Examensarbeten 2014:19

Fakulteten för skogsvetenskap
Institutionen för skogens ekologi och skötsel

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Sveriges Lantbruksuniversitet Utbytesprogram TRANSFOR-M
Examensarbete i biologi, 30 hp, avancerad nivå A2E ISSN 1654-1898
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Effekterna av markberedning på humus nedbrytningshastighet i skogen i British Columbia, Kanada

Shu Yao Wu

Nyckelord / *Keywords:*
Humus, decomposition, scarification, C mass, British Columbia, climate, site preparation, forestry

ISSN 1654-1898 Umeå 2014
Sveriges Lantbruksuniversitet / *Swedish University of Agricultural Sciences*
Fakulteten för skogsvetenskap / *Faculty of Forest Sciences*
Utbytesprogram TRANSFOR-M / *Exchange program TRANSFOR-M*
Examensarbete i biologi / *Master degree thesis in Biology*
EX0750, 30 hp, avancerad nivå A2E/ *advanced level* A2E

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I denna rapport redovisas ett examensarbete utfört vid Institutionen för skogens ekologi och skötsel, Skogsvetenskapliga fakulteten, SLU. Arbetet har handletts och granskats av handledaren, och godkänts av examinator. För rapportens slutliga innehåll är dock författaren ensam ansvarig.

This report presents an MSc/BSc thesis at the Department of Forest Ecology and Management, Faculty of Forest Sciences, SLU. The work has been supervised and reviewed by the supervisor, and been approved by the examiner. However, the author is the sole responsible for the content.

The effects of soil scarification on humus decomposition rate in forests in British Columbia, Canada

Abstract

Scarification is a widely used silviculture method and is suggested to improve organic matter decomposition rate. In this study, I made the use of an experiment that buried humus material into mineral soil after clear-cuts and studied its effects on humus decomposition rate in four biogeoclimatic zones (CWH, ESSF, ICH and IDF) in British Columbia. Litterbags containing local humus materials (mixture of F and H layers) were placed on the forest floor surface or buried in the soil (5-10 cm deep). Samples were retracted annually and dry mass and carbon (C) content were measured to calculate the remaining C mass in each sample for three continuous years. The remaining C mass at all of four sites was lower when buried than placed on the surface, but the difference was significant only at the drier IDF site. Humus in forests with better climatic conditions, such as abundant precipitation and suitable temperature, responded weakly to burying. Stimulation of humus decomposition through scarification is most likely to occur in dry forests in B.C.

Introduction

Post-harvest scarification is a widely applied silviculture practice in both North America and Europe. In Canada, 82% of forests were mechanically prepared already in year 1997 (Canadian Council of Forest Ministers 1998). Common methods of scarifying include tilling, disk trenching, roller-chopping, blading, mounding and harrowing (Jiménez Esquilín *et al.* 2008). Each of these methods removes or mixes the surface organic matter with the underlying mineral materials (Jiménez Esquilín *et al.* 2008). Scarification has been shown to improve tree seedling establishment and early growth by promoting faster root penetration, reducing competing vegetation, and improving soil temperature, moisture and aeration conditions (Hallsby 1995; Örlander *et al.* 1996; Chantal *et al.* 2003). Another suggested merit of scarification is the acceleration of organic matter decomposition and nutrient release (Salonius 1983; Johansson 1994; Lundmark-Thelin and Johansson 1997; Mallik and Hu 1997; Smolander and Heiskanen 2006). In natural environments, organic matter, such as plant litter, begins decomposing as soon as it rests on the soil. Simple components, such as sugar, low-molecular-weight phenolic and nutrients are lost quickly through leaching and microbial decomposition. More complex components, such as cellulose, hemicellulose and lignin, are lost more slowly (Prescott *et al.* 2000; Berg and McClaugherty 2008). During decay, available carbon sources are consumed; limiting nutrients are immobilized; stable organic compounds are synthesized and condensed into recalcitrant secondary compounds through biological activities and chemical

reactions by two dominant types of microbial decomposers: fungi and bacteria (Prescott *et al.* 2000; Berg and McClaugherty 2008; Bird *et al.* 2008).

A wide range of factors influence the rate of organic matter decomposition; these can be categorized into three major types: climate (including microclimate), chemical and physical characteristics of litter, and the abundance and composition of soil microbial and faunal communities (Figure 1) (Berg and McClaugherty 2008). Under conditions less than ideal, as controlled by the aforementioned factors, decomposition is not complete (Prescott *et al.* 2000). Newly formed recalcitrant compounds are preserved, leading to the development of a surface organic layer known as humus (Aber and Melillo 1991; Prescott 2010). On one hand, humus reduces short-term forest productivity through immobilizing nutrients, primarily nitrogen (N), in template and boreal forests (Keenan *et al.* 1993). On the other hand, retained humus also serves as a nutrient reserve, which promotes forest productivity in the long run by releasing the nutrients slowly (Prescott *et al.* 2000).

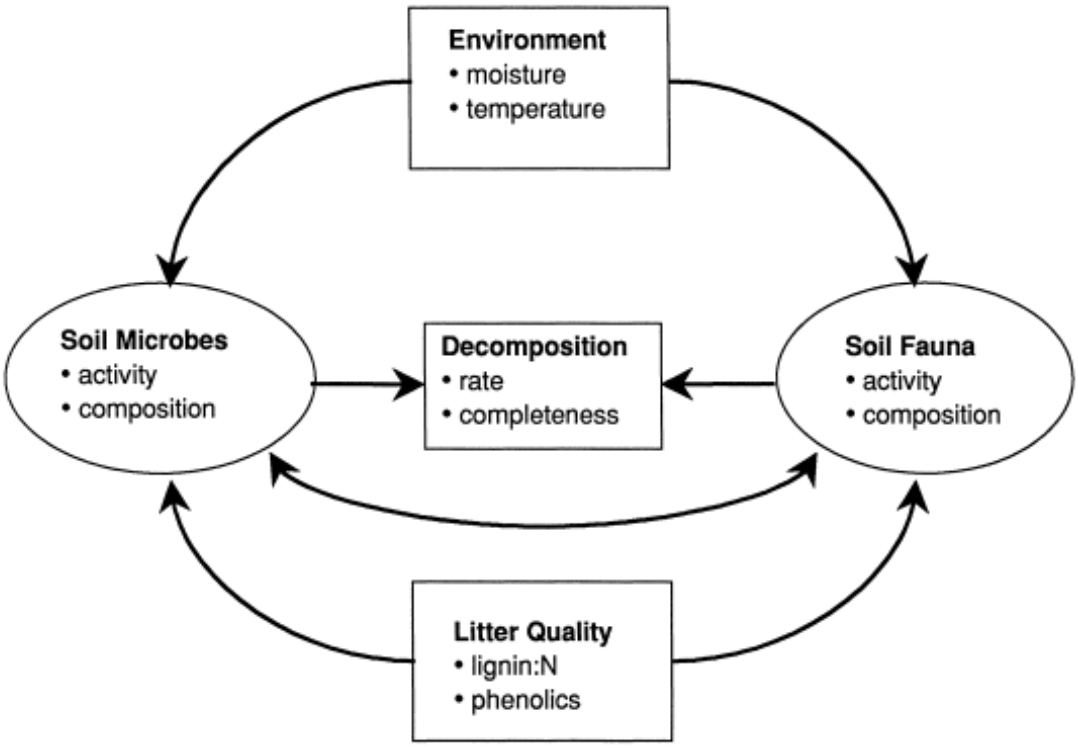

Figure 1. Interaction between biotic and abiotic factors that control the completeness and rate of decomposition. Adapted from Prescott *et al.* 2000.

A few previous studies have focused on the effect of scarification on the rate of organic matter decomposition in the early stage (Johansson 1994; Lundmark-Thelin and Johansson 1997; Mallik and Hu 1997; Pumpanen *et al.* 2004). Johansson (1994) reported that the decomposition and nutrient release rate of both green Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) needles was faster in scarified sites than in untreated control. Lundmark-Thelin and Johansson (1997) found that burying green needle litters and slash needle litters in disc-trenched ridges resulted in accelerated mass loss rates and increased nutrient availability as compared with litters decomposed on unscarified sites after three years. Both Mallik and Hu (1997) and Pumpanen *et al.* (2004) studied the soil respiration rate after site preparation and found elevated CO_2 effluxes in prepared plots. However, the effect of scarification on the rate

of decomposition of humus material, which has more stable chemical properties and fewer decomposers (Berg and McClaugherty 2008), has been little studied.

The province of British Columbia has a large variation in climates due to its size, mountainous topography and maritime influence (Zaibi 2013). The oceanic climate in the west coastal areas brings substantial amounts of precipitation annually. In comparison, the east and north interior areas are dominated by continental climate and are much drier. The mountainous topography affects the local distribution of precipitation, leading to even stronger climatic variations on the local scale. Both temperature and precipitation have been shown to be closely related to decomposition rate (Salonius 1983; Johansson *et al.* 1995; Berg and McClaugherty 2008). But moisture, which is highly associated with precipitation, was found to be the factor that most strongly influences litter decomposition rates, microbial community structure, and enzyme activities within the range of climates in British Columbia (Prescott *et al.* 2004; Brockett *et al.* 2012; Zaibi 2013). Scarification, such as mounding, can improve soil moisture conditions for organic matter decomposers by providing a buffering layer of mineral soil and preventing direct exposure to sunlight (Sutton 1993; Lundmark-Thelin and Johansson 1997), so the effects of scarification on humus decomposition rate may be stronger in drier climates in B.C. In this study, I made use of an experiment that buried humus material into mineral soil after clear-cuts in order to mimic scarification and test two hypotheses regarding scarification's effects on humus decomposition rate:

1. Humus will decompose faster when buried than when on the surface due to

microclimatic conditions improvements, such as better moisture level and less temperature fluctuation, in buried site.

2. Stimulation of decomposition rates of humus through burial will be greatest in dry climates. This is because moisture improvement, a result of scarification, has the strongest stimulation effects on decomposition in B.C.

Methods

Site Description

Sites that have been clear-cut recently were selected in four biogeoclimatic (BEC) zones in British Columbia, Canada, that represent different climatic conditions: the Costal Western Hemlock (CWH) zone, Engelmann Spruce-Subalpine Fir (ESSF) zone, Interior Cedar Hemlock (ICH) zone and Interior Douglas Fir (IDF) zone (Table 1). One site per BEC zone and three plots per site were chosen, except for the IDF zone, where I had three sites and one plot per site. Each plot was approximately 40 m x 40 m in size. The sites within each zone were selected in areas that experienced recent clear-cuts and the plots within the CWH, ICH and ESSF site were chosen randomly. Mean annual precipitation and temperature of CWH, ICW and IDF site were estimated from the Climate WNA model, which gives precise climatic prediction when given longitude, latitude and elevation (Table2; Wang *et al.* 2012). The estimations were compared with other reference (Meidinger and Pojar 1991) and determined to be valid. The climatic data of the ESSF site was derived from study of Prescott *et al.* (2003) at the same site.

Costal Western Hemlock (CWH)

The CWH site was located near the towns of Port McNeill and Port Hardy, BC on Northern Vancouver Island (elevation 450 m, gently undulating slope) (Table 1 and 2). Before harvest, the forest was an old-growth stand (>250 year-old) of western red cedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*). The stand was clear-cut in 1995 followed by slash burning. Soils are dominated by well to poorly drained Ferro-Humic Podzols with loam texture on unconsolidated morainal and fluvial outwash materials (Meidinger and Pojar 1991).

Engelmann Spruce-Subalpine Fir (ESSF)

The ESSF site was in the Sicamous Creek Silvicultural Systems Trial (elevation 1530 to 1830 m, slope 20 to 40%), located near the town of Sicamous, B.C. (Table 1 and 2). The pre-harvest forest was a 300-year-old stand with ~65% subalpine fir (*Abies lasiocarpa*) and 35% Engelmann spruce (*Picea engelmanni*) by volume. The site was clear-cut in 1994, spot site-prepared (mounded) in 1995 by excavators after harvest and replanted with Engelmann spruce seedlings in 1996.

Interior Cedar Hemlock (ICH)

The ICH site was at the Ice Road silviculture systems trial (elevation 910 m, slope 25 to 35%), located about 50 km south of the town of Nakusp, B.C. (Braumandl and Curran 1992) (Table 1 and 2). The dominant pre-harvest stand was 125-year-old even-aged western red cedar, with minor amounts of Douglas-fir (*Pseudotsuga menziesii*) and western larch (*Larix occidentalis*) (DeLong *et al.* 2005). The site was

harvested over the winter of 1995-1996 (DeLong *et al.* 2005). Surface soils are predominantly Brunisols with silt loam or fine sandy loam texture in this site.

Interior Douglas Fir (IDF)

The three IDF sites (elevation 1120 m, slope <5%) were located between 25 and 50 km northwest of Kamloops, B.C. (Table 1 and 2). The sites were a part of installations of long-term soil productivity (LTSP) study (Berch *et al.* 2010). Before harvest, the stands were dominated by 100- to 250- year-old Douglas-fir, with lesser amounts of lodgepole pine (*Pinus contorta*), hybrid spruce (*Picea engelmannii* x *glauca*) sand subalpine fir. Harvesting occurred in the winter of 1998, 1999 and 2000 in Dairy Creek, Black Pines, and O'Connor plots, respectively (Berch *et al.* 2010). The post-harvest sites were dominated by grass species. The soils at all three sites are deep, moderately well drained Brunisolic Gray Luvisols that derived from morainal blankets, with a thin (<10 cm) aeolian material capping.

Table 1. Site information and date of establishment of the decomposition experiment at each of the four sites (CWH, ESSF, ICH and IDF)

Zone	Site	Subzone	Latitude (N)	Longitude (W)	Date Established
CWH	Port McNeill	vm1	50°60'	127°35'	1999
ESSF	Sicamous Creek	wc2	50°49'	119°54'	1999
ICH	Ice Road	mw2	49°58'	118°43'	1999
IDF	Dairy Creek	dk	50°51'	120°25	2000
	Black Pines		50°56'	120°17'	
	O'Connor		50°53'	120°21'	

Table 2. Average temperature, precipitation, annual heat: moisture index and summer heat: moisture index at each of the four sites (CWH, ESSF, ICH and IDF) in the decomposition study.

Site	Mean Annual Temperature (°C)	Mean Annual Precipitation (mm)	Annual Heat: Moisture Index	Summer Heat: Moisture
CWH	7.2	2145	8	35.2
ESSF	1.2	930	12.2	37.3
ICH	5.1	1117	13.6	34.9
IDF	4.6	467	31.2	66.5

Note: The climatic data of CWH, ESSF and IDF were derived from the ClimateWNA model (Wang *et al.* 2012). The climatic data of ESSF was derived from Prescott *et al.* 2003. The values of the IDF site are the averages of three plots. The annual heat: moisture index (an index of soil dryness) is calculated as (mean annual temperature + 10)/(mean annual precipitation/1000). The summer heat: moisture index (an index of summer drought) is calculated as (mean warmest month temperature)/(mean summer (May to September) precipitation/1000)

Experimental Design

Humus samples consisting of a mixture of F and H material were collected from old-growth or mature stands near each site in the fall of 1998. Two grams (dry mass) of humus were put into bags constructed of fiberglass mesh with pore size approximately 0.5 mm, and returned to the origin site. Thirty sample bags were randomly buried at a depth of 5-10 cm in the mineral horizon in each plot in September 1999 (September 2000 for the IDF sites) to mimic the conditions after scarification. Another thirty bags were pinned on the surface of the forest floor beside the buried bags in pairs. Ten bags from each treatment (surface or buried) were collected from each plot annually for three years. As some bags were missing, the number of samples collected from each plot ranged from six to ten and only samples in two plots were

available in the ICH site. The mass of remaining material in each bag was measured after drying to a constant mass at 65 °C.

Samples from the same plot and same year were then combined, ground to a finer particle size using a coffee mill and dried at 70 °C overnight. The total number of samples per site after combining ranged from 12 to 18 due to sample missing. Carbon (C) concentration was measured using an elemental carbon and sulfur analyzer (CS-580A Helios) by ELTRA©, which measures the amount of generated CO_2 after combustion. The machine was calibrated using standardized orchard leaves from LECO© with a known 51.49 ± 0.63 % C content. Then, approximately 0.05 g per combined and ground samples were taken and analyzed. Abnormal C concentration results were retested two or three times and then the average values were used. The C concentration of the humus at the time zero were estimated based on the average C concentration of the first-year surface samples' concentrations, which I assumed had similar C concentrations. The remaining C mass of each sample was calculated by multiplying the remaining dry mass of each sample and the average C concentration of the corresponding plot. The differences of the remaining C mass between surface and buried samples were interpreted as the effect of scarification.

The remaining C mass in each plot was averaged for statistical analysis to reduce errors and variances. I used a two-way repeated measures analysis of variance (ANOVA) to test the overall scarification effects over the three years by pooling the surface and buried data from all four zones together. The plot-average remaining C mass between treatments each year was also compared within each zone by using four

separate ANOVA with repeated measures (one for each site) with treatment, year and their interactions as testing terms. Kolmogorov-Smirnov normality tests suggested that the data were normally distributed at all sites (all $p > 0.01$). Plot variances instead of total error were used as the error term to test variations between treatments and listed as experimental error. Differences among the plot-average surface and buried C mass each year in all zones was also compared by another repeated measures two-way ANOVA with site, year and their interaction as testing factors in order to test potential differences among climatic zones. Plot variances were used again to test site variation and listed as experimental error. All analyses were performed by SAS 9.3 for Windows version (SAS Institution). The accepted level of significance was $p < 0.05$.

Results

The C mass of humus at all four sites declined most during the first year of incubation, after which the rate of loss slowed (Figure 2). The C mass of humus in buried bags appeared to decline faster than that in surface bags, especially at the IDF site (Figure 2). However, several overlapping error bars indicated that the differences in humus C mass between buried and surface bags might not be statistically significant in each site (Figure 2).

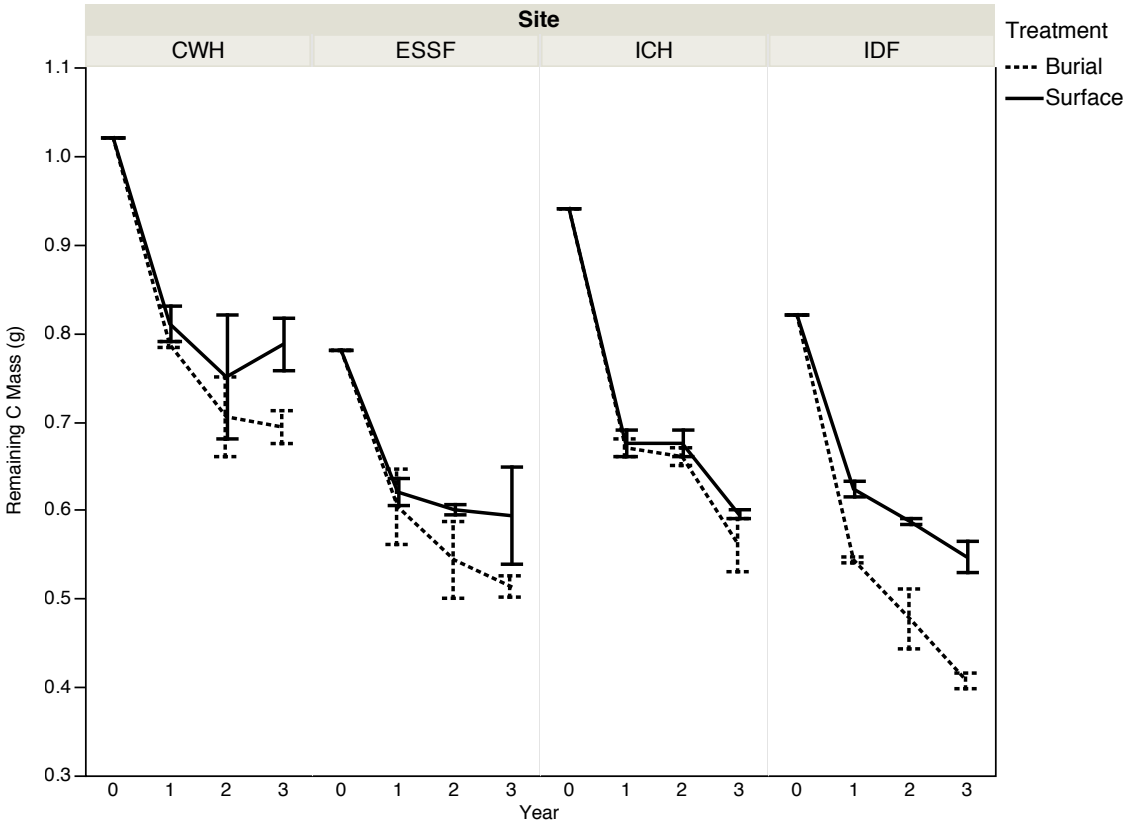

Figure 2. The C mass (g) of humus remaining in surface and buried bags at each of the four sites (CWH, ESSF, ICH and IDF) during each of three years of incubation. Error bars indicate standard error.

Statistical testing by four two-way ANOVA on the C mass from year one to three indicated that the remaining C mass at the IDF site was significantly affected by treatment (burial). The other three sites did not show significant results between

treatment types. The remaining C mass at all sites, except for the ESSF site, was significantly different among years (Table 3). Nevertheless, the responses of C mass did not significantly differ between different treatment and year at all four sites, as shown by the interaction terms.

Table 3. Results of four two-way ANOVA of remaining humus C mass in buried and surface bags over three years at the CWH, ESSF, ICH and IDF sites in British Columbia.

Source	Degrees of freedom	Sum of Squares	Mean squares	F-value	*p*-value
CWH					
Treatment Type (T)	1	0.01	0.01	2.78	0.171
Exp. Error	4	0.02	0.00	3.00	0.111
Y (Year)	2	0.02	0.01	5.64	**0.042**
T*Y	2	0.00	0.00	1.64	0.270
Error	6	0.01	0.00		
Total	15	0.06			
ESSF					
Treatment Type (T)	1	0.01	0.01	2.40	0.196
Exp. Error	4	0.02	0.00	1.92	0.200
Y (Year)	2	0.01	0.01	2.09	0.186
T*Y	2	0.00	0.00	0.57	0.588
Error	8	0.02	0.00		
Total	17	0.07			
ICH					
Treatment Type (T)	1	0.00	0.00	1.83	0.309
Exp. Error	2	0.00	0.00	2.11	0.237
Y (Year)	2	0.02	0.01	29.57	**0.004**
T*Y	2	0.00	0.00	0.74	0.532
Error	4	0.00	0.00		
Total	11	0.03			
IDF					
Treatment Type (T)	1	0.05	0.05	79.25	**0.001**
Exp. Error	4	0.00	0.00	0.86	0.526
Y (Year)	2	0.04	0.02	22.67	**0.001**
T*Y	2	0.00	0.00	1.50	0.280
Error	8	0.01	0.00		
Total	17	0.10			

Note: CWH: n = 16 R^2 = 85.59%; ESSF: n = 18, R^2 = 68.77%; ICH: n = 12, R^2 = 94.50%; IDF: n = 18, R^2 = 93.75%.

When all samples were pooled together, the overall differences of humus C mass between treatments were statistically significant (Table 4). Moreover, the overall C

mass was also significantly different between years (Table 4). The interaction term indicated the C mass did not respond to treatment differently between years (Table 4).

Table 4. Results of two-way ANOVA of the pooled remaining humus C mass in buried and surface bags in British Columbia from year one to year three (n = 86 in total, R^2 = 61.34%).

Source	Degrees of freedom	Sum of Squares	Mean squares	F-value	*p*-value
Treatment Type (T)	1	0.05	0.05	4.55	**0.001**
Y (Year)	3	1.21	0.40	38.95	**0.036**
T*Y	3	0.03	0.01	0.81	0.490
Error	78	0.81	0.01		
Total	85	2.09			

Differences in remaining humus C mass between the surface and buried bags (an indication of decomposition response to scarification) became larger over the three years at all four sites, indicating increasing effect of scarification (Figure 3). In all three years, the difference between the C mass remaining in surface and buried bags was greatest at the IDF site and smallest at the ICH site (Figure 3). Differences at the CWH and ESSF sites were intermediate and similar. However, large and overlapping error bars among the CWH, ESSF and ICH sites indicated large variations at these sites (Figure 3).

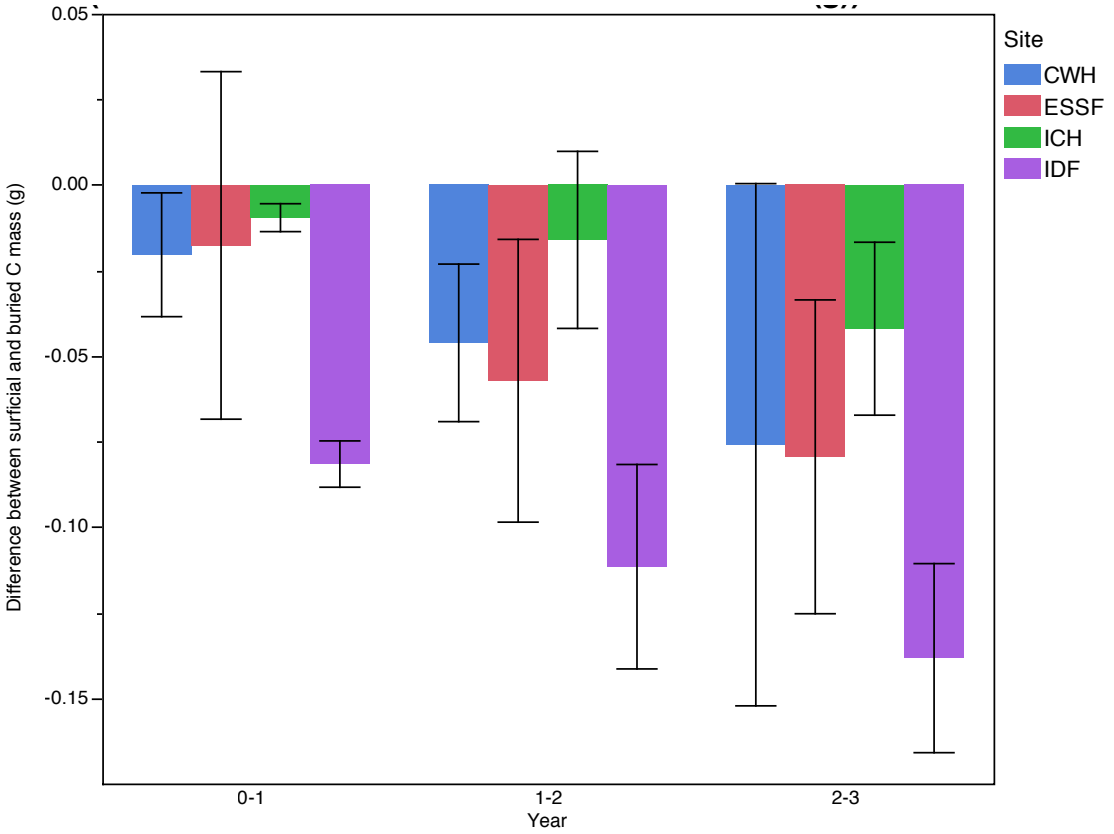

Figure 3. The difference between C mass of humus remaining in surface and buried bags (decomposition responses to scarification) at each of four sites (CWH, ESSF, ICH, and IDF) over three years in British Columbia. Error bars indicate standard error.

The decomposition responses to burying were not significantly different across sites or between years (Table 5). Furthermore, the difference between C mass remaining in the surface and buried bags at the four sites did not have significantly different response patterns over the three years either, as shown by the interaction term (Table 5). However, the relatively small R^2 value suggested that the model did not fit the data perfectly.

Table 5. Results of two-way ANOVA of the responses of humus C mass to scarification at each of four sites (CWH, ESSF, ICH, and IDF) in British Columbia from year one to year three (n = 31 in total, R^2 = 19.95%).

Source	Degrees of freedom	Sum of Squares	Mean squares	F-value	*p*-value
Zone (z)	3	0.01	0.00	1.11	0.407
Exp. Error	7	0.01	0.01	0.21	0.977
Y (Year)	2	0.00	0.00	0.06	0.942
Z*Y	6	0.01	0.00	0.14	0.989
Error	12	0.09	0.01		
Total	30	0.11			

Across the four sites, there was a negative relationship between the scarification effects (the difference between surface and buried C mass in year 3) and the average annual heat: moisture index, which implies that the drier the soil is, the stronger the stimulating effect of scarification on decomposition rate is (Figure 4).

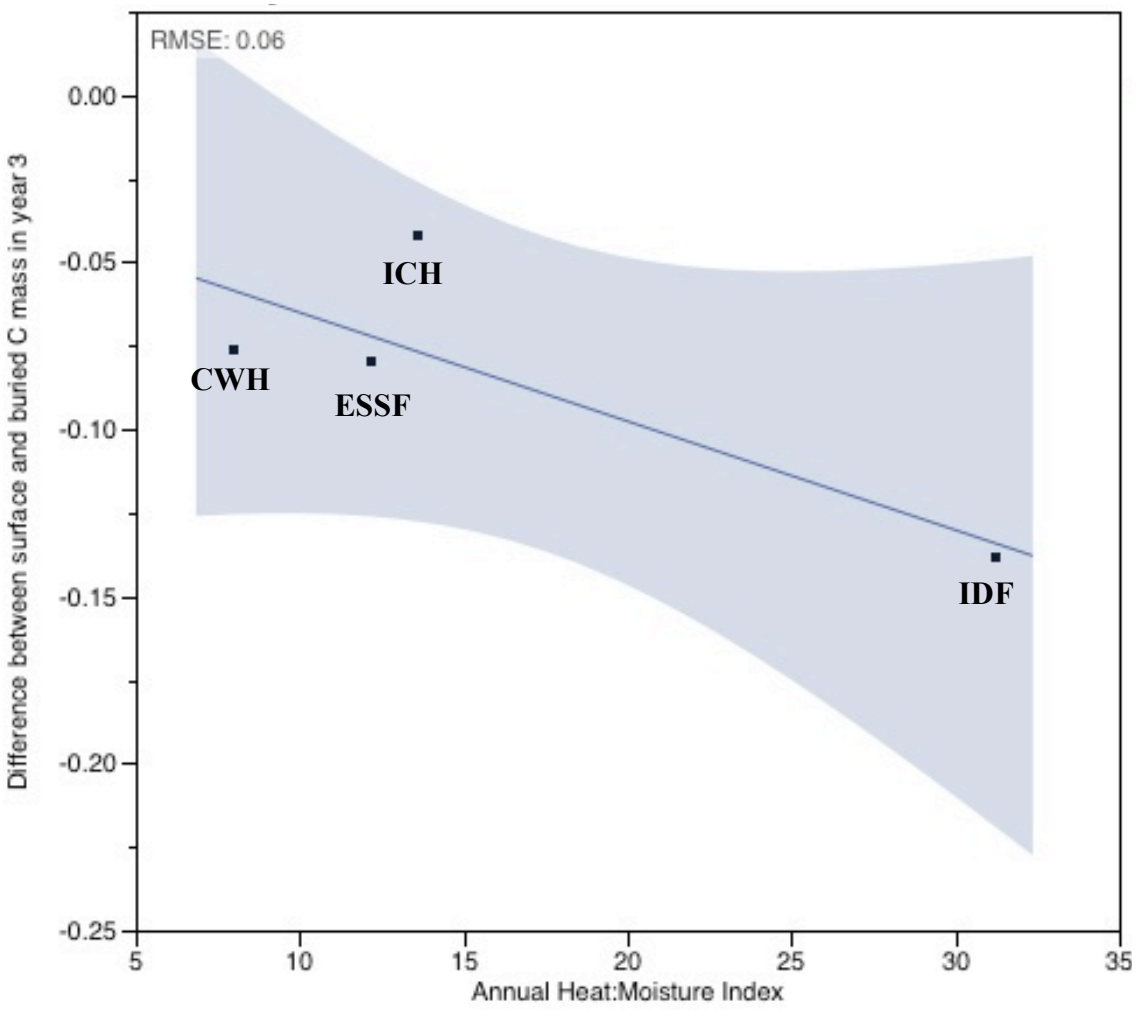

Figure 4. The relationship between scarification effect (average differences between surface and buried C mass in year 3) and annual heat: moisture index in forests in four BEC zones (CWH, ICH, ESSF and IDF). The root-mean-squire error is 0.06. The shaded area indicates confidence of fit.

Discussion

The first hypothesis was supported by the lower remaining C mass in buried treatment at the IDF site and the overall significant difference between treatments when data from all zones were pooled (Table 3 and 4). This finding is in accordance with several previous studies, which also found accelerated organic matter decomposition after scarification (Johansson 1994; Lundmark-Thelin and Johansson 1997; Mallik and Hu 1997; Pumpanen *et al.* 2004). Accelerated humus decomposition rates are probably related to enhanced microbial activity, which is triggered by improved microclimatic conditions, especially soil moisture. In the IDF zone, the summer heat: moisture index was high and growing season moisture deficits are common and severe (Meidinger and Pojar 1991; Table 2). Since our sites were located in the dry subzone, the drought effects might be even greater. By burying humus under mineral soils, the humus materials in the scarified plots probably experienced less desiccation and held more moisture by preventing direct sunlight exposure compared to humus on the top forest floor (Sutton 1993; Lundmark-Thelin and Johansson 1997). In addition to moisture improvement, soil temperature also likely increased and fluctuated less with depth in buried humus because having a buffering mineral layer above them creates a more stable environment (Ross and Malcolm 1982; Bulmer *et al.* 1998). Furthermore, since stratified microbial populations in each layer do not normally have physical access to the organic material in other layers in undisturbed forest (Salonius 1983), soil mixing might also improve habitat accessibility for the microbial population and increase the microbial population diversity. Although

Jiménez Esquilín *et al.* (2008) found a negative relationship between scarification and microbial biomass; their unrepresentative result may be due to their study being a long-term study (20-year interval) and that no soil microbial population data was collected between years. Factors other than scarification might also influenced the microbial biomass during the study period.

At the ICH, ESSF and CWH sites, the remaining C mass of humus was not significantly different between surface and buried bags. This might be related to the more suitable surface microclimatic conditions at these sites. The summer heat: moisture indexes in the ICH, ESSF and CWH sites were considerably lower than in the IDF site (Table 2), which implies less severe summer drought and less constrained natural decomposition rates. The finding supported our second hypothesis that the stimulation effect of scarification would be more substantial in dry climates. The comparison of decomposition responses to scarification in sites with similar mean annual temperature but different precipitation (IDF versus ICH in Figure 3) and the negative relationship between scarification effect and annual heat: moisture index also supported the hypothesis (Figure 4). Comparing the C mass responses in zones with similar annual precipitation but different temperature, such as ESSF versus ICH, also indicated an effect of temperature on the response of humus decomposition rate to scarification. However, temperature influences appear to be weaker than moisture because the contrast of decomposition responses in IDF versus ICH is more dramatic than in EFFS versus ICH (Figure 3).

It is interesting that the CWH site had consistent higher decomposition responses to scarification than the ICH site did, even though the ICH zone is drier and cooler than the CWH zone (Figure 3, Table 1). This is in accordance with Prescott *et al.* (2004)'s finding of naturally slower decomposition of forest floor material in CWH sites than ICH sites. The naturally slower humus decomposition at the CWH site may be related to the high annual precipitation (2145 mm per year). Sajedi *et al.* (2012) found that soils in the cedar-hemlock forests of northern Vancouver Island are very wet and poorly aerated. This excessive moisture can cause low soil oxygen availability, which limits biological processes, such as decomposition (Prescott *et al.* 2000; Sajedi *et al.* 2012). The soils in the CWH sites might be too anaerobic for humus decomposition organisms that require aerobic conditions and ensued lower microorganism diversity as compared to sites in other zones. Since only a small number of species can degrade the recalcitrant lignin and phenolic complexes, a high functional diversity of microorganisms is important in the late stages of decomposition (Berg and McClaugherty 2008). A diverse soil macrofaunal community has also been demonstrated to increase decomposition rate by microcosm studies (Setälä and Huhta 1991). However, the soil in the CWH zone may also be too wet for many macrofauna, leading to a low faunal activity rate (Prescott *et al.* 2000). Since the mixing of mineral and humus can improve the soil permeability by changing soil texture and creating better soil aeration status (Mielke *et al*. 1986; Mallik and Hu 1997), the CWH zone might benefit more from the mixing than the ICH due to their different initial conditions. Nevertheless, the large error bars in the CWH zone indicated that the

improvement of aeration status might not be critical in all plots and micro-topographic variations might be high too. These speculations require further studies on the microbial structure for confirmation.

Finally, the noteworthy diverging trend between the surficial and buried remaining C mass suggests that significant differences may arise between the surficial and buried C mass at these sites later in decomposition (Figure 3). The trend suggests that the effect of scarification on humus decomposition rate may become more and more obvious over time. Again, additional research with longer study periods and/or larger sample sizes is needed to test these speculations.

In summary, we found that by burying humus into mineral soil is likely to promote the decomposition rate of humus, particularly in dry environments. Accordingly, scarification may improve short-term nutrient availability by accelerating humus decomposition. This theory should be examined by further long-term studies in areas with different climatic conditions and forest types. Rates of release of nutrient such as nitrogen, manganese, and calcium could also be included in future studies to explore effects of scarification on nutrient supply. Moreover, studies with different spatial scale will also be useful to further understanding the effects of scarification on decomposition rate since the scale of disturbance plays an important role in determining the magnitude of humus responses (Smolander *et al.* 2000).

Acknowledgements

I sincerely thank Dr. Cindy Prescott for her data, advices and editing, Dr. Marie-Charlotte Nilsson Hegethorn for advices and editing, Candis Staley for field and lab assistance, Dr. Tony Kozak for statistical assistances, David Dunn and Rebecca Dixon from Pacific Forestry Centre chemistry services laboratory for carbon analysis, and Deborah Delong and Ayna Reid for site information.

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