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Variations in biomass, production, and respiration of fine roots in a young larch forest

（カラマツ若齢林における細根のバイオマス，生産量および呼吸の変動）

1. Introduction

Soil respiration (R_s) accounts for 30–80% of total respiration in forest ecosystems, indicating R_s plays a crucial role in terrestrial carbon cycles. The R_s is composed of root respiration (R_r) and microbial heterotrophic respiration (R_h). Plant roots are different in metabolism and functions according to size and order. Fine roots (typically < 2 mm in diameter) perform important functions and govern belowground carbon cycles. However, the phenological variation of the functions is not well understood. Thus, we adopted an approach to partition R_r into respirations for growth (R_g), maintenance (R_m), and ion uptake (R_{ion}) using modified empirical models. We conducted field experiments on R_s and fine root dynamics, and transpiration in a larch-dominated young forest on the bare ground after removing surface organic soil to parameterize the models.

2. Material and methods

The field experiments were conducted in 2017–2018 (E1) and 2019–2020 (E2) in a regenerating forest dominated by Japanese larch in Tomakomai, Hokkaido. The top organic soil was removed after typhoon disturbance in 2004. Collar pairs consisting of control (CC) and trenched (TC) ones were installed at 0.5 m (N) and 1 m (F) from isolated larch trees ($n = 10$ (E1) and 18 (E2)). Soil CO_2 fluxes (R_{CC} and R_{TC}) were periodically measured on the collars by a chamber method. The R_{CC} and R_{TC} were continuously estimated throughout the experimental periods from soil temperature (T_s) using exponential equations. CO_2 efflux through dead root decomposition (R_{DR}) in trenched collars was also estimated. The R_h was calculated as $R_{TC} - R_{DR}$, and R_r was derived as $R_{CC} - R_h$. Fine root biomass (B_f , g DM m^{-2}) and production (P_f , g DM $m^{-2} d^{-1}$) were periodically measured in CC by the sequential coring and ingrowth core methods, respectively. In addition, sap flow was measured by a thermal dispersion method only in E2. The following two models were applied to partition R_r (g C $m^{-2} d^{-1}$):

$$R_r = R_m + R_g = c_1 \cdot P_f + d_1 \cdot \exp(f_1 \cdot T_s) \cdot (B_f + B_c) \quad (1)$$

$$R_r = R_m + R_g + R_{ion} = c_2 \cdot P_f + d_2 \cdot \exp(f_2 \cdot T_s) \cdot (B_f + B_c) + g \cdot T_r \cdot B_f \quad (2)$$

where c , d , f , and g are fitting parameters, B_c coarse root biomass (g DM m^{-2}), and T_r transpiration per fine root biomass (g H_2O g DM $^{-1} d^{-1}$).

3. Results

Annual R_s was 493 ± 45 (N) and 311 ± 34 g C m⁻² yr⁻¹ (F) (mean $\pm$ standard error) in E1, and R_r accounted for 37% (N) and 16% (F) of R_s . Despite no seasonal variation in B_f , P_f decreased in the cold season. Annual P_f was 81 ± 22 (N) and 41 ± 10 g DM m⁻² yr⁻¹ (F), and annual mean B_f was 70 ± 9 (N) and 13 ± 3 g DM m⁻² yr⁻¹ (F). Model 1 (M1) was significantly parameterized ($r^2 = 0.59$, $p < 0.001$) using the field data ($n = 50$). Annual R_r was estimated to be 107 g C m⁻² yr⁻¹ and accounted for 25% of R_s . The R_r was partitioned into fine root R_g , fine root R_m , and coarse root R_{ion} by 30, 44 and 26%, respectively. In E2, annual R_s was 610 ± 26 (N) and 474 ± 52 g C m⁻² yr⁻¹ (F), and R_r accounted for 47% and 45% of R_s , respectively. The B_f increased slightly in the growing season, whereas P_f clearly decreased in the cold season and peaked in July. Annual P_f was 115 ± 7 (N) and 102 ± 10 g DM m⁻² yr⁻¹ (F), and mean B_f was 133 ± 13 (N) and 78 ± 14 g DM m⁻² yr⁻¹ (F). The B_c was less than a third of B_f . Models 1 and 2 were significantly parameterized ($r^2 = 0.51$ – 0.53 , $p < 0.001$) using the field data ($n = 144$). Although the parameters of d (R_m at 0°) and f (the temperature coefficient of R_m) were almost the same between the two models, the parameter of R_g (c) was smaller for M1. The R_m and R_{ion} peaked in June–July, whereas R_g peaked earlier in June. Annual R_r was estimated to be 215 g C m⁻² yr⁻¹ and accounted for 41% of R_s . The R_r was partitioned into fine root R_g , fine root R_m , coarse root R_{ion} , and fine root R_{ion} by 32, 46, 13 and 9%, respectively.

4. Discussion

The two models were significantly fitted to field data. Although all parameters in M1 were significant determined in both experiments, those from E2 would be more robust because of more data sets for curve fitting and the addition of spatial distribution of coarse root biomass. The parameters of d and f related to R_m were almost the same between M1 and M2 in E2; the Q_{10} of R_m calculated from parameter f was 2.46–2.61. However, the parameter of c for R_g was lower by 20% in M2, suggesting that R_{ion} was assigned to R_g in M1, because R_{ion} was reported to be proportional to R_g from laboratory experiments. Using M2, we estimated that fine roots account for 87% of total R_r annually, and fine root R_r was partitioned into R_g , R_m , and R_{ion} by 37, 53, and 10%, respectively. The R_g , R_m , and R_{ion} varied according to the seasonal variations of P_f , T_s , and T_r , respectively.

5. Conclusions

To partition R_r into R_g , R_m , and R_{ion} , we applied modified empirical models and parameterized them using seasonal field data of soil CO₂ efflux, B_f , P_f , B_c , T_s , and T_r measured in a young larch-dominated forest regrowing after the removal of surface organic soil. In such a simplified field condition, we succeeded in significant partitioning of root respiration in a field condition. Despite ignoring coarse root growth, the results suggest that our approach is capable of partitioning root respiration.