Plant and Soil 2017 vol.410 N1-2, pages 73-85

# The above-belowground coupling of the C cycle: fast and slow mechanisms of C transfer for root and rhizomicrobial respiration

Gavrichkova O., Kuzyakov Y.
*Kazan Federal University, 420008, Kremlevskaya 18, Kazan, Russia*

## Abstract

Background and aims: The coupling of photosynthesis with belowground processes appears to be much faster than the time needed for assimilate translocation with the phloem flow. Pressure/concentration waves have been hypothesized to release belowground C already present in the phloem, resulting in a very fast feedback of rhizosphere processes to photosynthesis changes. We evaluate the speed of aboveground-rhizosphere coupling under maize by two mechanisms: pressure/concentration waves and direct phloem transport. Methods: We combined two isotopic approaches: 1) the speed of direct phloem transport was evaluated by labeling shoots in 14CO2 and tracing 14C in the nutrient solution and in the CO2 flux, 2) pressure/concentration waves were evaluated by labeling the solution with [13C] glucose and tracing the isotope dilution during photoassimilation. Results: 14C shoot labeling of maize plants showed that 12 h were needed for 14C to peak in root-derived CO2. In contrast, in the solution labeling approach, CO2 flux increased within 2 h after switching on the light. Pressure/concentration waves contributed 5 % to diurnal respiration efflux and affected only root respiration. Root exudation was independent of the fast mechanism of above-belowground coupling. Conclusions: Photosynthesis affected root and rhizomicrobial respiration on variable time-scales: root respiration within the first 2 h by pressure/concentration waves, whereas rhizomicrobial respiration may depend on internal circadian cycles in regulating exudation rather than on light directly.

http://dx.doi.org/10.1007/s11104-016-2982-2

## Keywords

Phloem transport, Photosynthesis, Pressure/concentration waves, Rhizosphere, Soil respiration, Time lag

## References

[1] Andersen CP (2003) Source–sink balance and carbon allocation below ground in plants exposed to ozone. New Phytol 157:213–228

[2] Bahn M, Schmitt M, Siegwolf R, Richter A, Brüggemann N (2009) Does photosynthesis affect grassland soil-respired CO and its carbon isotope composition on a diurnal timescale? New Phytol 182:451–460

[3] Bahn M, Lattanzi FS, Hasibeder R, Wild B, Koranda M, Danese V, Brüggermann N, Schmitt M, Siegworf, Richter A (2013) Responses of belowground carbon allocation dynamics to extended shading in mountain grassland. New Phytol 198:116–126

[4] Baldocchi D, Tang J, Xu L (2006) How switches and lags in biophysical regulators affect spatial-temporal variation of soil respiration in an oak-grass savanna. J Geophys Ress-Biogeosci 111:G02008

[5] Barthel M, Hammerle A, Sturm P, Baur T, Gentsch L, Knohl A (2011) The diel imprint of leaf metabolism on the δ13C signal of soil respiration under control and drought conditions. New Phytol 192:925–938

[6] Biernath C, Fischer H and Kuzyakov Y 2008 Root uptake of N-containing and N-free low molecular weight organic substances by maize: A C/N tracer study. Soil Biol Biochem 40, 2237–2245

[7] Burri S, Sturm P, Baur T, Barthel M, Knohl A, Buchmann N (2014) The effect of physical back-diffusion of CO2 tracer on the coupling between photosynthesis and soil CO2 efflux in grassland. Isot Environ Healt S 50:497–513

[8] Cheng W, Coleman DC, Carroll CR, Hoffman CA (1993) In situ measurement of root respiration and soluble C concentrations in the rhizosphere. Soil Biol Biochem 25:1189–1196

[9] Dilkes NB, Jones DL, Farrar JF (2004) Temporal dynamics of carbon partitioning and rhizodeposition in wheat. Plant Physiol 134:706–715

[10] Ekblad A, Björn B, Holm A, Comstedt D (2005) Forest soil respiration rate and δC is regulated by recent above ground weather conditions. Oecologia 143:136–142

[11] Epron D, Bahn M, Derrien D, Lattanzi FA, Pumpanen J, Gessler A, Hogberg P, Maillard P, Dannoura M, Gerant D, Buchmann N (2012) Pulse-labelling trees to study C allocation dynamics: a review of methods, current knowledge and future perspectives. Tree Physiol 32:776–798

[12] Farrar JF, Jones DL (2000) The control of carbon acquisition by roots. New Phytol 147:43–53

[13] Ferrier JM, Tyree MT, Christy AL (1975) The theoretical time-dependent behavior of a Münch pressure-flow system: the effect of sinusoidal time variation in sucrose loading and water potential. Can J Bot 53:1120–1127

[14] Fisher D B 2000 Long-distance transport. In Biochemistry and Molecular Biology of Plants. Ed. Buchanan B. pp. 730–784.

[15] Gavrichkova O, Kuzyakov Y (2012) Direct phloem transport and pressure concentration waves in linking shoot and rhizosphere activity. Plant Soil 351:23–30

[16] Gavrichkova O, Proietti S, Moscatello S, Portarena S, Battistelli A, Matteucci G, Brugnoli E (2011) Short-term natural δC and δO variations in pools and fluxes in a beech forest: the transfer of isotopic signal from recent photosynthates to soil respired CO. Biogeosci 8:2833–2846

[17] Gessler A, Kreuzwieser J, Dopatka T, Rennenberg H (2002) Diurnal courses of ammonium net uptake by the roots of adult beech (Fagus sylvatica) and spruce (Picea abies) trees. Plant Soil 240:23–32

[18] Gessler A, Keitel C, Kodama N, Weston C, Winters AJ, Keith H, Grice K, Leuning R, Farquhar GD (2007) δC of organic matter transported from the leaves to the roots In Eucalyptus delegatensis: short-term variations and relation to respired CO. Funct Plant Biol 34:692–706

[19] Göttlicher A, Knohl A, Wanek W, Buchmann N and Richter A (2006) Short-term changes in carbon isotope composition of soluble carbohydrates and starch: from canopy leaves to the soil system. Rapid Commun Mass Spectrom 20:653–660

[20] Hölttä T, Vesala T, Sevanto S, Perämäki M, Nikinmaa E (2006) Modeling xylem and phloem water flows in trees according to cohesion theory and Münch hypothesis. Trees-Struct Funct 20:67–78

[21] Hölttä T, Mencuccini M, Nikinmaa E (2009) Linking phloem function to structure: analysis with a coupled xylem–phloem transport model. J Theor Biol 259:325–337

[22] Janssens IA, Lankreijer H, Matteucci G, Kowalski AS, Buchmann N, Epron D, Pilegaard K, Kutsch W, Longdoz B, et al. (2001) Productivity overshadows temperature in determining soil and ecosystem respiration across European forests. Glob Chang Biol 7:269–278

[23] Jones DL, Darrah PR (1992) Resorption of organic-components by roots of Zea mays L. and its consequences in the rhizosphere. 1. Resorption of C labelled glucose, mannose and citric-acid. Plant Soil 143:259–266

[24] Jones DL, Darrah PR (1993) Re-sorption of organic components by roots of Zea mays L. And its consequences in the rhizosphere. Plant Soil 153:47–59

[25] Jones DL, Hodge A, Kuzyakov Y (2004) Plant and mycorrhizal regulation of rhizodeposition. New Phytol 163:459–480

[26] Jones DL, Clode PL, Kilburn MR, Stockdale EA, Murphy DV (2013) Competition between plant and bacterial cells at the microscale regulates the dynamics of nitrogen acquisition in wheat (Triticum aestivum). New Phytol 200:796–807

[27] Kayler Z, Gessler A, Buchmann N (2010) What is the speed of link between aboveground and belowground processes? New Phytol 187:885–888

[28] Keel SG, Campbell CD, Högberg MN, Richter A, Wild B, Zhou X, Hurry V, Linder S, Näsholm T, Högberg P (2012) Allocation of carbon to fine root compounds and their residence times in a boreal forest depend on root size class and season. New Phytol 194:972–981

[29] Kuzyakov Y, Cheng W (2001) Photosynthesis controls of rhizosphere respiration and organic matter decomposition. Soil Biol Biochem 14:1915–1925

[30] Kuzyakov Y, Cheng W (2004) Photosynthesis controls of CO efflux from maize rhizosphere. Plant Soil 263:85–99

[31] Kuzyakov Y, Domanski G (2002) Model of rhizodeposition and CO efflux from planted soil and its validation by C pulse labeling of ryegrass. Plant Soil 219:87–102

[32] Kuzyakov Y, Gavrichkova O (2010) Time lag between photosynthesis and carbon dioxide efflux from soil: a review of mechanisms and controls. Glob Chang Biol 16:3386–3406

[33] Kuzyakov Y, Kretzschmar A, Stahr K (1999) Contribution of Lolium perenne rhizodeposition to carbon turnover of pasture soil. Plant Soil 213:127–136

[34] Kuzyakov Y, Leinweber P, Sapronov D, Eckhardt KU (2003) Qualitative assessment of rhizodeposits in non sterile soil by analytical pyrolysis. J Plant Nutr Soil Sc 166:719–723

[35] Liu Q, Edwards NT, Post WM, Gu L, Ledford J, Lenhart S (2006) Temperature independent diel variation in soil respiration observed from a temperate deciduous forest. Glob Chang Biol 12:2136–2145

[36] Macek T, Macková M, Káš J (2000) Exploitation of plants for the removal of organics in environmental remediation. Biotechnol Adv 18:23–34

[37] Makita N, Kosugi Y, Kamakura M (2014) Linkages between diurnal patterns of root respiration and leaf photosynthesis in Quercus crispula and Fagus crenataseedlings. J Agr Meteorol 70:151–162

[38] Mencuccini M, Hölttä T (2010a) The significance of phloem transport for the speed with which canopy photosynthesis and belowground respiration are linked. New Phytol 185:189–203

[39] Mencuccini M, Hölttä T (2010b) On light bulbs and marbles. Transfer times and teleconnections in plant fluid transport systems. New Phytol 187:888–891

[40] Minchin PEH, Lacointe A (2005) New understanding on phloem physiology and possible consequences for modelling long-distance transport. New Phytol 166:771–779

[41] Münch E (1930) Die Stoffbewegungen in der Pflanze. Gustav Fischer Jena:1–234

[42] Näsholm T, Ekblad A, Nordin A, Giesler R, Högberg M, Högberg P (1998) Boreal forest plants take up organic nitrogen. Nature 392:914–916

[43] Neumann G and Römheld V 2007 The reliese of root exudates as affected by the plant physiological status. In The Rhizosphere-Biosphere and Organic Substances at the Soil Plant Interface. Ed Pnton R, Varanini Z, Nannipieri P. Boca Raton, FL. Pp. 24–72. CRC Press, Taylor and Francis Group.

[44] Oburger E, Dell'mour M, Hann S, Wieshammer G, Puschenreiter M and Wenzel W W 2013 Evaluation of a novel tool for sampling root exudates from soil-grown plants compared to conventional techniques. Environ Exp Bot 87, 235–247

[45] Oburger E, Gruber B, Schindlegger Y, Schenkeveld WDC, Hann S, Kraemer SM, Wenzel WW, Puschenreiter M (2014) Root exudation of phytosiderophores from soil-grown wheat. New Phytol 203:1161–1174

[46] Perämäki M, Nikinmaa E, Sevanto S, Ilvesniemi H, Siivola E, Hari P, Vesala T (2001) Tree stem diameter variations and transpiration in Scots pine: an analysis using a dynamic sap flow model. Tree Physiol 21:889–897

[47] Sanaullah M, Chabbi A, Rumpel C, Kuzyakov Y (2012) Carbon allocation in grassland communities under drought stress followed by C pulse labeling. Soil Biol Biochem 55:132–139

[48] Shibistova O, Yohannes Y, Boy J, Richter A, Wild B, Watzka M, Guggenberger G (2012) Rate of belowground carbon allocation differs with successional habit of two afromontane trees. PLoS One 7:e45540

[49] Subke J-A, Vallack HW, Magnusson T, Keel SG, Metcalfe DB, Högberg P, Ineson P (2009) Short-term dynamics of abiotic and biotic soil CO effluxes after in situ CO pulse labelling of a boreal pine forest. New Phytol 183:349–357

[50] Tang J, Baldocchi DD, Xu L (2005) Tree photosynthesis modulates soil respiration on a diurnal time scale. Glob Chang Biol 11:1298–1304

[51] Thomson MV (2006) Phloem: the long and the short of it. Trends Plant Sci 11:26–32

[52] Thomson MV, Holbrook NM (2003) Scaling phloem transport: water potential equilibrium and osmoregulatory flow. Plant Cell Environ 26:1561–1577

[53] Thomson MV, Holbrook NM (2004) Scaling phloem transport: information transmission. Plant Cell Environ 27:509–519

[54] Werth M, Kuzyakov Y (2006) Assimilate partitioning affects C fractionation of recently assimilated carbon in maize. Plant Soil 284:319–333

[55] Wingate L, Ogée J, Burlett R, Bosc A, Devaux M, Grace J, Loustau D, Gessler A (2010) Photosynthetic carbon isotope discrimination and its relationship to the carbon isotope signals of stem, soil and ecosystem respiration. New Phytol 188:576–589

[56] Zibilske LM (1994) Carbon mineralization. In: Weaver RW, Angle JS, Bottomley PS (Eds) Methods of soil analysis, part 2. Microbiological and biochemical properties. Soil Sci Soc Am J, Madison, WI, p 835–864