Mycorrhizal type modifies the position of exudation carbon within the root economics space

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Supplementary Table 1 | Description of the studied forest sites. MAT, mean annual temperature; MAP, mean annual precipitation; Trop. For., tropical forest; Subtrop. For., subtropical forest; Temp. For., temperate forest; AM, arbuscular mycorrhizal; ECM, ectomycorrhizal.

Forest sites	Coordinates	MAT (°C)	MAP (mm)	Forest biomes	Sampled species	Family	Mycorrhizal type	Source references
Jianfengling	108.87° E, 18.74° N	20.87	1487	Trop. For.	*Cunninghamia lanceolata*	Cupressaceae	AM	Jiang et al. 2025[1]
Jianfengling	108.87° E, 18.74° N	20.87	1487	Trop. For.	*Podocarpus imbricatus*	Podocarpaceae	AM	Confirmation at genus
Jianfengling	108.87° E, 18.74° N	20.87	1487	Trop. For.	*Manglietia hainanensis*	Magnoliaceae	AM	Confirmation at genus
Jianfengling	108.87° E, 18.74° N	20.87	1487	Trop. For.	*Castanopsis hystrix*	Fagaceae	ECM	Ma et al. 2023[2]
Jianfengling	108.87° E, 18.74° N	20.87	1487	Trop. For.	*Ormosia semicastrata*	Fabaceae	AM	Confirmation at genus
Jianfengling	108.87° E, 18.74° N	20.87	1487	Trop. For.	*Bambusa rigida*	Poaceae	AM	Confirmation at genus
Jianfengling	108.87° E, 18.74° N	20.87	1487	Trop. For.	*Castanopsis carlesii*	Fagaceae	ECM	Jiang et al. 2025[3]
Jianfengling	108.87° E, 18.74° N	20.87	1487	Trop. For.	*Tectona grandis*	Lamiaceae	AM	Li et al. 2022[4]
Jianfengling	108.87° E, 18.74° N	20.87	1487	Trop. For.	*Macaranga denticulata*	Euphorbiaceae	AM	Liu et al. 2017[5]
Xishuangbanna	101.26° E, 21.95° N	22.06	1625	Trop. For.	*Garcinia xishuanbannaensis*	Clusiaceae	AM	Confirmation at genus
Xishuangbanna	101.26° E, 21.95° N	22.06	1625	Trop. For.	*Myristica fragrans*	Myristicaceae	AM	Singh 2005[6]
Xishuangbanna	101.26° E, 21.95° N	22.06	1625	Trop. For.	*Castanopsis faberi*	Fagaceae	ECM	Liu et al. 2018[7]
Xishuangbanna	101.26° E, 21.95° N	22.06	1625	Trop. For.	*Macaranga denticulata*	Euphorbiaceae	AM	Liu et al. 2017[5]
Xishuangbanna	101.26° E, 21.95° N	22.06	1625	Trop. For.	*Dendrocalamus giganteus*	Poaceae	AM	Confirmation at genus
Xishuangbanna	101.26° E, 21.95° N	22.06	1625	Trop. For.	*Knema tenuinervia*	Myristicaceae	AM	Confirmation at genus
Xishuangbanna	101.26° E, 21.95° N	22.06	1625	Trop. For.	*Tectona grandis*	Lamiaceae	AM	Li et al. 2022[4]
Xishuangbanna	101.26° E, 21.95° N	22.06	1625	Trop. For.	*Ochroma pyramidale*	Malvaceae	AM	Confirmation at genus
Xishuangbanna	101.26° E, 21.95° N	22.06	1625	Trop. For.	*Hevea brasiliensis*	Euphorbiaceae	AM	Bao et al. 2025[8]
Dinghushan	112.54° E, 23.17° N	21.41	1785	Subtrop. For.	*Pinus massoniana*	Pinaceae	ECM	Jiang et al. 2025[1]
Dinghushan	112.54° E, 23.17° N	21.41	1785	Subtrop. For.	*Schima superba*	Theaceae	AM	Jiang et al. 2025[1]

Dinghushan	112.54° E, 23.17° N	21.41	1785	Subtrop. For.	*Erythrophleum fordii*	Fabaceae	AM	Li et al. 2022[4]
Dinghushan	112.54° E, 23.17° N	21.41	1785	Subtrop. For.	*Cryptocarya chinensis*	Lauraceae	AM	Hu et al. 2025[9]
Dinghushan	112.54° E, 23.17° N	21.41	1785	Subtrop. For.	*Machilus chinensis*	Lauraceae	AM	Liang et al. 2024[10]
Dinghushan	112.54° E, 23.17° N	21.41	1785	Subtrop. For.	*Castanopsis chinensis*	Fagaceae	ECM	Hu et al. 2025[9]
Dinghushan	112.54° E, 23.17° N	21.41	1785	Subtrop. For.	*Engelhardia roxburghiana*	Juglandaceae	ECM	Tan et al. 2025[11]
Dinghushan	112.54° E, 23.17° N	21.41	1785	Subtrop. For.	*Syzygium odoratum*	Myrtaceae	AM	Confirmation at genus
Dinghushan	112.54° E, 23.17° N	21.41	1785	Subtrop. For.	*Castanopsis fissa*	Fagaceae	ECM	Liang et al. 2020[12]
Dashanchong	113.32° E, 28.40° N	16.89	1416	Subtrop. For.	*Fokienia hodginsii*	Cupressaceae	AM	Jiang et al. 2025[1]
Dashanchong	113.32° E, 28.40° N	16.89	1416	Subtrop. For.	*Schima superba*	Theaceae	AM	Jiang et al. 2025[1]
Dashanchong	113.32° E, 28.40° N	16.89	1416	Subtrop. For.	*Cinnamomum camphora*	Lauraceae	AM	Jiang et al. 2025[1]
Dashanchong	113.32° E, 28.40° N	16.89	1416	Subtrop. For.	*Cunninghamia lanceolata*	Cupressaceae	AM	Jiang et al. 2025[1]
Dashanchong	113.32° E, 28.40° N	16.89	1416	Subtrop. For.	*Lithocarpus glaber*	Fagaceae	ECM	Wang et al. 2024[13]
Dashanchong	113.32° E, 28.40° N	16.89	1416	Subtrop. For.	*Quercus glauca*	Fagaceae	ECM	Cheng et al. 2025[14]
Dashanchong	113.32° E, 28.40° N	16.89	1416	Subtrop. For.	*Vernicia fordii*	Euphorbiaceae	AM	Confirmation at genus
Dashanchong	113.32° E, 28.40° N	16.89	1416	Subtrop. For.	*Litsea coreana*	Lauraceae	AM	Confirmation at genus
Dashanchong	113.32° E, 28.40° N	16.89	1416	Subtrop. For.	*Choerospondias axillaris*	Anacardiaceae	AM	Jiang et al. 2025[1]
Tianmushan	119.46° E, 30.29° N	15.12	1384	Subtrop. For.	*Schima superba*	Theaceae	AM	Jiang et al. 2025[1]
Tianmushan	119.46° E, 30.29° N	15.12	1384	Subtrop. For.	*Cryptomeria japonica*	Cupressaceae	AM	Xi et al. 2024[15]
Tianmushan	119.46° E, 30.29° N	15.12	1384	Subtrop. For.	*Torreya grandis*	Taxaceae	AM	Xi et al. 2024[15]
Tianmushan	119.46° E, 30.29° N	15.12	1384	Subtrop. For.	*Quercus acutissima*	Fagaceae	ECM	Jiang et al. 2025[1]
Tianmushan	119.46° E, 30.29° N	15.12	1384	Subtrop. For.	*Platycladus orientalis*	Cupressaceae	AM	Liang et al. 2023[16]
Tianmushan	119.46° E, 30.29° N	15.12	1384	Subtrop. For.	*Cyclobalanopsis gracilis*	Fagaceae	ECM	Lu et al. 2025[17]
Tianmushan	119.46° E, 30.29° N	15.12	1384	Subtrop. For.	*Paulownia tomentosa*	Paulowniaceae	AM	Comas et al.2014[18]
Tianmushan	119.46° E, 30.29° N	15.12	1384	Subtrop. For.	*Phoebe sheareri*	Lauraceae	AM	Xu et al. 2021[19]
Qinling	108.45° E, 33.59° N	8.29	800	Temp. For.	*Castanea mollissima*	Fagaceae	ECM	Jiang et al. 2025[1]

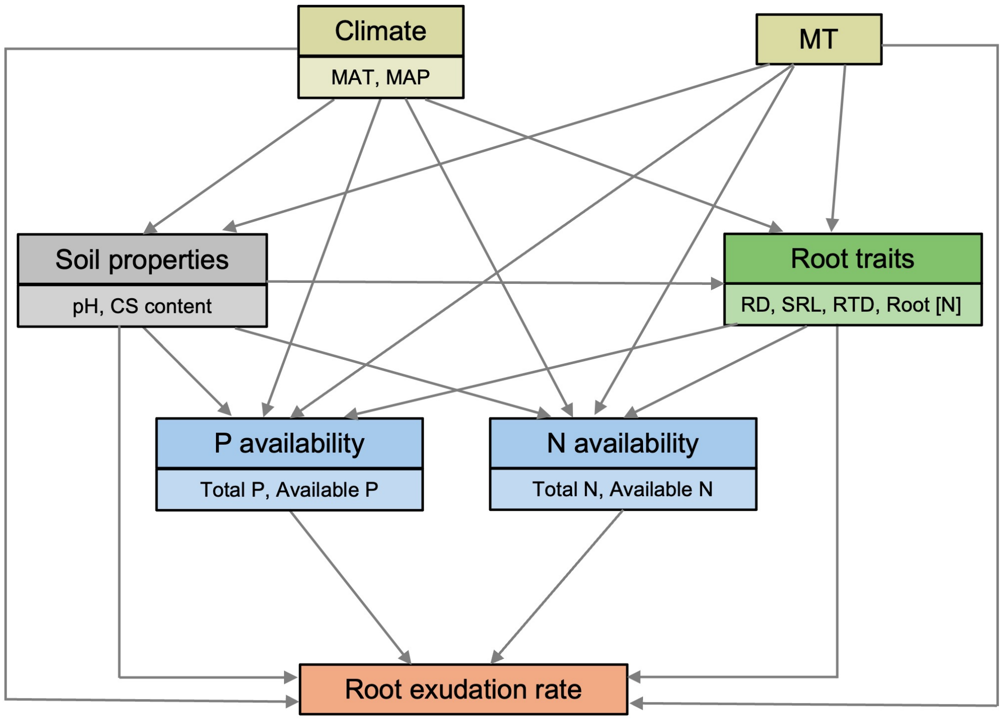
Qinling	108.45° E, 33.59° N	8.29	800	Temp. For.	*Diospyros lotus*	Ebenaceae	AM	Yan et al. 2022[20]
Qinling	108.45° E, 33.59° N	8.29	800	Temp. For.	*Quercus variabilis*	Fagaceae	ECM	Wei et al. 2020[21]
Qinling	108.45° E, 33.59° N	8.29	800	Temp. For.	*Pinus tabuliformis*	Pinaceae	ECM	Liu et al. 2017[5]
Qinling	108.45° E, 33.59° N	8.29	800	Temp. For.	*Broussonetia papyrifera*	Moraceae	AM	He et al. 2017[22]
Qinling	108.45° E, 33.59° N	8.29	800	Temp. For.	*Platycarya strobilacea*	Juglandaceae	ECM	Confirmation at genus
Qinling	108.45° E, 33.59° N	8.29	800	Temp. For.	*Larix potaninii*	Pinaceae	ECM	Ding et al. 2020[23]
Qinling	108.45° E, 33.59° N	8.29	800	Temp. For.	*Pinus armandii*	Pinaceae	ECM	Ding et al. 2020[23]
Qinling	108.45° E, 33.59° N	8.29	800	Temp. For.	*Betula albosinensis*	Betulaceae	ECM	Zhao et al. 2023[24]
Chengde	117.59° E, 40.85° N	6.26	526	Temp. For.	*Larix gmelinii*	Pinaceae	ECM	Yu et al. 2025[25]
Chengde	117.59° E, 40.85° N	6.26	526	Temp. For.	*Juglans mandshurica*	Juglandaceae	AM	Lv et al. 2023[26]
Chengde	117.59° E, 40.85° N	6.26	526	Temp. For.	*Tilia amurensis*	Malvaceae	ECM	Han et al. 2025[27]
Chengde	117.59° E, 40.85° N	6.26	526	Temp. For.	*Betula costata*	Betulaceae	ECM	Yu et al. 2025[25]
Chengde	117.59° E, 40.85° N	6.26	526	Temp. For.	*Pinus tabuliformis*	Pinaceae	ECM	Liu et al. 2017[5]
Chengde	117.59° E, 40.85° N	6.26	526	Temp. For.	*Fraxinus chinensis*	Oleaceae	AM	Confirmation at genus
Chengde	117.59° E, 40.85° N	6.26	526	Temp. For.	*Acer pictum*	Sapindaceae	AM	Confirmation at genus
Chengde	117.59° E, 40.85° N	6.26	526	Temp. For.	*Quercus wutaishanica*	Fagaceae	ECM	Liu et al. 2017[5]
Maoershan	127.67° E, 45.41° N	2.74	595	Temp. For.	*Ulmus davidiana*	Ulmaceae	AM	Zeng et al. 2023[28]
Maoershan	127.67° E, 45.41° N	2.74	595	Temp. For.	*Larix gmelinii*	Pinaceae	ECM	Yu et al. 2025[25]
Maoershan	127.67° E, 45.41° N	2.74	595	Temp. For.	*Pinus koraiensis*	Pinaceae	ECM	Yu et al. 2025[25]
Maoershan	127.67° E, 45.41° N	2.74	595	Temp. For.	*Quercus mongolica*	Fagaceae	ECM	Yu et al. 2025[25]
Maoershan	127.67° E, 45.41° N	2.74	595	Temp. For.	*Fraxinus mandshurica*	Oleaceae	AM	Lv et al. 2023[26]
Maoershan	127.67° E, 45.41° N	2.74	595	Temp. For.	*Betula platyphylla*	Betulaceae	ECM	Yu et al. 2025[25]

Supplementary Table 2 | Functional roles of plant growth-promoting microorganisms.

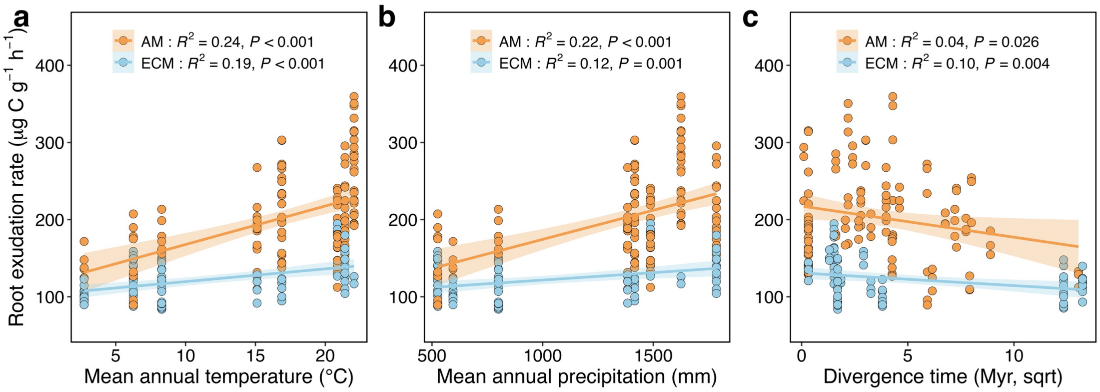
Functional category	Main functions	Examples of mechanisms
Biofertilization	Enhancement of plant nutrient uptake	Carbon dioxide fixation, iron acquisition, nitrogen fixation, phosphate solubilization
Bioremediation	Detoxification of heavy metals and degradation of xenobiotics	Sequestration of metals, enzymatic breakdown of pollutants
Phytohormone and plant signaling production	Production of growth regulators and signaling compounds	Indole-3-acetic acid, gibberellic acid, phospholipids, ubiquinone
Stress control	Alleviation of abiotic and biotic stresses	Neutralization of acid/salt/water stress; production of antibiotics, antifungals, stress proteins
Immune response stimulation	Induction of plant defense systems	Systemic resistance and systemic acquired resistance
Colonization of plant systems	Effective root or tissue colonization	Adhesion, biofilm formation, secretion of colonization-related proteins
Competitive exclusion	Suppressing harmful microbes	Adaptive mutations, secretion systems, cell membrane remodeling, polysaccharide metabolism

Supplementary Table 3 | Phylogenetic signals for root traits across mycorrhizal types. Blomberg's *K* and Pagel's *λ* are presented with their corresponding *P* values, derived from randomization tests and likelihood-based tests, respectively. Values in bold indicate statistically significant phylogenetic signals ($P < 0.05$). AM, arbuscular mycorrhizal; ECM, ectomycorrhizal.

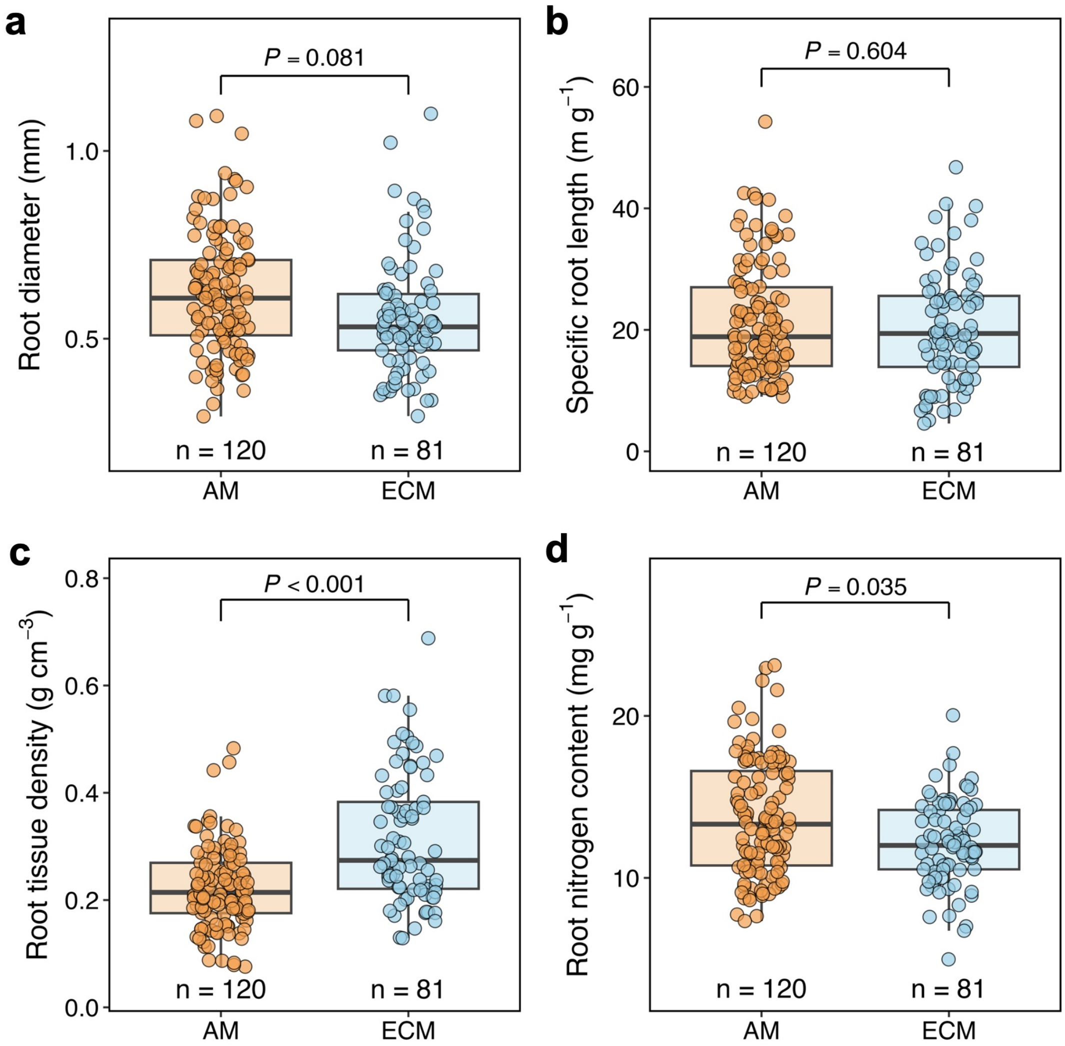
	AM				ECM			
	Blomberg's *K*	*P*	Pagel's *λ*	*P*	Blomberg's *K*	*P*	Pagel's *λ*	*P*
Root exudation rate	0.21	0.312	**0.68**	**0.019**	**0.08**	**0.012**	< 0.001	1
Root diameter	0.17	0.51	< 0.001	1	0.05	0.159	**0.55**	**< 0.001**
Specific root length	0.22	0.333	0.42	0.295	0.03	0.561	< 0.001	1
Root tissue density	0.11	0.807	< 0.001	1	0.03	0.627	< 0.001	1
Root nitrogen content	0.13	0.693	**0.60**	**0.014**	0.06	0.054	< 0.001	1



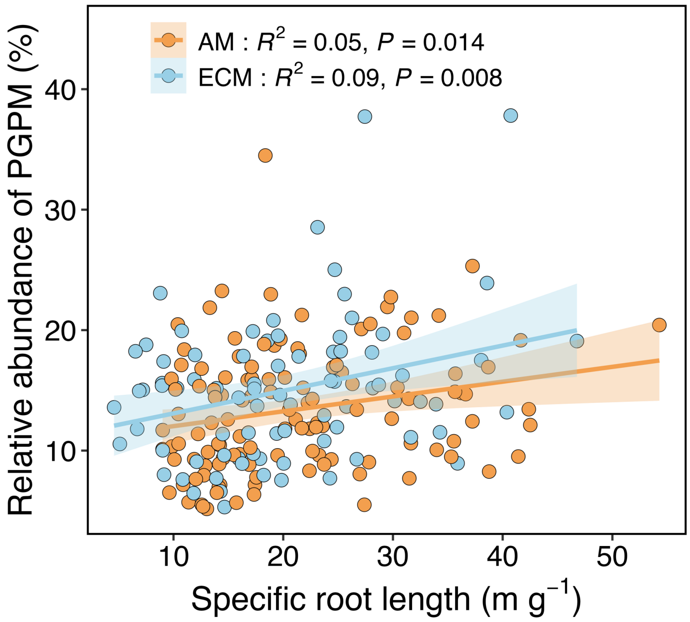
Supplementary Figure 1 | Hypothesized pathways in the partial least squares path model of factors influencing root exudation rate. We hypothesized that climate and mycorrhizal type influence root exudation rate both directly and indirectly through soil properties, root traits, and soil phosphorus availability and nitrogen availability. MAT, mean annual temperature; MAP, mean annual precipitation; MT, mycorrhizal type; CS content: clay and silt content; RD, root diameter; SRL, specific root length; RTD, root tissue density; Root [N], root nitrogen content; P, phosphorus; N, nitrogen.



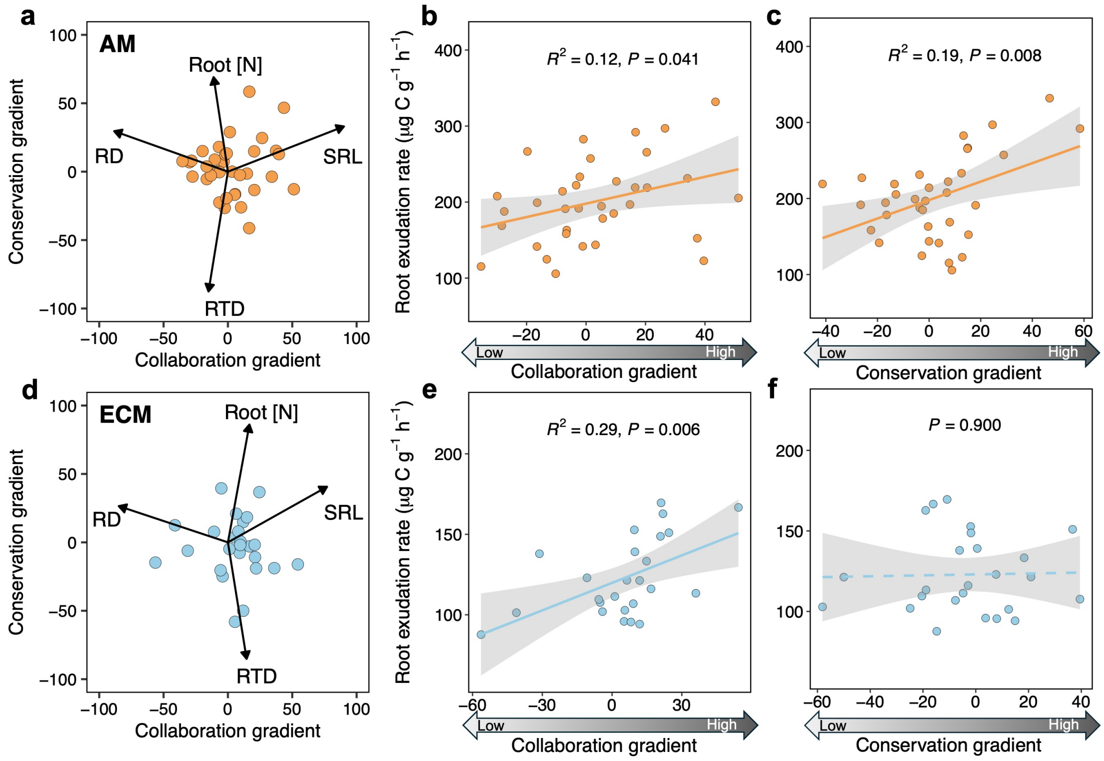
Supplementary Figure 2 | Covariation of root exudation rate with climate and divergence time across mycorrhizal types. Lines represent fitted linear relationships and shaded areas indicate 95% confidence intervals. Solid lines indicate significant relationships (P < 0.05). Statistical significance was assessed using linear regression models (two-sided tests) separately for each mycorrhizal type. AM, arbuscular mycorrhizal; ECM, ectomycorrhizal.



Supplementary Figure 3 | Root traits distribution across arbuscular mycorrhizal (AM) and ectomycorrhizal (ECM) tree species. Statistical significance was assessed using linear mixed-effects model (two-sided tests), with mycorrhizal type as a fixed effect and species nested within site as a random effect. Boxplots show the median (centre line), interquartile range (box), and whiskers extend to 1.5 times interquartile range.



Supplementary Figure 4 | Covariation between relative abundance of plant growth-promoting microbes (PGPM) and specific root length across mycorrhizal types. Lines represent fitted linear relationships and shaded areas indicate 95% confidence intervals. Solid lines indicate significant relationships ($P < 0.05$). Statistical significance was assessed using linear regression model (two-sided tests) separately for each mycorrhizal type. AM, arbuscular mycorrhizal; ECM, ectomycorrhizal.



Supplementary Figure 5 | Root economics space and the covariation of root exudation rate with the collaboration and conservation gradients across arbuscular mycorrhizal (AM, a-c) and ectomycorrhizal (ECM, d-f) tree species. Lines represent fitted linear relationships and shaded areas indicate 95% confidence intervals. Solid lines indicate significant relationships ($P < 0.05$), while dashed lines indicate non-significant relationships ($P > 0.05$). Statistical significance was assessed using linear regression models (two-sided tests) separately for each mycorrhizal type. RD, root diameter; SRL, specific root length; RTD, root tissue density; Root [N], root nitrogen content.

Supplementary References

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