

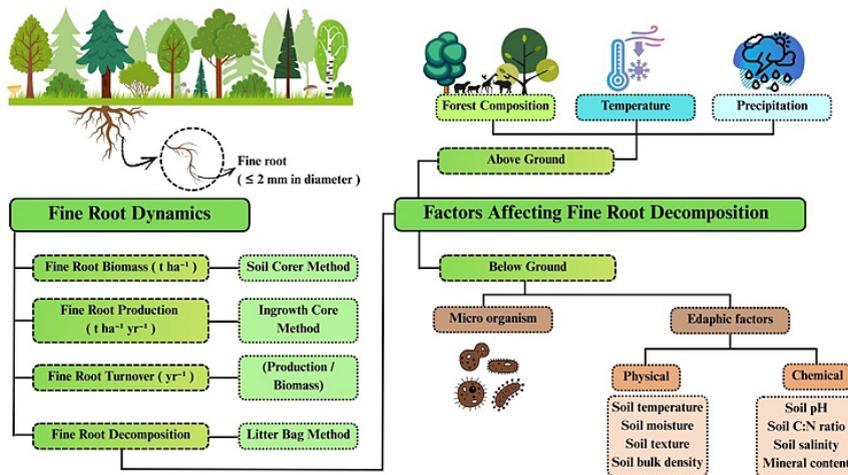
Unraveling the Unfathomable Domain of Fine Root Dynamics in the Forest Ecosystems

SURENDRA SINGH BARGALI

Department of Botany, DSB Campus, Kumaun University, Nainital, Uttarakhand, India.

**Article History**

Published on: 26 November 2025

**Introduction**

The fine roots are the key determinants of belowground ecological processes that govern sustenance of the forest ecosystems. Fine roots have a major role in water and nutrient acquisition and regulation of carbon, nitrogen dynamics through belowground carbon and nitrogen fluxes and decomposition.^{1,2,3,4} Fine root production rates vary within a growing season with peak values during months with ample amount

CONTACT Surendra Singh Bargali ✉ surendrakiran@rediffmail.com 📍 Department of Botany, DSB Campus, Kumaun University, Nainital, Uttarakhand, India.



© 2025 The Author(s). Published by Enviro Research Publishers.

This is an  Open Access article licensed under a Creative Commons license: Attribution 4.0 International (CC-BY).Doi: <http://dx.doi.org/10.12944/CARJ.13.3.1>

of resource availability and suitable microclimatic conditions.^{5,6} Fine roots are functionally important fraction of net primary production which act as a source and sink for carbon in the terrestrial ecosystems. Due to their high turnover rates and association with soil biota, they have a major role in soil stabilization and nutrient restoration.^{7,8}

The ecologically significant physiological and functional traits of fine roots have drawn the attention of ecologists in the recent years resulting in researches focused on fine root ecology. Further researches are required to explore the complex relationships between root traits and strengthen the foundation of their functional importance at ecosystem level. Multidisciplinary assessment including detailed investigation of fine root morphology, physiology, chemical attributes, and their interaction with the soil environment is prerequisite to link belowground traits to ecosystem functioning.^{9,10} The forest land use changes due to rapid urbanization and population growth and its deleterious impact on forest structure and belowground systems need intricate detailing to interpret the overall ecological impact.^{11,12,13}

Multifaceted Influencers of Fine Root Dynamics

Fine root dynamics encompasses complex network of biotic and abiotic factors which are entangled to balance the ecological proceedings at ecosystem level. Fine roots adapt to different strategies for growth and survival under varying environmental gradients.^{14,15} The abiotic factors such as temperature, moisture, soil texture, soil pH significantly affect the microbial activities, fine root growth and decomposition.¹⁶ The relationship between fine root productivity and temperature, precipitation in forest ecosystems has been well investigated and documented.^{17,18} The organic constituents of the fine roots such as lignin, carbon and nitrogen content also have a role in fine root dynamics, as higher lignin contents make the fine roots recalcitrant and less susceptible to degradation. The microclimatic conditions of the soil such as nutrient, water availability, aeration, microbial communities along with the ecological associations of fine roots with other species also influences the physiological and functional ability of fine roots and affects fine root production.^{19,20}

The floristic composition, forest structure, diversity and density of tree species also affect the fine root dynamics, as fine root system attributes vary tremendously among different tree species.²¹ The multifariousness in soil nutrient distribution also affects the spatial distribution of fine roots. High species richness has a positive impact on fine root dynamics, as it results in competition among the species for resources, ultimately leading to niche differentiation and better use of soil resources for higher fine root productivity.²²

Soil and Fine Root Interface

Fine roots play a crucial role in altering physical, chemical and biological activity of soil and thus ability to transform and stabilize soil and in turn morphological and physiological changes in fine root with changing edaphic environment.²³ Fine root proliferation results in increased porosity of soil that improves air circulation and enhances microbial activities. The soil bulk density also effects the fine root dynamics, as higher bulk density of soil results in mechanical resistance that obstruct the proliferation of fine roots.²⁴ The compaction of soil is reduced which facilitates water infiltration.^{25,26} The nitrogen and carbon concentrations of the soil regulate the metabolic activities in the fine roots and soil microbes,^{27,28,29} thus affect the physiological functions such as nutrient uptake and transport and resource allocation.^{30,31} Fine roots exudates various substances such sugars, amino acids, proteins, phenolic compounds that act as nutrient and energy supplier for the microbial communities residing the soil, thus are involved in rhizosphere priming and maintaining soil health.^{32,33}

Ecological Aspects of Fine Roots

Fine roots account for a major fraction of net primary productivity in forest ecosystems and the turnover and decomposition of fine roots adds 30–80% of organic carbon to the soil.^{34,35} Fine root litter accounts for

33% of annual forest litter inputs, thus have a crucial role in returning nutrients back to the ecosystem.^{36,35,37} Fine roots also play a crucial role in belowground carbon sequestration and nutrient cycling.³⁸ Fine roots are highly sensitive to changing environments and adapt to different resource use strategies under varying environmental limitations.³⁹

Conclusion

The current strengths, challenges, and gaps in the field of fine root needs to be identified and evaluated to formulate future research in the field of root ecology based on systematic framework of hypothesis to establish well-fortified links between root traits and their benefaction to the effectiveness of a forest ecosystem. The impact of fine root functional traits on rhizosphere environment needs to be assessed to determine overall community structure and resource utilization in forest ecosystems. Coupling vegetational attributes, soil characteristics and factors involved with fine roots at wider scale might have implications for sustainable management of forest lands under constantly changing landscapes.

References

1. Usman S, Singh SP, Rawat YS, Bargali SS. Fine root decomposition and nitrogen mineralization patterns in *Quercus leucotrichophora* and *Pinus roxburghii* forests in Central Himalaya. *For Ecol Manag.* 2000;131:191-199.
2. Batkhuu NO, Byambadorj SO, Park BB, Terzaghi M, Scippa GS, Stanturf JA, Donato C, Antonio M. Root biomass distribution of *Populus sibirica* and *Ulmus pumila* afforestation stands is affected by watering regimes and fertilization in the Mongolian semi-arid steppe. *Front Plant Sci.* 2021;12:638828. <https://doi.org/10.3389/fpls.2021.638828>
3. De la Riva EG, Borden K, Ostonen I, Saengwilai P, Prieto I. Editorial: Root functional traits: from fine root to community-level variation. *Front Plant Sci.* 2023;14:1152174. <https://doi.org/10.3389/fpls.2023.1152174>
4. Pandey R, Bargali SS, Bargali K, Karki H, Chaturvedi RK. Dynamics of nitrogen mineralization and fine root decomposition in sub-tropical *Shorea robusta* Gaertner f. forests of Central Himalaya. *Sci Total Environ.* 2024;921. <https://doi.org/10.1016/j.scitotenv.2024.170896>
5. Fortier J, Truax B, Gagnon D, Lambert F. Abiotic and biotic factors controlling fine root biomass, carbon and nutrients in closed-canopy hybrid poplar stands on post-agricultural land. *Sci. Rep.* 2019;9(1):342. <https://doi.org/10.1038/s41598-019-42709-6>
6. Pandey R, Bargali SS, Bargali K. Seasonal dynamics of soil Inorganic N and N-mineralization in sub-tropical Sal forest in Central Himalaya, India. *J Sci Res.* 2022;66(3):161-175. <https://doi.org/10.37398/JSR.2022.660320>
7. Hao H, Wei Y, Cao D, Guo Z, Shi Z. Vegetation restoration and fine roots promote soil infiltrability in heavy-textured soils. *Soil Tillage Res.* 2020;198:104542. <https://doi.org/10.1016/j.still.2019.104542>
8. Karki H, Bargali K, Bargali SS. Spatial and seasonal pattern of fine root biomass and turnover rate in different land use systems in Central Himalaya, India. *Russ J Ecol.* 2021;52(1):36–48.
9. Freschet GT, Roumet C, Comas LH, Weemstra M, Bengough AG, Rewald B, Bardgett RD, De Deyn GB, Johnson D, Klimešová J, Lukac M, McCormack ML, Meier IC, Pages L, Poorter H, Prieto I, Wurzbürger N, Zadworny M, Bagniewska-Zadworna A, Blancaflor EB, Brunner I, Gessler A, Hobbie SE, Iversen CM, Mommer L, Picon-Cochard C, Postma JA, Rose L, Ryser P, Scherer-Lorenzen M, Soudzilovskaia NA, Sun T, Valverde-Barrantes OJ, Weigelt A, York LM, Stokes A. Root traits as drivers of plant and ecosystem functioning: current understanding, pitfalls and future research needs. *New Phytol.* 2021;232:1123-1158. <https://doi.org/10.1111/nph.17072>
10. Pandey R, Bargali SS, Bargali K, Pandey VC. Temporal variability in fine root dynamics in relation to tree girth size in sub-tropical *Shorea robusta* forests. *Land Degrad Dev.* 2023;34(5):1522-1537. <https://doi.org/10.1002/ldr.4550>

11. Karki H, Bargali K, Bargali SS. Spatial and temporal trends in soil N-mineralization rates under the agroforestry systems in Bhabhar belt of Kumaun Himalaya, India. *Agrofor Syst.* 2021;95:1603-1617. <https://doi.org/10.1007/s10457-021-00669-9>
12. Cornejo NS, Becker JN, Hemp A, Hertel D. Effects of land-use change and disturbance on the fine root biomass, dynamics, morphology, and related C and N fluxes to the soil of forest ecosystems at different elevations at Mt. Kilimanjaro (Tanzania). *Oecologia.* 2023;201:1089–1107. <https://doi.org/10.1007/s00442-023-05353-6>
13. Tran LTN, An JY, Carayugan MB, Hernandez JO, Rahman SA, Youn WB, Carvalho JI, Jo MS, Han SH, Nguyen H-H, Park BB. Fine-root distribution and soil physicochemical property variations in four contrasting urban land-use types in South Korea. *Plants.* 2024;13:164. <https://doi.org/10.3390/plants13020164>
14. Karki H, Bargali K, Bargali SS. Dynamics of fine root and soil nitrogen in *Mangifera indica* based agroforestry systems in Central Himalaya, India. *Land Degrad Dev.* 2022;33(17):3523-3538. <https://doi.org/10.1002/ldr.4406>
15. Saha S, Huang L, Khoso MA, Wu H, Han D, Ma X, Poudel TR, Li B, Zhu M, Lan Q, Sakib N, Wei R, Islam MZ, Zhang P, Shen H. Fine root decomposition in forest ecosystems: an ecological perspective. *Front Plant Sci.* 2023;14:1277510. <https://doi.org/10.3389/fpls.2023.1277510>
16. Lull C, Gil-Ortiz R, Bautista I, Lidon A. Seasonal variation and soil texture-related thinning effects on soil microbial and enzymatic properties in a semiarid pine forest. *Forests.* 2023;14(8):1674. <https://doi.org/10.3390/f14081674>
17. Gao G, Liu Z, Wang Y, Wang S, Ju C, Gu J. Tamm review: Fine root biomass in the organic (O) horizon in forest ecosystems: Global patterns and controlling factors. *For Ecol Manage.* 2021;491:119208. <https://doi.org/10.1016/j.foreco.2021.119208>
18. Li W, Wang C, Liu H, Wang W, Sun R, Li M, Shi Y, Zhu D, Du W, Ma L, Fu S. Fine root biomass and morphology in a temperate forest are influenced more by canopy water addition than by canopy nitrogen addition. *Front Ecol Evol.* 2023;11:1132248. <https://doi.org/10.3389/fevo.2023.1132248>
19. Bardule A, Polmanis K, Krumsteds LL, Bardulis A, Lazdins A. Fine root morphological traits and production in coniferous and deciduous tree forests with drained and naturally wet nutrient-rich organic soils in hemiboreal Latvia. *iForest.* 2023;16:165-173. <https://doi.org/10.3832/ifor4186-016>
20. Pandey R, Bargali SS, Bargali K, Karki H, Kumar M, Sahoo UK. Fine root dynamics and associated nutrient flux in Sal dominated forest ecosystems of Central Himalaya, India. *Front for Glob Change.* 2023;5:1064502. <https://doi.org/10.3389/ffgc.2022.1064502>
21. Herzog C, Hartmann M, Frey B, Stierli B, Rumpel C, Buchmann N, Brunner I. Microbial succession on decomposing root litter in a drought-prone Scots pine forest. *ISME J.* 2019;13(9):2346–2362. <https://doi.org/10.1038/s41396-019-0436-6>
22. Wang Z, Cai Y, Liang J, Zhong Q, Jiang H, Lu X, Gao X, Yu S, Dai X. Effects of tree species diversity on fine root morphological characteristics, productivity and turnover rates. *Forests.* 2022;13:1740. <https://doi.org/10.3390/f13101740>
23. Li T, Ren J, He W, Wang Y, Wen X, Wang X, Ye M, Chen G, Zhao K, Hou G, Li X, Fan C. Anatomical structure interpretation of the effect of soil environment on fine root function. *Front Plant Sci.* 2022;13:993127. <https://doi.org/10.3389/fpls.2022.993127>
24. Cao Y, Su Y, Huang G, Li Y. Soil texture modulates the intensity of fertile islands through affecting the distribution of shrub fine roots. *J Arid Environ.* 2021;189:104503. <https://doi.org/10.1016/j.jaridenv.2021.104503>
25. Wendel AS, Bauke SL, Amelung W, Knief C. Root-rhizosphere-soil interactions in biopores. *Plant Soil.* 2022;475(1-2):253–277. <https://doi.org/10.1007/s11104-022-05406-4>
26. Manral V, Bargali K, Bargali SS, Karki H, Chaturvedi RK. Seasonal dynamics of soil microbial biomass C, N and P along an altitudinal gradient in Central Himalaya, India. *Sustainability.* 2023;15:1651. <https://doi.org/10.3390/su15021651>
27. Padalia K, Bargali SS, Bargali K, Khulbe K. Microbial biomass carbon and nitrogen in relation to cropping systems in Central Himalaya, India. *Curr Science.* 2018;115(9):1741-1750.

28. Bargali K, Manral V, Padalia K, Bargali SS, Upadhyay VP. Effect of vegetation type and season on microbial biomass carbon in Central Himalayan forest soils, India. *Catena*. 2018;171(12):125-135. <https://doi.org/10.1016/j.catena.2018.07.001>
29. Manral V, Bargali K, Bargali SS, Jhariya MK, Padalia K. Relationships between soil and microbial biomass properties and annual flux of nutrients in Central Himalayan forests, India. *Land Degrad Dev*. 2022;33(12):2014-2025. <https://doi.org/10.1002/ldr.4283>
30. Bargali SS, Padalia K, Bargali K. Effects of tree fostering on soil health and microbial biomass under different land use systems in central Himalaya. *Land Degrad Dev*. 2019;30(16):1984-1998. <https://doi.org/10.1002/ldr.3394>
31. Manral V, Bargali K, Bargali SS, Shahi C. Changes in soil biochemical properties following replacement of Banj oak forest with Chir pine in Central Himalaya, India. *Ecol Process*. 2020;9:30. <https://doi.org/10.1186/s13717-020-00235-8>
32. Deng Z, Wang Y, Xiao C, Zhang D, Feng G, Long W. Effects of plant fine root functional traits and soil nutrients on the diversity of rhizosphere microbial communities in tropical cloud forests in a dry season. *Forests*. 2022;13:421. <https://doi.org/10.3390/f13030421>
33. Karki H, Pandey R, Bargali K, Bargali SS, Kumar M. Variations in fine root dynamics of *Tectona grandis* among natural and managed systems of Central Himalaya, India. *Trees For People*. 2025. <https://doi.org/10.1016/j.tfp.2025.101010>
34. Lai Z, Zhang Y, Liu J, Wu B, Qin S, Fa K. Fine-root distribution, production, decomposition, and effect on soil organic carbon of three revegetation shrub species in northwest China. *For Ecol Manage*. 2016;359:381–388. <https://doi.org/10.1016/j.foreco.2015.04.025>
35. Awasthi P, Bargali K, Bargali SS, Khatri K, Jhariya MK. Nutrient Partitioning and Dynamics in *Coriaria nepalensis* Wall dominated shrublands of degraded hills of Kumaun Himalaya. *Front For Glob Change*. 2022;5:913127. <https://doi.org/10.3389/ffgc.2022.913127>
36. See CR, McCormack ML, Hobbie SE, Flores-Moreno H, Silver WL, Kennedy PG. Global patterns in fine root decomposition: climate, chemistry, mycorrhizal association and woodiness. *Ecol Lett*. 2019;22(6):946–953. <https://doi.org/10.1111/ele.13248>
37. Awasthi P, Bargali K, Bargali SS, Khatri K. Nutrient return through decomposing *Coriaria nepalensis* litter in degraded hills of Kumaun Himalaya, India. *Front For Glob Change*. 2022;5. <https://doi.org/10.3389/ffgc.2022.1008939>
38. He L, Jia Z, Li Q, Zhang Y, Wu R, Dai J, Gao Y. Fine root dynamic characteristics and effect on plantation's carbon sequestration of *three Salix* shrub plantations in Tibetan Plateau alpine sandy land. *Ecol Evol*. 2021;11(6):2645-2659. <https://doi.org/10.1002/ece3.7221>
39. Fort F, Freschet GT. Plant ecological indicator values as predictors of fine-root trait variations. *J Ecol*. 2020;108:1565–1577. <https://doi.org/10.1111/1365-2745.13368>