Plant Root Characteristics and Dynamics in Arctic Tundra Ecosystems, 1960-2012

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Summary

Plant roots play a critical role in ecosystem function in arctic tundra, but root dynamics in these ecosystems are poorly understood. To address this knowledge gap, we found and assessed 149 studies (~ 141 locations) that examined some aspect of fine-root biomass, distribution, production, turnover, or decomposition in arctic tundra and the contribution of roots to tundra ecosystem carbon and nutrient fluxes.

Across all tundra ecosystems, belowground plant biomass exceeded aboveground biomass, with the exception of polar desert tundra. Roots were shallowly-distributed in the thin layer of soil that thaws annually, and were often found in surface organic soil horizons. Root traits including distribution, chemistry, anatomy, and resource partitioning play an important role in controlling plant species competition, and therefore ecosystem carbon and nutrient fluxes, under changing climatic conditions, but have only been quantified for a small fraction of tundra plants. Further, the annual production and mortality of fine roots are key components of ecosystem processes in tundra, but extant data are sparse. Tundra root traits and dynamics should be the focus of future research efforts. Better representation of the dynamics and characteristics of tundra roots will improve the utility of models for evaluating the responses of tundra ecosystems to changing environmental conditions.

Please use this citation to reference the data.

Iversen C.M., Sloan V.L., Sullivan P.F., Euskirchen E.S., McGuire A.D., Norby R.J., Walker A.P., Warren J.M., Wullschleger S.D. 2014. Plant Root Characteristics and Dynamics in Arctic Tundra Ecosystems, 1960-2012. Next Generation Ecosystem Experiments Arctic Data Collection, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA. Data set accessed at http://dx.doi.org/10.5440/1114222.

Data Characteristics

- Systematically identified and compiled data on root traits and root-soil interactions in arctic tundra.
- Data were compiled from various sources, including primary literature, books, and theses.

Data Files:

- Plant_roots_in_arctic_tundra_20140827.csv
- Plant_roots_in_arctic_tundra_20140827.xlsx

Documentation:

- V_Plant_Root_Characteristics_and_Dynamics_in_Arctic_Tundra_Ecosystems_1960-2012_User_Guidance_Document_v1.pdf
- Plant_roots_in_arctic_tundra_Supporting_Information_Table_S1_20140729.pdf

Data Dictionary: Plant_roots_in_arctic_tundra_20140827.csv

Column_Headings	Definitions
Study	A code for sorting individual studies; created from the first two letters of lead reference author last name and the last 2-digits of the publication year (e.g. AI58, Vi64, Kh69). Some have an additional letter (e.g. Ch78a, Ch78b) where two studies had the same first author and publication year.
Publication_year	The year the study was published; 4-digits.
Author_year	First author name and publication year. See 'Plant_roots_in_arctic_tundra_Supporting-Information-Table-S1_20140729' for full citation.
Journal_Book_Thesis	The name of the journal, book, or thesis where the study was published. Book is indicated by 'Book' prefix, while thesis is indicated by 'Thesis' prefix. Journal names have no prefix. See 'Plant_roots_in_arctic_tundra_Supporting-Information-Table-S1_20140729' for full citation.
Study_Description	An abbreviated description of the paper, book chapter, or thesis.
Notes	Indicates whether the original paper was accessible, and if not, from which paper the data were obtained.
Review_paper	Indicates whether the paper was a review (i.e., a compilation of previously published data). If yes, a review, then cell contains a '1'; otherwise, '0'.
Experimental_manipulation	Indicates whether the study included an experimental manipulation, and what that manipulation was. The data from the treated plots are not included here; only data from the control treatment are included.

Location_Place	Indicates place name given by author of paper; locations are worldwide.
Ecosystem	Indicates ecosystem as given by author of paper.
Project	Indicates names of the projects given by author of paper. Includes acronyms.
Latitude_Decimal	Latitude of study site or location of sample collection. Units are decimal degrees.
Longitude_Decimal	Longitude of study site or location of sample collection. Units are decimal degrees.
Elevation_m	Elevation of study site or location of sample collection; where an elevation range was given, we give the mean. Units are meters.
Year_Initial	The year when sample collection or experimental measurement was initiated; 4-digit number.
Year_Final	The year when sample collection or experimental measurement was ended; 4-digit number.
Pot_tiller	Indicates whether sample measurements were collected from plants grown in pots, or whether measurements were made on plant tillers rather than on a m2 basis. If '1' then measurements were made on plants grown in pots, or roots collected from excavation of tillers. If '0' then measurements were made on an aerial (m2) or volumetric (m3) soil basis. Units are 0, 1, or blank when the author of the paper did not specify.
Polar_desert	Indicates whether measurements were made in a polar desert, as indicated by the author of the paper. Units are No, Yes.
Species	Indicates the species name associated with root samples. 'Mixed' indicates that measurements were made on aggregates of more than one species. The 'species' designation indicates that the genus was known, but not the specific species. Blanks indicate that species was not specified by the authors.
PFT	Plant functional type, designated according to USDA plants database; species in the 'Poaceae' family are 'grasses', species in the 'Cyperaceae' family are sedges, species in the 'Juncaceae' family are rushes. 'Mixed' refers to measurements that included species from more than one PFT. Blanks indicate that plant species was not specified by the authors, and therefore PFT could not be specified.
Aboveground_biomass_g_m2	The sum of biomass of aboveground plant parts, including leaves and stems but not inflorescences. Units are grams per meter squared of ground area.

Belowground_biomass_g_m2	The sum of biomass of belowground plant parts, including fine roots, coarse roots, belowground stems, and rhizomes. Units are grams per meter squared of ground area.
B_A	The ratio of belowground biomass column (g/m2) to aboveground biomass column (g/m2). Unitless.
Fineroot_Leaf	The ratio of fine-root biomass (g/m2) to leaf biomass (g/m2). Unitless.
Maximum_rooting_ depth_cm	The maximum rooting depth of fine- and coarse roots and rhizomes as described in paper. Units are centimeters.
Average_root_diameter_mm	The average fine-root diameter; where a range was given, we give the mean diameter. Units are millimeters.
Soil_monolith_excavation	Indicates whether roots were sampled by excavating or cutting out a soil monolith. Values are 0, 1, or blank where the authors of the paper did not specify collection method, or where data were from a review paper or inaccessible article.
Soil_cores	Indicates whether roots were sampled by a volumetric soil core. Values are 0 or 1, for 'no' and 'yes', respectively, or blank where the authors of the paper did not specify collection method or where data were from a review paper or inaccessible article.
Ingrowth_cores	Indicates whether roots were sampled using root in-growth cores. Values are 0 or 1, for 'no' and 'yes', respectively, or blank where the authors of the paper did not specify collection method or where data were from a review paper or inaccessible article.
Minirhizotrons	Indicates whether roots were sampled using minirhizotrons. Values are 0 or 1, for 'no' and 'yes', respectively, or blank where the authors of the paper did not specify collection method or where data were from a review paper or inaccessible article.
Isotopic_tracer_stable_isotope	Indicates whether stable isotopes were used to sample some aspect of root distribution or dynamics. Values are 0 or 1, for 'no' and 'yes', respectively, or blank where the authors of the paper did not specify whether isotopes used or not or where data were from a review paper or inaccessible article.
Polygonal_topography	Indicates whether roots were sampled from polygonal tundra, as described by authors of paper. Values are 0 or 1, for 'no' and 'yes', respectively, or blank where the authors of the paper did not specify whether roots were sampled from polygonal tundra or where data were from a review paper or inaccessible article.

Degraded_permafrost	Indicates whether roots were sampled from areas of degraded permafrost, as described by authors of paper. Values are 0 or 1, for 'no' and 'yes', respectively, or blank where the authors of the paper did not specify whether roots were sampled from areas of degraded permafrost or where data were from a review paper or inaccessible article.
Root_standing_crop	Indicates whether study measured root standing crop (i.e., root biomass). Units are 0, 1 for 'no' and 'yes', respectively.
Root_production	Indicates whether study measured root production (i.e., root growth). Units are 0, 1 for 'no' and 'yes', respectively.
Root_turnover_decomposition	Indicates whether study measured root turnover (including mortality and lifespan) or root decomposition rates. Units are 0, 1 for 'no' and 'yes', respectively.
Root_depth_distribution	Indicates whether study measured the vertical distribution of roots throughout the soil profile. Units are 0, 1 for 'no' and 'yes', respectively.
Root_morphology	Indicates whether study measured root diameter, color, shape, texture, mass per length, or density. Units are 0, 1 for 'no' and 'yes', respectively.
Aerenchyma	Indicates whether study measured the presence or absence of root aerenchyma, or quantified root porosity. Units are 0, 1 for 'no' and 'yes', respectively.
Mycorrhizae	Indicates whether study measured whether roots were colonized by mycorrhizal fungi, and in some cases, the identity or type of mycorrhizae and extent of colonization. Units are 0, 1 for 'no' and 'yes', respectively.
Nutrient_cycling	Indicates whether study measured root nutrient concentration, or soil nutrient cycling. Units are 0, 1 for 'no' and 'yes', respectively.
Carbon_cycling	Indicates whether study measured root respiration, or soil CO2 efflux. Units are 0, 1 for 'no' and 'yes', respectively.
Environmental_forcing	Indicates whether study measured the effects of nutrient addition or warming on root distribution or dynamics. Units are 0, 1 for 'no' and 'yes', respectively.

Example Data Records:

Study,Publication_year,Author_year,Journal_Book_Thesis,Study_Description,Notes,Review_paper,Experimental_manipulation,Location_Place,Ecosystem,Project,Latitude_Decimal,Longitude_Decimal,Elevation_m,Year_Initial,Year_Final,Pot_Tiller,Polar_desert,Species,PFT,Aboveground_biomass_g_m2,Belowground_biomass_g_m2,B_A,Fineroot_Leaf,Maximum_rooting_depth_

cm,Average_root_diameter_mm,Soil_monolith_excavation,Soil_cores,Ingrowth_cores,Minirhizotrons,Isotopic_tracer_stable_isotope,Polygonal_topography,Degraded_permafrost,Root_standing_crop,Root_production,Root_turnover_decomposition,Root_depth_distribution,Root_morphology,Aerenchyma,Mycorrhizae,Nutrient_cycling,Carbon_cycling,Environmental_forcing,,
Ku83,1983,"Kummerow et al, 1983",American Journal of Botany,Spring growth,,0,,"Fairbanks, Alaska",Subarctic muskeg,,64.859,-147.836,150,1982,1982,0,No,Vaccinium uliginosum,Deciduous shrub,,,,,,1,0,0,0,0,0,0,1,1,0,0,1,0,1,0,0,0,,
Al75,1975,"Allessio and Tieszen, 1975",American Journal of Botany ,Belowground carbon allocation,,0,,"Barrow, Alaska",Wet meadow tundra,US IBP,71.300,-156.700,,1972,1972,0,No,Dupontia fisheri,Grass,,,,,,0,1,0,0,1,1,0,0,1,0,0,0,0,0,1,0,,,
Bi76,1976,"Billings et al, 1976",Arctic and Alpine Research,Root boxes,,0,Temperature,"Barrow, Alaska",Coastal wet tundra,US IBP,71.300,-156.700,,1974,1975,0,No,Carex aquatilis,Sedge,,,,,15,,1,0,0,0,0,0,0,1,0,0,1,0,0,0,0,0,0,,,

Data Acquisition Materials and Methods

We systematically identified and compiled data on root traits and root-soil interactions in arctic tundra. We defined arctic tundra according to Walker et al. (2005): low-growing vegetation north of the Arctic treeline. Because data on roots in arctic tundra are scarce, we also included data from sites with similar plant species or plant communities (e.g., subarctic tundra in Abisko, Sweden and subalpine tundra in Eagle Creek, Alaska). Data were compiled from various sources, including primary literature, books, and theses.

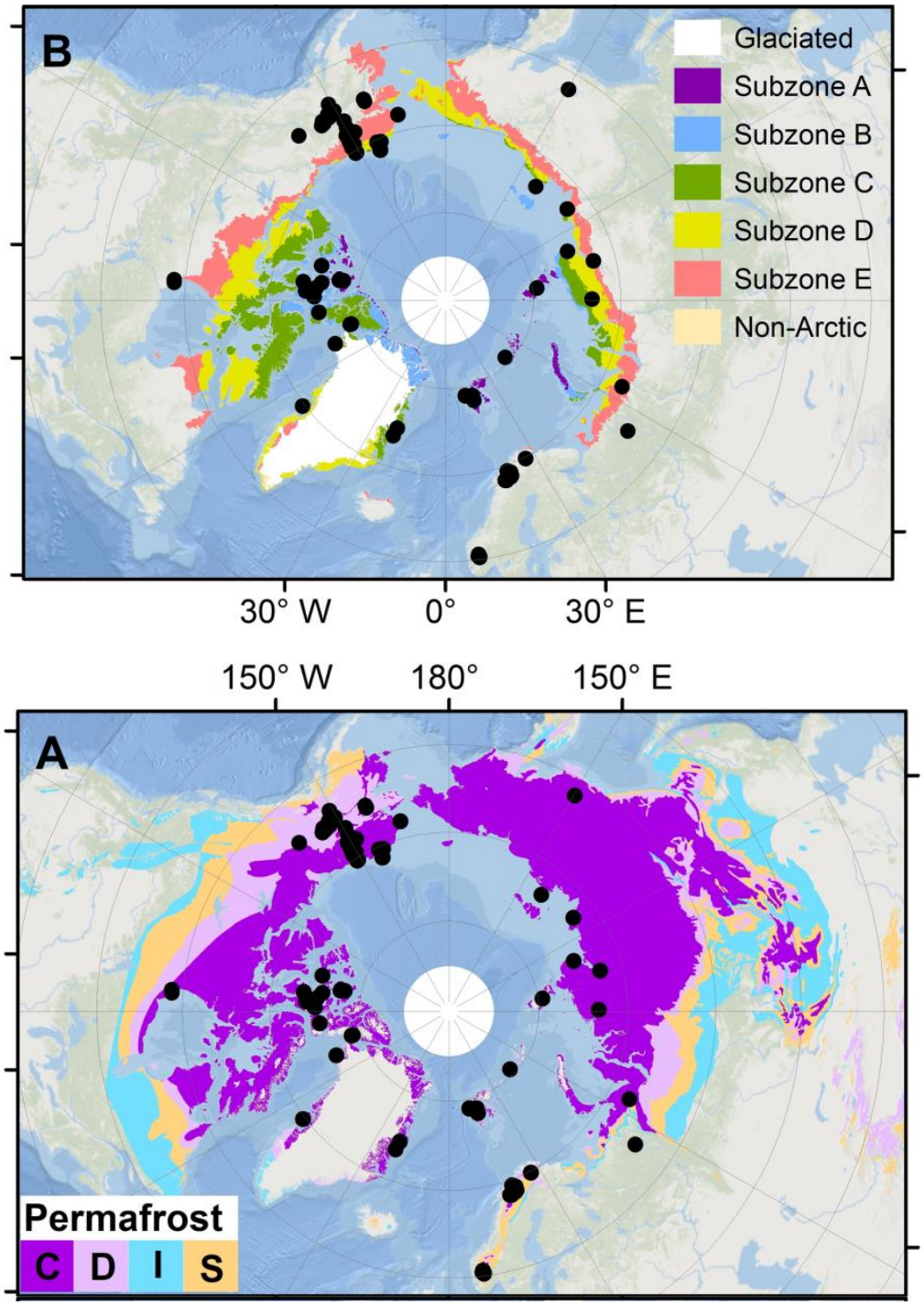

Fig. 1: The area of tundra represented by studies examining some aspect of root ecology is generally limited to locations associated with long-term ecological research sites; data points are represented by filled circles overlain on two maps (n = 1039 species-specific sampling points). Map A is the Circum-Arctic Map of Permafrost and Ground Ice Conditions Map (Brown et al., 1997) and Map B is the Circum-Arctic Vegetation Map (Walker et al., 2005). Colors on Map A correspond with the extent of permafrost in the Arctic (i.e., continuous, C; discontinuous, D; isolated, I; and sporadic, S). Land mass north of 45°N not underlain by permafrost is represented

in grey, and the map includes additional information on the location of lakes (dark blue) and glacier (stippled). Colors on Map B correspond with the different bioclimatic subzones in arctic tundra: Subzone A is characterized by cryptogam, forb barrens, and includes polar desert and semi-desert tundra; Subzone B is also characterized by cryptogam, forb barrens, but vegetated areas are characterized by graminoid- or prostrate dwarf shrub-dominated tundra; Subzone C is characterized by graminoid, prostrate dwarf-shrub, and forb tundra; Subzone D is characterized by areas of non-tussock sedge, dwarf-shrub, and moss tundra; and Subzone E is characterized by erect shrub vegetation (see Walker et al., 2005 for more detailed descriptions of bioclimatic subzones).

Our main focus in this literature review was on fine plant roots, which are an important component of ecosystem C and nutrient budgets because of their high respiration rates, high nutrient content, short lifespan relative to larger-diameter woody roots, and their role in stimulating microbial activity through the release of water and soluble exudates. Fine roots have generally been defined as less than 2 mm in diameter (Pregitzer, 2002), and we used that definition here because it was most appropriate to the available literature. Recently, the definition of fine roots has evolved to a more functional characterization, where fine roots are short-lived, non-woody roots whose main function is the uptake of nutrients and water from the soil (Guo et al., 2008). This functional definition is more relevant for understanding root processes and their representation in large-scale models, and we discuss how a next generation of measurements might improve our functional understanding of roots in tundra ecosystems.

References

Brown, J., O.J. Ferrians, Jr., J.A. Heginbottom, and E.S. Melnikov, eds. 1997. Circum-Arctic map of permafrost and ground-ice conditions. Washington, DC: U.S. Geological Survey in Cooperation with the Circum-Pacific Council for Energy and Mineral Resources. Circum-Pacific Map Series CP-45, scale 1:10,000,000, 1 sheet.

Guo DL, Li H, Mitchell RJ, Han WX, Hendricks JJ, Fahey TJ, Hendrick RL. 2008. Fine root heterogeneity by branch order: exploring the discrepancy in root turnover estimates between minirhizotron and carbon isotopic methods. *New Phytologist* 177: 443–456. doi: 10.1111/j.1469-8137.2007.02242.x

Pregitzer, K. S. (2002), Fine roots of trees – a new perspective. *New Phytologist*, 154: 267–270. doi: 10.1046/j.1469-8137.2002.00413_1.x

Walker, D. A., Raynolds, M. K., Daniëls, F., J.A., Einarsson, E., Elvebakk, A., Gould, W. A., Katenin, A. E., Kholod, S. S., Markon, C. J., Melnikov, E. S., Moskalenko, N. G., Talbot, S. S., Yurtsev, B. A.(†). and The other members of the CAVM Team (2005), The Circumpolar Arctic vegetation map. *Journal of Vegetation Science*, 16: 267–282. doi: 10.1111/j.1654-1103.2005.tb02365.x

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