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Do logging residue piles trigger extra decomposition of soil organic matter?

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ABSTRACT

Logging residue piles have been suggested to markedly increase the decomposition of the underlying peat soil leading to large carbon dioxide emissions. We aimed at scrutinizing this postulate with straightforward decomposition (mass loss) measurements. For the purpose, authentic soil organic matter (humus and peat) was incubated in mesh bags under piles and at control plots. The effect of piles was assumed to result from physical (shading and insulation on soil surface) and chemical-biological (leaching of nutrients and fresh organic matter) sources. To distinguish between the two, artificial piles of inorganic matter were established to mimic the bare physical effects. Enhancement of decomposition in the soil under the real and artificial piles was assessed by measuring the mass loss of cellulose strips.

Logging residue piles had clear physical effects on soil: temperatures were lowered and their diurnal variation subdued, and relative humidity at the soil surface was higher. The effect on soil moisture was also evident, but more variable, including both decreases and increases. These effects, mimicked by the artificial piles, decreased rather than increased cellulose mass loss. As the real piles, on the other hand, increased mass loss, we conclude that logging residue piles may enhance decomposition in soil due to chemical-biological mechanisms.

Also the results on humus and peat mass loss indicate that piles can both increase and decrease decomposition. Consistent, remarkable increase in mass loss was not observed. Thus, our results do not support the postulate of logging residue piles dramatically increasing decomposition of soil organic matter. Rather, they hint that the effect of logging residue piles on soil is an interplay of physical and chemical-biological effects and carbon transport via roots and fungi. To fully understand and quantify these effects, vertical C fluxes between piles and soil and horizontal C fluxes within soil need to be assessed in addition to decomposition in soil and piles.

1. Introduction

Substitution of fossil fuels with bioenergy has been proposed as a way to reduce greenhouse gas emissions in our efforts to tackle climate change. Especially in the Nordic countries, a substantial new source of forest bioenergy has been logging residue that includes branches, foliage and tree tops (Helmisaari et al., 2014). Before this practice started, logging residue was typically left on site after logging.

The mitigation of climate change by substituting fossil fuels with logging residue has been criticized. Two major concerns have been raised: (1) The burning of residue for energy at once instead of letting it slowly decompose at the site decreases the forest's carbon (C) storage and thus considerably reduces the benefit of avoiding emissions from burning fossil fuels (e.g., Karlsson et al., 2014; Lindholm et al., 2011; Olajuyigbe et al., 2014; Repo et al., 2012). (2) The removal of nutrients with logging residue may decrease the forest's C storage by slowing down the growth of the next tree generation (e.g., Achat et al., 2015; Curzon et al., 2014; Holub et al., 2013; Wall and Hytönen, 2011; Wei et al., 2000) and thus further reduce the benefits of substituting fossil fuels. Mäkipää et al. (2014) modeled both effects and concluded that harvesting logging residue reduced the average C storage of forest during a forest rotation more than burning logging residue reduced C emissions by substituting diesel oil.

So far, one aspect of leaving versus harvesting logging residue has received little attention: Logging residue may stimulate decomposition processes of soil organic matter (SOM) in the underlying soil (Adamczyk et al., 2015, 2016). Usually the harvester leaves the logging residue in piles at the site, each pile typically consisting of the branches,

Abbreviations: CTRL, control treatment; LRP, logging residue pile treatment; $ART_{min/medium/max}$, artificial logging residue pile treatment with minimum/medium/maximum amount of insulation

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foliage and top of one harvested tree. These piles may affect physical conditions, namely temperature and moisture of the underlying soil (Roberts et al., 2005) by providing insulation and shading on the soil surface. Also, precipitation leaches mineral nutrients from the piles to soil (Wall, 2008) and the piles serve as a source of fresh organic C that can cause priming of decomposition in soil (Karhu et al., 2016; Kuzyakov et al., 2000). These physical and chemical-biological effects can alter microbial processes in soil and thereby affect the carbon dioxide (CO_2) emissions from SOM decomposition.

As far as we know, only Mäkiranta et al. (2012) have quantified the impacts of logging residue piles on soil CO_2 emissions or soil C balance. They studied a forestry-drained peatland after clearfelling and found that logging residue piles increased forest floor respiration by more than twice compared to the mass loss from the residue. In just two growing seasons following clearfelling, a remarkable extra release of CO_2 by 680 ± 220 g C m^{-2} was detected. It was postulated to result from the increased decomposition of peat soil under the logging residue piles. Neither the physical and chemical-biological effects of logging residue piles nor SOM decomposition were measured, however. Thus, no conclusions on how the piles may have caused the increase in SOM decomposition could be drawn. Also, results from one site only raise the question if the phenomenon pertains forestry-drained peatlands in general.

If decomposition of SOM is increased because of physical effects, it could be controlled by simply scattering the residues instead of piling them. If the increase is due to chemical-biological effects, the scattering of residues would not help as much. Also, it is important to know if the increased SOM decomposition originates from the fresh SOM at the soil surface that would anyway decompose during a few years. In peatlands, carbon can also be released from peat that constitutes a long-term C storage.

The most straightforward way to estimate the effect of logging residue piles on soil C storage and thus on CO_2 emissions would be repeated soil sampling after clearfelling. Unfortunately, peat soil C storage is so big and variable that even long-term studies (Simola et al., 2012; Minkkinen and Laine, 1998) addressing an order of magnitude higher C storage changes than those observed by Mäkiranta et al. (2012) have yielded very uncertain estimates. This problem of spatial heterogeneity can be solved by following the mass loss of samples with known mass, a widely used method especially in litter decomposition studies (e.g., Grover and Baldock, 2010; Straková et al., 2012; Tuomi et al., 2009; Vitt et al., 2009).

We aimed at scrutinizing the postulate that logging residue piles increase the decomposition of SOM. The effect of logging residue piles on decomposition in soil was estimated by incubating both authentic SOM samples and cellulose strips *in situ* at different depths. Experiments on three study sites with varying drainage intensity and soil fertility were established to evaluate how site specific or general these effects are. To distinguish between physical and chemical-biological effects, "artificial logging residue piles" providing shading and insulation but not leaching organic matter or nutrients to soil were constructed on one of the study sites.

2. Material and methods

2.1. Study sites

Three forest stands (Tables 1 and 2) were chosen in the vicinity of Hyytiälä Forestry Field Station, Southern Finland, among stands that had been harvested during the winter 2012–2013. The stands were clearfelled with the cut-to-length method following the standard forestry procedure of Metsähallitus (the agency that manages Finnish state forests), their planning and logging personnel having no knowledge of the forthcoming study. An approximately 50 × 50 m study site was delimited at the center of each stand. Logging residue piles covered 23–35% of the site area (Table 3).

The sites were chosen to represent different levels of drainage intensity and fertility with different proportions of tree species (Tables 1 and 2). Sites A and C represent the *Dwarf shrub* site type (Laine, 1989), which is the least fertile type where forestry is still economically viable. Site B, on the other hand, represents the more fertile *Vaccinium myrtillus* site type. The difference in fertility is reflected both in tree stand and ground vegetation composition. By stem volume, Scots pine (*Pinus sylvestris*) dominated the tree stand at all the sites (Table 2). Differing from the poorer sites, site B had a dense understory of Norway spruce (*Picea abies*). Although not affecting much the total stem volume, spruce with its dense and long crown was a major component in the logging residue piles at that site. Also downy birch (*Betula pubescens*) was abundant in the understory at all sites, but branches and twigs of its leafless crowns were rather scattered and contributed little to the logging residue piles. Dwarf shrub projection coverage at the nutrient poor sites A (19%) and C (14%) was higher compared to the nutrient rich site B (9%). Site B, in turn, had higher forb coverage (9%) compared to sites A (1%) and C (4%). Site C had high peat moss coverage (14%) and abundant cottongrass (*Eriophorum vaginatum*, 3%), reflecting poor drainage at that site (Table 1).

The sites had virtually the same elevation and were located within a radius of 650 m (Table 1), thus having virtually the same weather conditions. Precipitation and air temperature were obtained from the Siikaneva measurement station (see Mathijssen et al., 2016 for site description), located one kilometer from our study sites. Daily mean temperature was 14.3 °C and precipitation sum was 227 mm during June–September 2013.

2.2. Experiment lay-out

At each site, five logging residue piles distributed evenly around the site were selected as treatment plots (LRP). At sites A and C, each pile clearly consisted of branches and foliage of a single pine tree and the piles were rather even in size. The piles were somewhat smaller at site C than at site A. The area covered by a single pile was about 1 m^2. At site B, piles varied in size and contained a varying mixture of pine and spruce residues. There, the five piles were selected by visual inspection so that they represented the distribution of all available piles in terms of size and species composition. We did not try to estimate the masses of needles and woody components in each pile: A precise estimation would have required tearing apart the piles, and we wanted to disturb the structure of the piles as little as possible.

In the vicinity of each treatment plot, a control plot (area 1 m^2) without any logging residue (CTRL) was marked. The CTRL plots were placed so that they were at least two meters apart from any pile. This was as far as it was possible to get from piles without manipulating the sites.

At site A, also 15 artificial logging residue piles (ART) were constructed during the last days of May 2013, to distinguish between physical and chemical-biological effects of the piles. The main body of the artificial piles consisted of polystyrene foam peanuts, used to mimic the thermal insulation and shading by logging residue, but without leaching of C or nutrients. A plastic mesh netting was placed on top of each pile to restrain the lightweight peanuts. Finally, the piles were covered with green camouflage netting to gain radiation properties equivalent to logging residue piles. As the magnitude of insulation by logging residue piles was not known prior to the experiment, differing amounts of foam peanuts were used to gain three levels of treatment (ART_{min}: 7 l/m^2, ART_{medium}: 15 l/m^2, ART_{max}: 30 l/m^2), each consisting of five artificial piles.

2.3. Mass loss of soil organic matter

The effect of logging residue piles on the decomposition of SOM was tested with authentic, site-specific humus and peat samples at CTRL and LRP plots. The samples were collected on June 5th, 2013 at each site