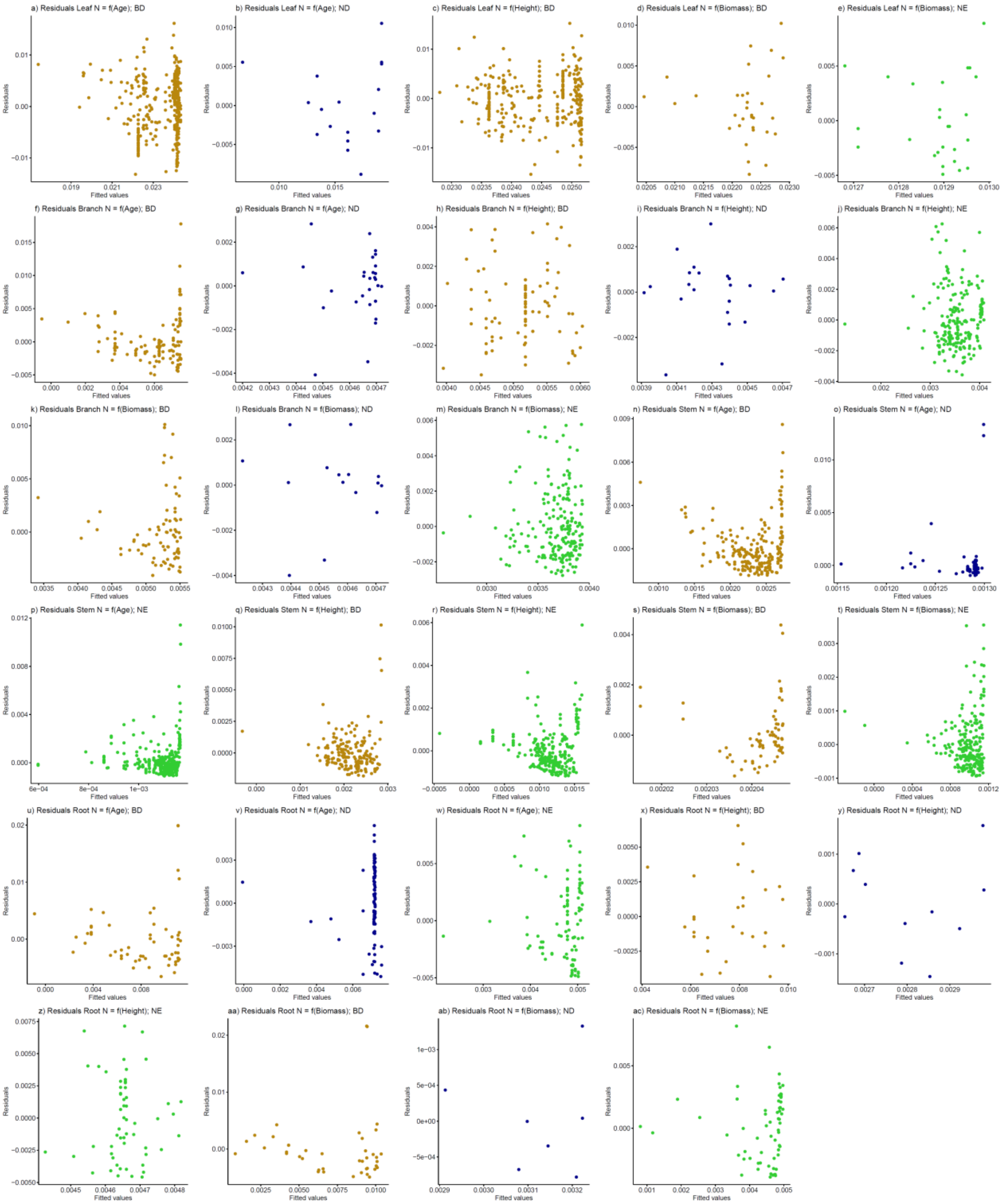

Fig. S7: Residuals from the fitted linear models (shown in Fig. 2) between a-e) leaf, f-m) branch, n-t) stem, and u-ac) root N concentration and tree age, tree height, and compartment biomass for leaf types (BD = broadleaf deciduous, ND = needleleaf deciduous, NE = needleleaf evergreen) separately.

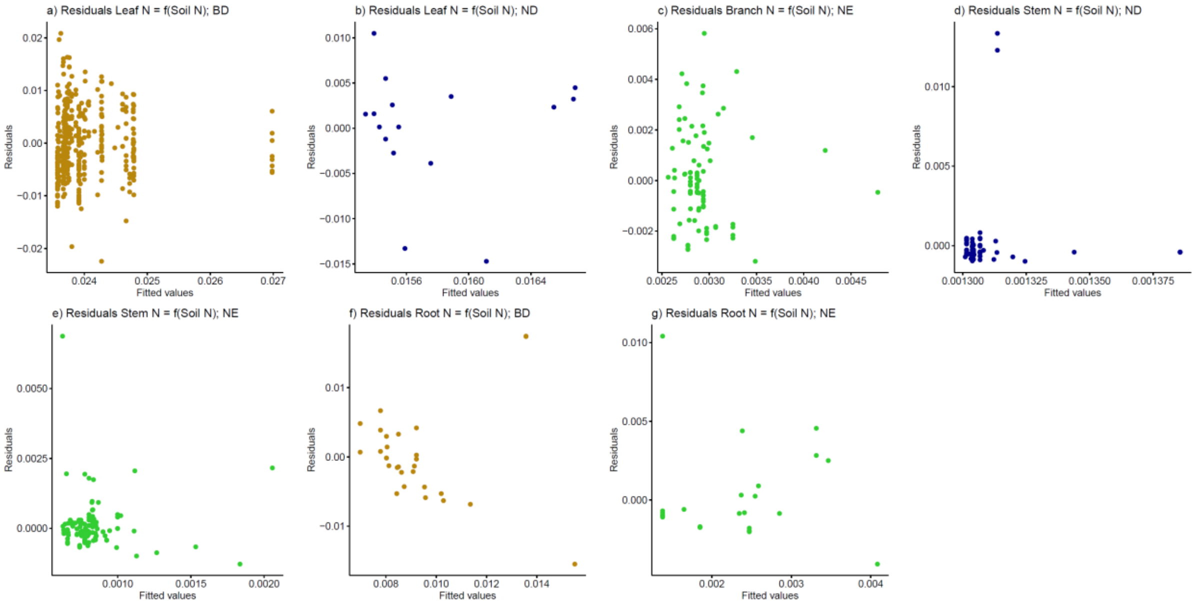

Fig. S8: Residuals from the fitted linear models (shown in Fig. 5) between a-b) leaf, c) branch, d-e) stem, and f-g) root N concentration and soil N concentration for leaf types (BD = broadleaf deciduous, ND = needleleaf deciduous, NE = needleleaf evergreen) separately.