

Plasticity of roots to acquire soil nutrients: From the tropics to the Arctic

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Abstract

Since the first vascular plants appeared on land at least 430 million years ago, plant-soil feedback has started through the root-soil interface. Plant species have inherently specific and diverse root traits, but root functional and morphological plasticity is important to respond to soil changes or diversity in terms of nutrient forms and availabilities, especially in ecosystems with low plant species diversity. This paper synthesized how tree plasticity facilitates soil nutrient acquisition from the tropics to the Arctic. The fine roots of dipterocarp (*Shorea laevis*) and rhizosphere microbes increase malate release in acidic soils for phosphorus solubilization, aluminum detoxification, and lignin degradation. The development of finer roots is a well-known strategy for the acquisition of limited nutrients, but the allocation of roots foraging “nutrient hotspots” in deeper soil is an alternative strategy. Scots pine increases the allocation of finer roots into the subsoil to solubilize P bonded to Al/Fe oxides in fine-textured podzol, but not in the coarse-textured podzol with deeper nutrient hotspots. The black spruce trees increase the biomass allocation to the belowground to acquire soil nitrogen, especially when black spruce roots absorb urea in the shallow soil on permafrost. Even in northern ecosystems with limited species diversity, a combination of functional plasticity and vertical plasticity of root system architecture facilitates soil phosphorus or nitrogen limitation.

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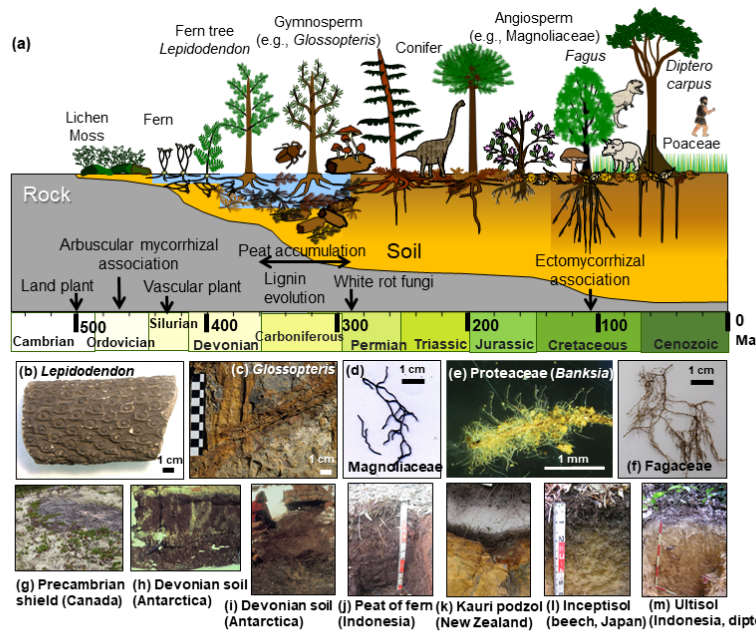


Fig. 1 Evolution of plant and soil (a), roots of representative plants (b–f), and soil (g–m). Plant divergence date is based on Lu et al. (2014) and Li et al. (2019). Photo credit: Pablo Alberto Salguero Quiles (b), Dr. Robert A Gastaldo (c), h, and Dr. Gregory J. Retallack (h–i).

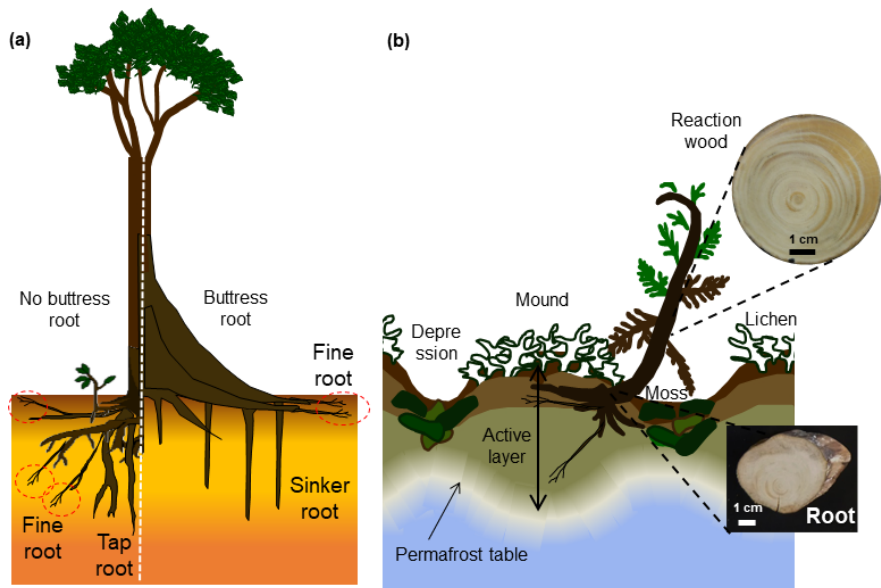


Fig. 2 Advantage of buttress root to develop root mat in tropical forest (a), and root expansion of drunken black spruce trees on shallow permafrost (b).

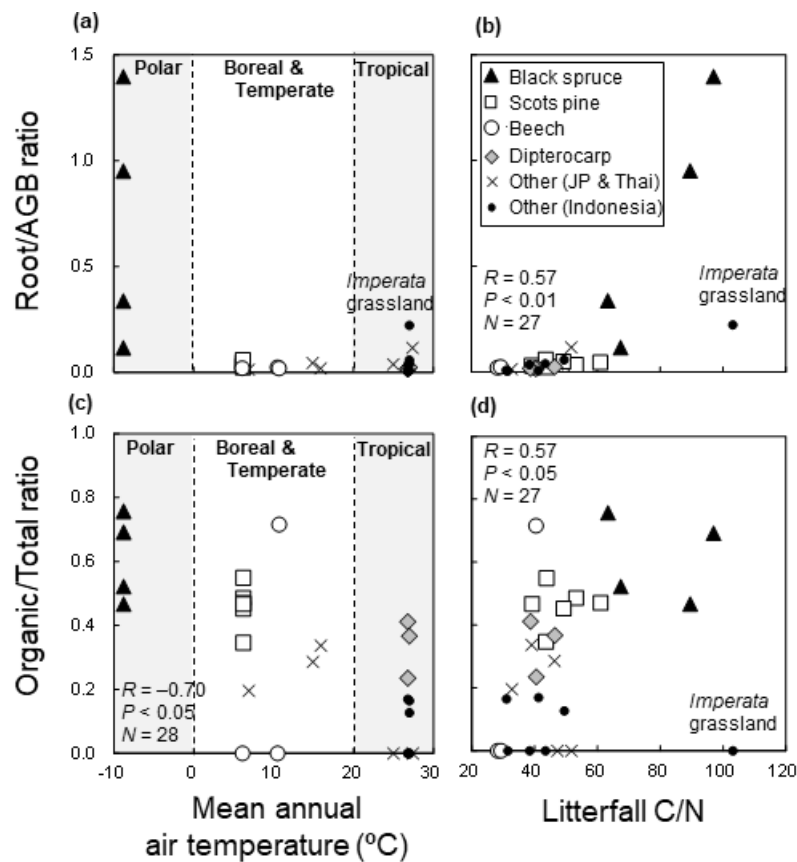


Fig. 3 Fine root biomass to aboveground biomass (AGB) ratio related to mean annual air temperature (a) and litterfall C/N ratio (b), and ratio of fine root biomass in the organic layer to fine root biomass in the whole soil profile related to mean annual air temperature (c) and litterfall C/N ratio (d). Data source is presented in Table S1.

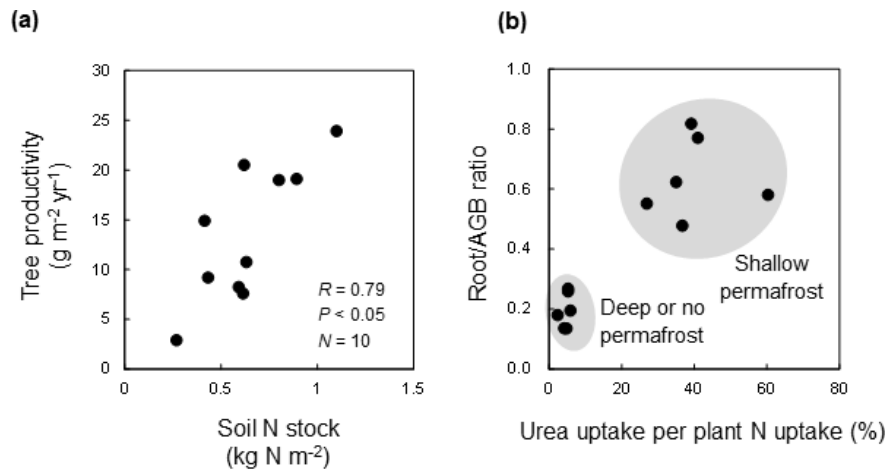


Fig. 4 Relationships between annual tree productivity and soil nitrogen stock in the active layer (a) and between fine root biomass to aboveground biomass (AGB) ratio and the contribution of urea to soil N assimilated in tracer study (b). Data source is Fujii and Hayakawa (2022c).

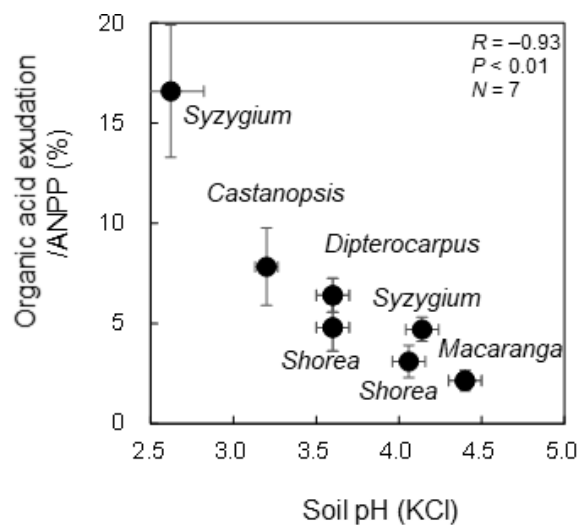


Fig. 5 Relationship between the proportion of root exudation rate of three organic acids (oxalate, malate, and citrate) relative to aboveground net primary production (ANPP) and soil pH. Data sources are Aoki et al. (2012) and Fujii et al. (2021b). Bar indicates standard errors ($N = 3-5$).

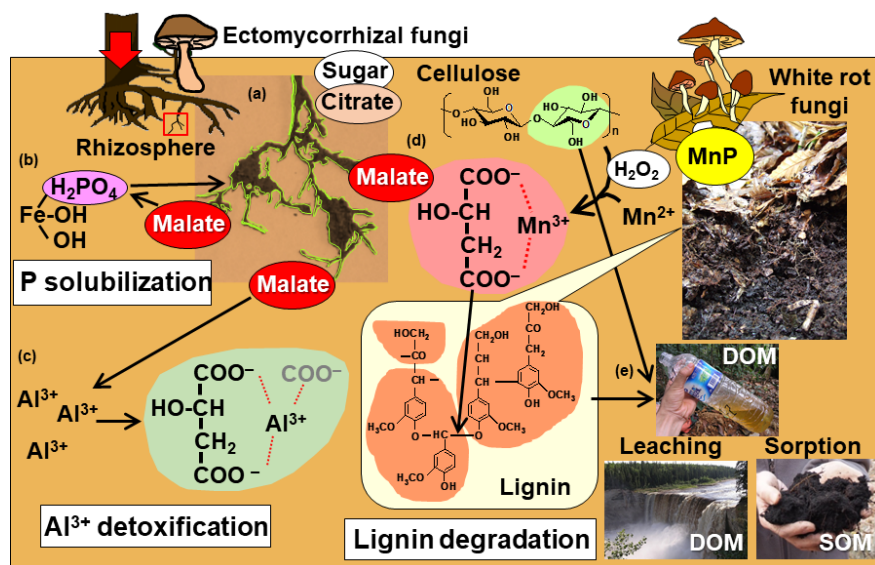


Fig. 6 Malate-mediated biogeochemistry in forest soil. Root exudates such as sugar and citrate are transformed to malate by ectomycorrhizal fungi and rhizosphere microbes (a). Malate releases phosphate bonded to iron oxides in rhizosphere (b), while malate detoxifies Al^{3+} in soil solution by forming complex (c). Malate also forms a complex with Mn^{3+} , which is activated by H_2O_2 derived from cellulose decomposition. This works as a diffusible oxidant [mediator of manganese peroxidase (MnP) from white rot fungi] to oxidize lignin in litter (d), and lignin-derived and cellulose-derived fragments constitute a majority of dissolved organic matter (DOM) from the organic layer, and contribute to DOM export to and soil organic matter (SOM) storage (e). Data source is Fujii et al. (2021b).

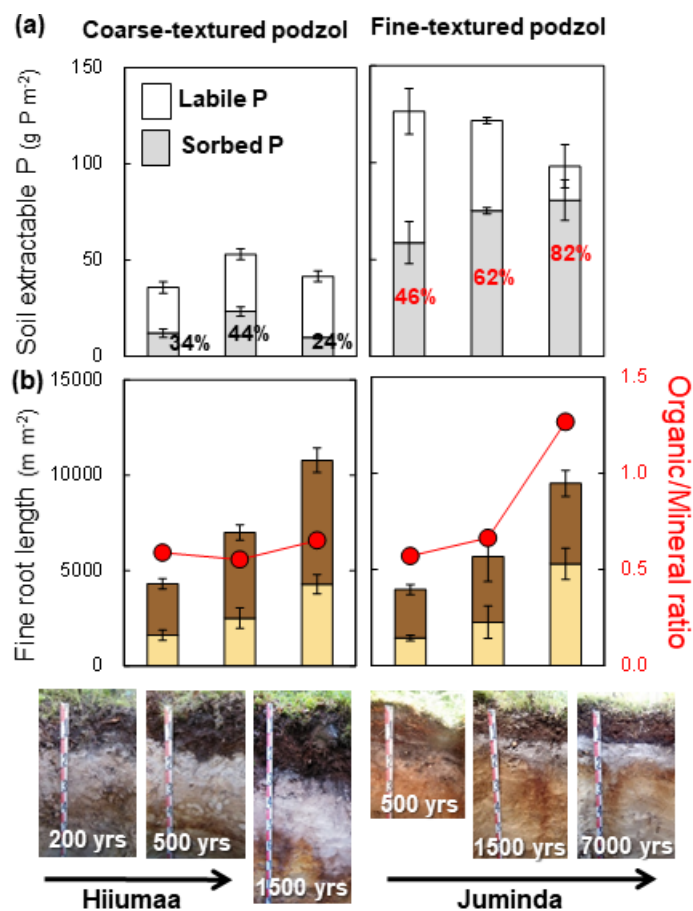


Fig. 7 Soil extractable phosphorus (P) in fine-textured podzol and coarse-textured podzol along coastal sand dune chronosequences in Estonia (a) and the sum of fine root length in the soil profile and the ratio of fine root length in the organic layer to fine root length in the mineral soil (b). Data source is Fujii et al. (2021c).

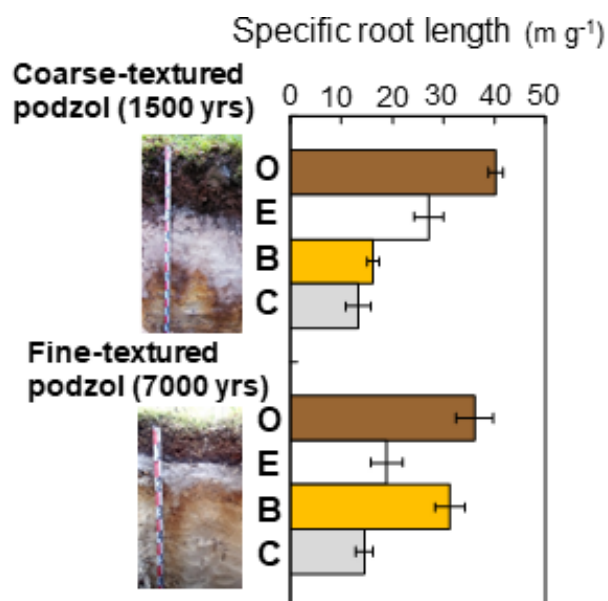


Fig. 8 Specific root length at each soil horizons in fine-textured podzol (1500 yrs old) and coarse-textured podzol (7000 yrs old). Bar indicates standard errors ($N = 5$). Data source is Fujii et al. (2021c).