Soil Biology and Biochemistry 116 (2018) 1–3

Contents lists available at ScienceDirect

Soil Biology and Biochemistry

journal homepage: www.elsevier.com/locate/soilbio

Fire-derived charcoal might promote fine root decomposition in boreal forests

Semyon Bryanin[a,*], Evgeniya Abramova[a], Kobayashi Makoto[b]

[a] Institute of Geology and Nature Management, Far East Branch, Russian Academy of Sciences, Blagoveshchensk, 675000, Russia
[b] Teshio Experimental Forest, Field Science Center for Northern Biosphere, Hokkaido University, Horonobe, 098-2943, Japan

ARTICLE INFO

Keywords:
Fine roots
Decomposition
Fire disturbance
Charcoal
Boreal forest
Priming effect

ABSTRACT

Boreal forest soils are a huge carbon sink, but the forests are regularly subjected to fire disturbance. The fine roots in these forests substantially contribute to soil carbon accumulation. Charcoal is a fire by-product that influences ecosystem processes including soil organic matter decomposition. However, the extent to which charcoal affects fine root decomposition is unclear. We performed field litterbag experiments over 515 days involving the incubation of fine larch roots with varying concentrations of charcoal in soil. At the end of experiment the loss of root mass in samples incubated with higher concentrations of charcoal was greater (42% and 40%) than that in the control (30%) and a treatment containing the average measured soil charcoal content (27%). The degree of mass loss generally increased with increasing charcoal content. Our result provides the first field evidence that fire-derived charcoal may enhance the decomposition of fine larch roots, and consequently CO_2 release from boreal forests.

Boreal forest soils are a large sink of global carbon, with fine root litter making a large contribution to this sink (Berg and McClaugherty, 2014). Forest fires affect large areas of the boreal zone each year (Conard and Ivanova, 1997; Weber and Stocks, 1998). Charcoal formation is a by-product and lasting legacy of these fires in boreal forests, and is a major factor controlling carbon dynamics in this environment. Fire-derived charcoal is deposited on the soil surface and incorporated into the soil, where it influences physiochemical and biological processes (Pluchon et al., 2016; Singh and Cowie, 2014). Numerous studies have shown ambiguous charcoal effects on the mineralization of soil organic matter. Short-term laboratory experiments have shown that charcoal promotes the decomposition of native soil organic matter, depending on the charcoal formation temperature (Luo et al., 2011), soil characteristics, and vegetation type (Pluchon et al., 2016). In contrast, field evidence indicates that charcoal may enhance the rate of humus decomposition over the long-term (Wardle et al., 2008). However, other studies have demonstrated negative effects of charcoal on decomposition, because of the stabilization of labile soil organic carbon via its sorption onto the charcoal (Cross and Sohi, 2011; Lu et al., 2014; Singh and Cowie, 2014). There is also evidence that charcoal does not promote litter decomposition (Abiven and Andreoli, 2011), and that its influence depends on the charcoal quality (Zimmerman et al., 2011). In summary, organic matter decomposition in the presence of charcoal has received much scientific attention, but the relationship is highly context-dependent. However, little is known about the effect of charcoal on the decomposition of fine roots, which are known to have a significant ecosystem function, especially in boreal forests.

Fine roots (< 2 mm in diameter) comprise only a small part of the ecosystem biomass, but their turnover is a major mechanism of carbon accumulation in boreal forest soils (Gower et al., 2001; Vogt et al., 1995). Fine roots proliferate in the upper soil, where various levels of fire-derived charcoal occur (Bryanin and Makoto, 2017; Makoto et al., 2011b). Given that fine roots develop and decompose in the proximity of charcoal, we hypothesized that charcoal influences the decomposition of fine larch roots, and that the influence is dependent on charcoal content in boreal forest soils.

The study was performed at 554 m.a.s.l. in an experimental plot (54°0′ N, 127°2′ E) in the Zeysky Nature Reserve, on the southern slope of the Tukuringra mountain range in the Russian Far East. The forest is dominated by *Larix gmelinii* (Rupr.) and the forest floor is covered mostly by *Vaccinium vitis-idaea* L. Previous studies involved organic matter and charcoal being mixed in equal proportions (Pluchon et al., 2016; Wardle et al., 2008), but this is not an accurate representation of the soil conditions in post-fire forests. We prepared the incubation mix to mimic the range of charcoal contents (0–3.9 g kg^{-1}) measured in the upper 10 cm of soil. We produced charcoal for the experiment using larch branches that were heated in a muffle furnace at 450 °C for 45 min. The temperature and duration used was typical of the

* Corresponding author.
E-mail address: bruanin@gmail.com (S. Bryanin).

http://dx.doi.org/10.1016/j.soilbio.2017.09.031
Received 29 November 2016; Received in revised form 19 September 2017; Accepted 30 September 2017

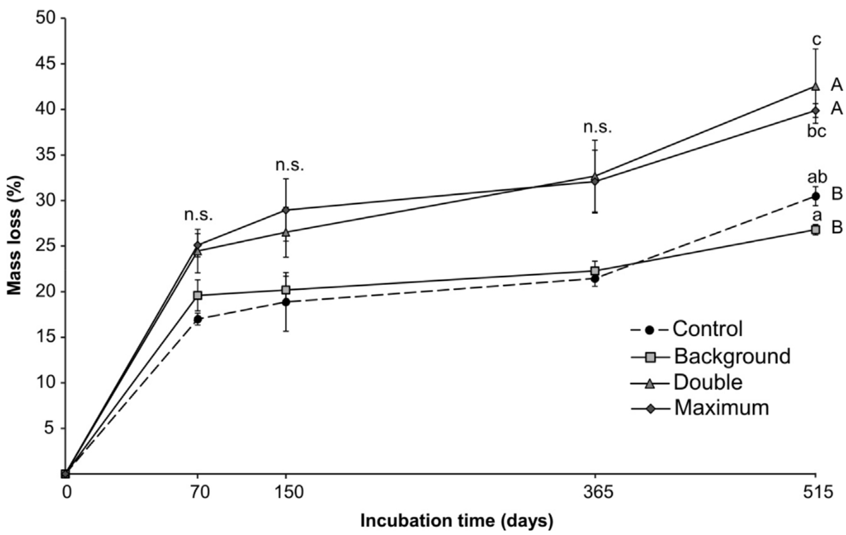

Fig. 1. Mass loss during decomposition of fine larch roots in the presence of various charcoal concentrations: Control: no charcoal. Background: mean charcoal content measured in the field (0.95 g kg–1). Double: twice the mean charcoal content measured in the field (1.9 g kg–1). Maximum: charcoal content equal to the maximum concentration measured in the field (3.9 g kg–1). Bars show the SE (n = 5). Different lower-case letters indicate a significant difference ($p < 0.05$) between charcoal treatments on particular harvesting dates, based on ANOVA and the Stell–Dwass post hoc test. Different capital letters indicate significant differences (Holm–Bonferroni corrected $P < 0.05$) during the entire decomposition period, based on a generalized linear mixed model (GLMM) where incubation time set as a random factor (e.g. Makoto et al., 2012).

smouldering and charring processes that occur in boreal forest surface fires (Makoto et al., 2011a; Pluchon et al., 2014). The resulting charcoal was crushed and sieved to create homogenous particles of 0.5–2.0 mm in size as in (Makoto et al., 2010, 2011a).

Approximately 1.0 g of fine roots (0.5–2 mm) that had been washed, sorted, and dried at 40 °C were thoroughly mixed and placed in nylon litterbags (10 × 10 cm; mesh size: 45 μm). The experimental control comprised root bags lacking charcoal. The experimental treatments included: (i) a 'background' treatment comprising root bags having a charcoal content equal to the mean measured value (0.95 g kg^{-1}); (ii) root bags having a charcoal content twice that of the mean content (1.9 g kg^{-1}); and (iii) root bags having a charcoal content equal to the maximum charcoal content measured in the field (3.9 g kg^{-1}).

The experiment was started in May 2015, and experimental samples were retrieved on days 70, 150, 365 and 515. Each control and treatment included 5 replicates for each sampling date (80 litterbags each in total). In the plots we replaced the surface soil layer with a subsurface soil containing traces of charcoal (Gundale and DeLuca, 2007). The litterbags were inserted into a small slit made at a 45° angle in the upper 10 cm of mineral soil in roots original sites, and the soil was lightly pushed over the bags to ensure that contact occurred.

Following harvest the samples were dried to a constant weight at 40 °C, and the loss of mass from the initial state was calculated. We checked for normality of the data using the Shapiro–Wilk test. Differences between treatments were assessed by the Wald's pairwise comparison test using a generalized linear mixed model (GLMM); the incubation period was the random factor (e.g. Makoto et al., 2012). All analyses were undertaken using the nlme package in R software version 3.3.1 (R Core Team, 2016).

In all treatments there was a rapid loss of fine root mass from 25% to 17% during the initial period (0–70 days), regardless of the amount of charcoal added (Fig. 1). The differences in the mass loss rates among treatments were significant only at the end of the experiment (515 days, $P < 0.05$, Fig. 1). At this time, relative to the control and background treatment the mass loss was 42% in the 1.9 g kg^{-1} charcoal treatment, and 40% in the treatment containing the maximum charcoal level. Thus, the fine roots in these treatments decomposed significantly faster than in the control and background treatment, which did not differ significantly in mass loss at any time during the experimental period (Fig. 1).

The results indicate that charcoal enhanced the late stages (> 70 days) of fine root decomposition. This finding is consistent with those of other studies showing that charcoal affects only the late stages of leaf litter decomposition (Kerré et al., 2017; Singh and Cowie, 2014). Initially the roots decompose because of the release of labile organic matter through hydrolysis (Berg, 1984). Mass loss during later stages of decomposition results from the slow degradation of lignin and cellulose (Harmon et al., 2009). This suggests that charcoal may enhance the microbial decay of these substances during the later stages of fine root decomposition.

Although root decomposition in the root-bag method differs from the natural process, this method has been broadly used in comparative studies worldwide (e.g. Freschet et al., 2013). Our results suggest that fire-derived charcoal causes a detectable and content-dependent shift in fine root decomposition in boreal forests. The mass loss increased as a function of charcoal content, but the rate of loss was not linear. Low levels of charcoal did not cause mass loss (Fig. 1), but a charcoal level twice the average, and the maximum natural charcoal level, had similar effects. The charcoal content at the study site varied from 0 to 3.9 g kg^{-1}, demonstrating a significant spatial variation in charcoal content that is attributed to the occurrence of charred tree logs and stumps. Our findings suggest that soils in post-fire boreal systems include hot spots for the decomposition of fine roots.

Our results show that depending on its concentration, fire-derived charcoal can promote the late stages of root decomposition and enhance carbon release from boreal soil, at least during the two years following fire. This study was a preliminary investigation of the effect of charcoal on fine root decomposition. To enhance our understanding of the ecosystem function of charcoal, future long-term non-destructive studies are needed to determine the underlying mechanisms.

Acknowledgements

Authors gratefully acknowledge Dr. Sorokin A.A. and Dr. Takagi K. and to the technical stuffs in Teshio Experimental Forest (Hokkaido University) for their support during investigation and manuscript preparation. We also express our sincere thanks to Lisovsky V.V. for his invaluable support during fieldwork.

References

Abiven, S., Andreoli, R., 2011. Charcoal does not change the decomposition rate of mixed litters in a mineral cambisol: a controlled conditions study. Biology and Fertility of Soils 47, 111–114. http://dx.doi.org/10.1007/s00374-010-0489-1.

Berg, B., 1984. Decomposition of root litter and some factors regulating the process: long-term root litter decomposition in a scots pine forest. Soil Biology and Biochemistry 16, 609–617. http://dx.doi.org/10.1016/0038-0717(84)90081-6.

Berg, B., McClaugherty, C., 2014. Plant Litter: Decomposition, Humus Formation, Carbon Sequestration, third ed. Springer Berlin Heidelberg, Berlin, Heidelberg. http://dx.doi.org/10.1007/978-3-642-38821-7.

Bryanin, S.V., Makoto, K., 2017. Fire-derived charcoal affects fine root vitality in a post-fire Gmelin larch forest: field evidence. Plant and Soil 416, 409–418. http://dx.doi.org/10.1007/s11104-017-3217-x.

Conard, S.G., Ivanova, G.A., 1997. Wildfire in Russian boreal forests—potential impacts of fire regime characteristics on emissions and global carbon balance estimates. Environmental Pollution 98, 305–313. http://dx.doi.org/10.1016/S0269-7491(97)00140-1.

Cross, A., Sohi, S.P., 2011. The priming potential of biochar products in relation to labile carbon contents and soil organic matter status. Soil Biology and Biochemistry 43, 2127–2134. http://dx.doi.org/10.1016/j.soilbio.2011.06.016.

Freschet, G.T., Cornwell, W.K., Wardle, D.A., Elumeeva, T.G., Liu, W., Jackson, B.G., Onipchenko, V.G., Soudzilovskaia, N.A., Tao, J., Cornelissen, J.H.C., 2013. Linking litter decomposition of above- and below-ground organs to plant-soil feedbacks worldwide. Journal of Ecology 101, 943–952. http://dx.doi.org/10.1111/1365-2745.12092.

Gower, S.T., Krankina, O., Olson, R.J., Apps, M., Linder, S., Wang, C., Olson, R.J., Krankina, O., Gower, S.T., Canada, A.T.H., 2001. Net primary production and carbon allocation patterns of boreal forest ecosystems. Ecological Applications 11, 1395–1411.

Gundale, M.J., DeLuca, T.H., 2007. Charcoal effects on soil solution chemistry and growth of Koeleria macrantha in the ponderosa pine/Douglas-fir ecosystem. Biology and Fertility of Soils 43, 303–311. http://dx.doi.org/10.1007/s00374-006-0106-5.

Harmon, M.E., Silver, W.L., Fasth, B., Chen, H., Burke, I.C., Parton, W.J., Hart, S.C., Currie, W.S., Laundre, J., Wright, J., Yarie, J., Wedin, D., Clinton, B., Lugo, A., Fahey, T., Melillo, J., Anderson, J., McClellan, M., Halstead, S., Blair, J., Sollins, P., Lodge, J., Baron, J., Nankarni, N., Morris, J., Gower, T., Edmonds, R., White, C., Zedler, P., Gholz, H., Blum, L., 2009. Long-term patterns of mass loss during the decomposition of leaf and fine root litter: an intersite comparison. Global Change Biology 15, 1320–1338. http://dx.doi.org/10.1111/j.1365-2486.2008.01837.x.

Kerré, B., Willaert, B., Smolders, E., 2017. Lower residue decomposition in historically charcoal-enriched soils is related to increased adsorption of organic matter. Soil Biology and Biochemistry 104, 1–7. http://dx.doi.org/10.1016/j.soilbio.2016.10.007.

Lu, W., Ding, W., Zhang, J., Li, Y., Luo, J., Bolan, N., Xie, Z., 2014. Biochar suppressed the decomposition of organic carbon in a cultivated sandy loam soil: a negative priming effect. Soil Biology and Biochemistry 76, 12–21. http://dx.doi.org/10.1016/j.soilbio.2014.04.029.

Luo, Y., Durenkamp, M., De Nobili, M., Lin, Q., Brookes, P.C., 2011. Short term soil priming effects and the mineralisation of biochar following its incorporation to soils of different pH. Soil Biology and Biochemistry 43, 2304–2314. http://dx.doi.org/10.1016/j.soilbio.2011.07.020.

Makoto, K., Choi, D., Hashidoko, Y., Koike, T., 2011a. The growth of Larix gmelinii seedlings as affected by charcoal produced at two different temperatures. Biology and Fertility of Soils 47, 467–472. http://dx.doi.org/10.1007/s00374-010-0518-0.

Makoto, K., Hirobe, M., DeLuca, T.H., Bryanin, S.V., Procopchuk, V.F., Koike, T., 2011b. Effects of fire-derived charcoal on soil properties and seedling regeneration in a recently burned Larix gmelinii/Pinus sylvestris forest. Journal of Soils and Sediments 11, 1317–1322. http://dx.doi.org/10.1007/s11368-011-0424-6.

Makoto, K., Shibata, H., Kim, Y.S., Satomura, T., Takagi, K., Nomura, M., Satoh, F., Koike, T., 2012. Contribution of charcoal to short-term nutrient dynamics after surface fire in the humus layer of a dwarf bamboo-dominated forest. Biology and Fertility of Soils 48, 569–577. http://dx.doi.org/10.1007/s00374-011-0657-y.

Makoto, K., Tamai, Y., Kim, Y.S., Koike, T., 2010. Buried charcoal layer and ectomycorrhizae cooperatively promote the growth of Larix gmelinii seedlings. Plant and Soil 327, 143–152. http://dx.doi.org/10.1007/s11104-009-0040-z.

Pluchon, N., Gundale, M.J., Nilsson, M.C., Kardol, P., Wardle, D.A., 2014. Stimulation of boreal tree seedling growth by wood-derived charcoal: effects of charcoal properties, seedling species and soil fertility. Functional Ecology 28, 766–775. http://dx.doi.org/10.1111/1365-2435.12221.

Pluchon, N., Vincent, A.G., Gundale, M.J., Nilsson, M.-C., Kardol, P., Wardle, D.A., 2016. The impact of charcoal and soil mixtures on decomposition and soil microbial communities in boreal forest. Applied Soil Ecology 99, 40–50. http://dx.doi.org/10.1016/j.apsoil.2015.11.020.

R Core Team, 2016. R: a Language and Environment for Statistical Computing.

Singh, B.P., Cowie, A.L., 2014. Long-term influence of biochar on native organic carbon mineralisation in a low-carbon clayey soil. Scientific Reports 4, 3687. http://dx.doi.org/10.1038/srep03687.

Vogt, K.A., Vogt, D.J., Palmiotto, P.a., Boon, P., O'Hara, J., Asbjornsen, H., 1995. Review of root dynamics in forest ecosystems grouped by climate, climatic forest type and species. Plant and Soil 187, 159–219. http://dx.doi.org/10.1007/BF00017088.

Wardle, D.A., Nilsson, M.-C.M.-C., Zackrisson, O., 2008. Fire-derived charcoal causes loss of forest humus. Science 320http://dx.doi.org/10.1126/science.1154960. 629–629.

Weber, M.G., Stocks, B.J., 1998. Forest fires and sustainability in the boreal forests of Canada. Ambio 27, 545–550 doi:citeulike-article-id:4422466.

Zimmerman, A.R., Gao, B., Ahn, M.Y., 2011. Positive and negative carbon mineralization priming effects among a variety of biochar-amended soils. Soil Biology and Biochemistry 43, 1169–1179. http://dx.doi.org/10.1016/j.soilbio.2011.02.005.